Review Article

Access this article online
Quick Response Code:
Website:
www.jehp.net
DOI:
10.4103/jehp.jehp_643_19

A systematized review of cognitive load theory in health sciences education and a perspective from cognitive neuroscience

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Received: 25-10-2019
Accepted: 12-12-2019
Published: 28-07-2020

Abstract:

INTRODUCTION: To design instructions in health sciences education, it is highly relevant to heed the working memory and the approaches for managing cognitive load. In this article, we tried to mention the implications of cognitive load theory (CLT) for optimizing teaching-learning in health sciences education and discussing cognitive load from the perspective of cognitive neurosciences as brain-aware medical education.

MATERIALS AND METHODS: We searched databases of Pubmed, Proquest, SCOPUS, and ISI Web of Science for relevant literature in September 1, 2018.

RESULTS: The 27 articles out of a total of 46 records, along with 23 papers from snowballing and hand searching were included in this study. Main items encompassed; "Various types of cognitive loads," "Aim of cognitive load theory," "Strategies to managing Cognitive Load," "Cognitive Load Theory in novice and experienced learners and "expertise reversal effect," Medical and Health Sciences Curriculums and Cognitive Load Theory," "Challenges of Cognitive Load Theory."

CONCLUSIONS: We discussed six important themes for CLT in health sciences education according to the literature. Mental imagery (visualization) as one of the useful techniques to optimize germane load was suggested, as it processes further gain access to neural circuits that are engaged in sensory, motor, executive, and decision-making pathways in the brain.

Keywords:

Cognitive load theory, cognitive science, education, medical, neuroscience

Introduction

There exist various educational theories for medical and health sciences education from different disciplines such as educational psychology and cognitive theories.[1-3] Cognitive Load Theory (CLT) is an instructional approach on the basis of human cognitive architecture knowledge, including the limitations of the working memory, how information is organized in long-term memory (LTM), and how the two memory structures are correlated.[4] Working memory is constrained regarding duration and capacity, hence able to maintain and process only a limited amount of data at a certain time. Therefore, working memory acts as the main bottleneck for learning. CLT postulates that the extent of working memory load (exerted by cognitive processes) must not surpass its limited capacity during a learning task.[5]

History of CLT dates back to 1950, yet the concept was actually defined 1980–1990 by an Australian educational psychologist named John Sweller,[6] who considered the different sides of human cognitive architecture pertinent to the instructional design and utilized by CLT depending on

How to cite this article: Ghanbari S, Haghani F, Barekatain M, Jamali A. A systematized review of cognitive load theory in health sciences education and a perspective from cognitive neuroscience. J Edu Health Promot 2020;9:176.

evolutionary educational psychology. Evolutionary educational psychology more clarified the aspects of knowledge which CLT both did and did not apply to; the same goes for the way in which data were stored, processed, and utilized during and following instruction. In brief, the theory is associated with the attempt to learn new information and how the instructional design is able to positively influence the effort required to fathom the new material.[6] CLT is also the basis of the approaches employed, including formative/summative assessments, micro-learning, and instructing various learning styles.[7]

In medical education, we deal with the fact that the cognitive load on students is extremely high because of the advanced concepts and the workload,[8] and the final objective is to aid instructional designers in communicating with their audience and enhance the educational experience of the students. Sharma holds that "Recognition of the importance of CLT is now being recognized as key in ensuring the development of the master learner."[9,10]

As regards among major topics in the development of master learners in health science education is CLT which is needed to be noticed accurately with a new evidence-based perspective. In this article, we tried to mention the implications of CLT for optimizing teaching-learning in health sciences education and discussing cognitive load from the perspective of cognitive neurosciences, which is a developing field of the study called by neuroeducation studies.

Materials and Methods

We searched databases of PubMed, Proquest, SCOPUS, and ISI Web of Science for the relevant literature in September the first (2018). The main search strategy was: (cognitive load theory) AND ("medical educat*" OR "health sciences educat*" OR "health professions educat*" OR "health care professions educat*" OR "education in health sciences" OR "education in Health Professions" OR "education in medicine" OR "education in health care professions" OR "educating health professions" OR "educating health care professions" OR "educating medicine" OR "educating health sciences" OR "clinical teaching" OR "clinical educat*" OR "teaching round*") and it adapted according to different databases [Table 1].

The inclusion criteria were as follows: (a) document type of article, (c) English language, and (d) Studies published. We did not exclude any article after article inclusion. One author scanned all the titles and then abstracts to identify potentially relevant articles. Then, full-text versions of these articles were obtained and reviewed. A subsequent searching of reference lists of all full-text studies (snowballing) and a hand searching was also performed to get new related articles [Figure 1].

Results

Preliminary database searching identified 46 articles which 18 duplicate references removed. One item excluded in the screening phase as it was a book and 27 articles were reviewed according to the full texts. Twenty-three articles added by hand searching and cross-referencing, and finally, 50 articles were used in this study according to direct relevancy to medical and health sciences education. Reviewing the 50 articles resulted in six categories of information which were reported here by "Various types of cognitive loads," "Aim of cognitive load theory," "Strategies to managing Cognitive Load," "Cognitive Load Theory in novice and experienced learners and "expertise reversal effect," "Medical and

Table 1: Databases, search strategies, and number of articles found by preliminary searching

Database	Search strategy	Number of articles found
ISI web of sciences	TITLE: (CLT) AND TOPIC: (("medical educat*" OR "health sciences educat*" OR "health professions educat*" OR "health care professions educat*" OR "education in health sciences" OR "education in Health Professions" OR "education in medicine" OR "education in health care professions" OR "educating health professions" OR "educating health care professions" OR "educating medicine" OR "educating health sciences" OR "clinical teaching" OR "clinical educat*" OR "teaching round*")) Refined by: DOCUMENT TYPES: (ARTICLE) AND LANGUAGES: (ENGLISH)	5
SCOPUS	TITLE (CLT) and (LIMIT-TO (DOCTYPE, "ar")) and (LIMIT-to (SUBJAREA, "Medi") OR LIMIT-TO (SUBJAREA, "NURS") OR LIMIT-TO (SUBJAREA, "HEAL") OR LIMIT-TO (SUBJAREA, "NEUR")) AND (LIMIT-TO (LANGUAGE, "English"))	14
Pubmed	CLT [Title], Filters activated: Humans, English. Journal article	21
Proquest	ti ((CLT)) AND Ab (("Medical Educat*" OR "Health Sciences Educat*" OR "Health Professions Educat*" OR "Health Care Professions Educat*" OR "Education In Health Sciences" OR "Education In Health Professions" OR "Education In Medicine" OR "Education In Health Care Professions" OR "Educating Health Professions" OR "Educating Health Care Professions" OR "Educating Medicine" OR "Educating Health Sciences" OR "Clinical Teaching" OR "Clinical Educat*" OR "Teaching Round*")) Limits applied, Databases: 6 databases searched, Limited by: Peer reviewed, Document type: Article, Language: English, Narrowed by: Peer reviewed: Peer reviewed	6

CLT=Cognitive load theory

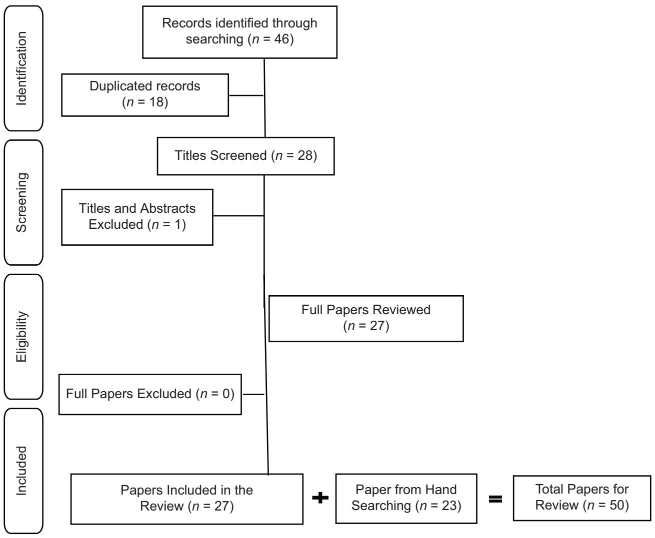

Figure 1: Flowchart for including papers in the review

Health Sciences Curriculums and Cognitive Load Theory," "Challenges of Cognitive Load Theory Table 2: Overview of included papers (the authors' name, year of publication, article type, title, site of study, and results and suggestion)."

Various types of cognitive loads

Intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL) are three types of cognitive load. Most educational psychologists believe that intrinsic load is associated with task performance, while the germane load is concerned with task learning and it encompassing the mind activities associated with schema construction and automation. Others hold that the construct of the intrinsic load must include schema acquisition, and the germane load is to be curbed to additional activities that improve learning including consciously applying learning strategies (e.g., compare and contrast). Another point of view is also argued that intrinsic load includes all activities attributable to germane load, and rejecting to have independent germane load construct.[6-9,34] The difference between intrinsic and extraneous load is contextual and significantly depends on the definition of the objective of the learning task. One task's intrinsic load is another's extraneous load.[34,35]

Aim of cognitive load theory

Learning is the development and automation of cognitive schemas. Schema is "a cognitive construct organizing the elements of information based on the fashion they will be dealt with." Instructional methods generated by CLT optimize learning through reducing the extraneous load, fitting the intrinsic load to the learner's developmental stage, and promoting germane load. The absence of retrieval cues associated with the desired item stored in LTM is the bottleneck for its retrieval; hence, the importance of schema construction and automation is clear. As schema is cognitive structure organizing information elements based on the way they are processed, it can decrease elements' interactivity, thereby reducing the ICL. Compared with a simple collection of lower-level components, cognitive construct shows a higher level of organized knowledge.[1,34]

Organized knowledge is not able to augment the retrieval cues, but it is capable of reducing the need for such cues. Schema automation results from providing learners the communicating concepts, and also simulated learning, case-study practice, repeated learning chances, and self-directed learning.[2,36] Schemas-containing automated procedural knowledge is also regarded to be obtained as a whole. Retrieving suitable schemas and producing more suitable solutions can be done by learners with higher knowledge. Controlling germane load is providing learners with content and data, yet providing limited guidance to occur learning transfer to new contexts.[18,33,37]

The extent to which components in single schemas interact is called element interactivity. If schemas are learned successively, rather than simultaneously, the ICL will be reduced. Optimally, schemas should be also learned simultaneously due to a holistic perception of element interactions. However, it is important to know that in this case, the higher element interactivity existing between schemas comes more ICL. Nonetheless, successive learning can ameliorate the instructional design in medical education.[28,38,39] In other words, learners' ICL is reduced when instructional design focuses on successively instructing one idea or schema and obtaining mastery before moving on.[7] It is remarkable that stress is one of the essential manifestations of cognitive overload.[40]

It is to be noted that, as schema construction and automation, learning is a longitudinal phenomenon and different sorts of cognitive loads change with time. Moreover, students with shared previous experience, experiencing similar learning tasks in identical formats (equalizing extraneous and intrinsic load), can undergo highly variant stages of germane load which depends on effort, motivation, and metacognitive skills.[24,40]

Strategies for managing cognitive load

Simple-to-complex ordering of learning tasks and working from low- to high-fidelity environments, intrinsic load titration to the clinician developmental stage, augmenting the allotted time or decomposing the tasks through simulations, can decrease ICL. Instructional designers cooperate with faculty members to help students avoid cognitive overload. The difficulty of learning tasks should be in line with student progress.

Table 2: Overview of included papers (the authors' name, year of publication, article type, title, site of study, and results and suggestion)

Number	First author year of publish	Article type	Title	Site of study	Results and suggestion
1	Leppink 2017[11]	Educational article	CLT: Practical implications and an important challenge	Maastricht University, the Netherlands	Researchers in this study investigated instruction and assessment designing according to CLT. The guidelines focused on reducing cognitive activities which are not helpful for learning by understanding the multifaceted relationship of learning and assessment. They eventually concluded that the use of CLT has been useful in medical education
2	van Merriënboer 2010[4]	Commentary	CLT in health professional education: Design principles and strategies	Maastricht University, the Netherlands	This article deals with guidelines that can reduce extraneous load, manage intrinsic load and improve germane load. After examining 15 different guidelines, each of them was evaluated with respect to their advantages and disadvantages
3	Young 2016[12]	Viewpoint	Advancing the next generation of handover research and practice with CLT	Hofstra North Shore-LIJ School of Medicine, The Zucker Hillside Hospital	This article addresses the issue of patients' handover and the importance of improving handover process. The authors maintain that handover protocols have improved over time, but this improvement is still not enough and enhanced safety which can be achieved by using CLT
4	Mulcock 2017[13]	Quasi-experimental three-group design	Beyond the dedicated education unit: Using CLT to guide clinical placement	Boise State University Hospital	Researchers developed a home-base clinical model using CLT. The purpose of this model was to examine whether students' stress was reduced by combining CLT in the home-base clinical model. The results indicate that between the two groups, the home-base clinical model group had less stress during clinical training
5	Fraser 2015[14]	Review article	CLT for the design of medical simulations	Department of Medicine University of Calgary	Simulation-based education is recognized as an effective and emerging tool in medical education. In this review article, the authors propose to amend simulation-based education using the principles of CLT
6	Hadie 2018[15]	RCT	Creating an engaging and stimulating anatomy lecture environment using the CLT-bLM: Students' experiences	Universiti Sains Malaysia, Kota Bharu, Malaysia	In this study, the effect of CLT-bLM on students' cognitive involvement and motivation in teaching anatomy course was investigated. The results of this RCT showed that students who were Lectured by the (CLT-bLM) method had higher cognitive engagement than the control group
7	Hazan-Liran 2017[16]	Lab experiments	Stroop-like effects in a new-code learning task: A CLT perspective	University of Haifa	The purpose of this study was to investigate the impact of competing for task-irrelevant information that creates extraneous cognitive load on learning. The results showed that extraneous cognitive load can have a negative effect on learning and should be avoided
8	Hessler 2013[17]	Quasi-experimental pretest-posttest design	Interactive learning research: Application of CLT to nursing education	University of Northern Colorado	Traditional hand-written paper case study was compared with the interactive self-paced computerized case study in two groups of students. CLT principles were used to design interactive case studies. The results showed that although there was no statistically significant difference between the two groups, scores of the interactive case study group were higher
9	Schilling 2017[18]	Theoretical paper	In respect to the CLT: Adjusting instructional guidance with student expertise	Northern Arizona University	In this article, the author claimed that adequate clinical instructional support should be provided to novice learners to facilitate their learning process. This will decrease extraneous cognitive load
10	Kavic 2013[6]	Editorial	CLT and learning medicine. Photo medicine and laser surgery	Ohio Medical University	Some explanations about CLT introduction, types, and principles

Contd...

Table 2: Contd...

Number	First author year of publish	Article type	Title	Site of study	Results and suggestion
11	Khalil 2005[19]	Theoretical paper	Design of interactive and dynamic anatomical visualizations: The implication of CLT	Florida State University	In this article, the author proposed designing of interactive and dynamic anatomical visualizations using CLT. The article presented some examples of instructional indications of CLT on the design of dynamic visualizations for anatomy learning and teaching
12	Kluge 2013[20]	Experimental study	Combining principles of CLT and diagnostic error analysis for designing job aids: Effects on motivation and diagnostic performance in a process control task	University of Duisburg-Essen, Lotharstr. Duisburg, Germany	In this two-part study, different aspects of procedural aid and additional decision aid for process control were evaluated. The aim of this study was to investigate the effect of CLT implementation on extraneous cognitive load and germane load for designing job aids. The results may lead to a better understanding of the performance of individuals in the control of the task process
13	Leppink 2016[21]	Twelve tips for Medical Teacher	Twelve tips for medical curriculum design from a CLT perspective	Maastricht University, the Netherlands	In this article, the authors have proposed a number of tips for designing a medical curriculum with the help of CLT. Tips were suggested according to the task fidelity, task complexity, and instructional support of the students' performance. The task fidelity in this study gradually increased from literature to simulated patient to real patients
14	Mitra 2017[22]	Original quantitative article	Pupillary response to complex interdependent tasks: A cognitive-load theory perspective	North Carolina State University	Pupil dilation is one of the factors that can determine the amount of cognitive load. In this study, three interdependent questions were asked from a number of undergraduate students. The results of the research can be used for instructional design
15	Devolder 2009[23]	Brief communication	Optimizing physicians' instruction of PACS through e-learning: CLT applied	Belgium Ghent University Hospital	In this study, a picture archiving and communication system was used to increase physicians' knowledge transfer. The principles of this system were designed using CLT to make it more useful and beneficial to physicians. The authors conclude that such systems are useful at the individual and organizational level
16	Tabbers 2004[24]	Experimental study	Multimedia learning and CLT: Effects of modality and cueing	Open University of the Netherlands	In this study, the impact of designing multimedia instructions using CLT principles was investigated. 151 students participated in this study and their learning rate was evaluated. Contrary to expectations, the results showed that multimedia instructions were not useful
17	Sharma 2016[25]	Letter to editor	Colonoscopy adenoma detection rates: Room for CLT?	National University Health System, Singapore	The author outlined the principles of CLT and suggested that the use of CLT principles in education could lead to improved colonoscopy adenoma detection
18	Kaylor 2014[26]	Original article (Instructional designing and evaluation)	Preventing information overload: CLT as an instructional framework for teaching pharmacology	University of Alabama	Pharmacology education is one of the challenging areas of nursing education. In this research, Pharmacology education is investigated within the framework of CLT. Finally, the researchers make four suggestions for better Pharmacology education to enhance the quality of education
19	Young 2016[27]	Observational study	Unpacking the complexity of patient handoffs through the lens of CLT	Shore School of Medicine, Hempstead, New York	In this study, the authors emphasize the importance of properly performing the patient handoffs process. After holding the expert panel and reviewing the experts' opinion, by using the CLT principles, they suggested a conceptual model to improve patient Handoffs
20	Rana 2017[28]	Educational paper	Teaching and learning tips 2: CLT	Deaconess medical center	Teaching to dermatology students can be challenging because of the variability in prior knowledge and experience. The authors of this article attempt to propose ways to reduce the cognitive burden of novice students and increase the learning rate of professionals using CLT principles

Contd...

Table 2: Contd...

Number	First author year of publish	Article type	Title	Site of study	Results and suggestion
21	Reedy 2015[29]	Theoretical paper	Using CLT to inform simulation design and practice	King's College London	This study focuses on the use of CLT to optimize simulation design and practice. CLT is a method for understanding the impact of the environment on education and its process. This article claims that when designing and implementing simulation-based learning, extraneous load must be minimized
22	van Gerven 2000[30]	Theoretical paper	CLT and the acquisition of complex cognitive skills in the elderly: Toward an integrative framework	Maastricht University, Maastricht, the Netherlands	This study examined the benefits of instructional formats based design using CLT to acquire complex cognitive skills by seniors who wanted to learn complex materials. The researchers concluded that studying the impact of CLT usage on the elderly could be useful to improve their functions
23	Young 2014[8]	AMEE Guide for Medical Teacher	CLT: Implications for medical education: AMEE Guide No. 86	Hofstra North Shore-LIJ School of Medicine, New York, New York, USA	In this article, application of CLT principles in different medical education setting such as workplace, self-directed learning and classroom was explored. Authors maintain that CLT principles have high relevance to medical education because of concurrent synthesis of varied sets of knowledge
24	Adams 2016[31]	Letter to editor	The application of CLT to dual-task simulation training	University of Texas Southwestern Medical Center	The author explains CLT principles in general and expound that although dual-task simulation may not be a good option for novice medical learners, it is necessary for health care providers. He propose the use of CLT for professional health-care staff to improve their performance
25	Sun 2017[32]	Original article (theoretical and practical paper)	Optimizing the design of high-fidelity simulation-based training activities using CLT-lessons learned from a real-life experience	McGill University Montreal, Canada	In this study, the impact of using CLT to improve the design of high-fidelity simulation-based training activities was investigated. Researchers maintain that high-fidelity simulation-based training, which is sometimes used to train health system crisis management, is complex. These materials need proper training principles for teaching, and CLT principles seem appropriate. The researchers propose suggestions for implementing CLT in high-fidelity simulation-based learning
26	Schilling 2016[33]	Theoretical paper	CLT of learning: Underpinnings and model	University of Southern Maine	This article tries to intertwine CLT and learning model. Authors argue that for encouragement of optimal learning having information about information storing in the brain is critical. Hence, CLT can provide an acceptable background for facilitating learning in student
27	Sharma 2016[9]	Out of hours (commentary)	CLT and teaching in primary care	National University Health System, Singapore	Types of cognitive load and cognitive load strategies were explained

CLT=Cognitive load theory, CLT-bLM=CLT-based lecture model, RCT=Randomized controlled trial, PACS=Picture archiving and communication system, AMEE=Association for medical education in Europe

More advanced students are to be given access to simulated tasks in computer models, simulation centers, or practice on cadavers in a slightly more realistic, yet still safe, environment. Students should work with real patients at the end of their education. Medical education professionals must sure that students obtain a proper support level at each stage of education. It is important to analyze learners, write measurable goals, and determine the outcomes with attention to CLT principles.[11,14,29,31,32] The extraneous load can be decreased through performing completion tasks, goal-free tasks, and worked examples, integrating various data sources, utilizing various modalities, decreasing redundancy, and minimizing interruptions and other such distractions. The instructional design utilizes interactive infographics, including pop-up information, texts, and pictures. When a student puts a mouse cursor on a particular area of a picture, an ancillary video opens to for a more precise clarification. Health professions educator should include more activities that lead students to an unspecified goal to reduce the extraneous load. For instance, designers can devise an activity requiring learners to think of myriad examples as to the reason why members of the community might not be comfortable with the research practices of the institution. Faculty members can incorporate both the worked example and completion principle in the courses. For example, suturing instruction might contain footage of a person finishing a suture followed by guided practice using mannequins. They might also be able to employ a split attention principle where "just in time" materials are provided in the form of user guides and simulation. In order to use the modality principle, faculty can utilize examples and video lectures instead of reading assignments. According to redundancy principle, they can decrease or eliminate excessive information sources and combine them via Learning Management Systems (LMS)[5,11,13,16-18] Finally, augmenting variability over tasks, implementing contextual interference, encouraging strategies facilitating the production of a precise patient mental model, including prior knowledge activation, performance monitoring, and understanding and compare/contrast, and evoking self-explanation can all optimize the germane load. A good instructional designing can utilize various case study instances to employ the variability principle and augment the GCL. Laboratories can utilize the contextual interference principle, and as they move through the semester, the faculty can randomize the tasks completed by students. The advantages of addressing underlying pertinent data via prelecture materials before incorporating other novel concepts in formal lecture forms can be also helpful. Further, the amount of effort dedicated to performance and learning is determined by the clinician. Self-regulated learning takes place at various levels such as efforts to fathom the diseases, language, ideas, numbers, and acronyms, or trying to remember the cases or draw from the handover generalizable lessons. Approaches are self-monitoring to specify when insufficient understanding is present, asking elucidating questions, maintaining various representations in the working memory for compare and contrast, and previous knowledge activation on the disease or the patient which is an applied strategy to optimize germane load [Table 3].[4,8,9,11,12,15,19,20,22,30]

An example of utilizing CLT for instruction design in pharmacology was suggested by Kaylor with using a game of true/false, case studies unfolding collaboration, watching videos on YouTube for brand

Table 3: Strategies for managing cognitive loads

CLT strategies	Instructional techniques	Explanation	Clinical example
Managing intrinsic load	Progress from facile to dificile	Increasing task difficulties step by step	Visiting simple patients to patient with complex comorbidity gradually
	Progress from low to high physical fidelity	Providing low physical fidelity such as paper-based scenario to higher ones such as simulators	Providing the chances to observe a clinical teacher in skill laboratory, then working on simulation and at last on a real patient
	Isolated element	Presenting only some of the task elements to the novices	Novices can be asked to do just physical examination separately from history taking
Decreasing extraneous load	Multi-modal learning	Using auditory, visual, tactile, smell, kinesthetic stimulations to facilitate learning	Using verbal presentation of a visual laboratory data to novices
	Transient information	Providing written statements besides verbal transient information	Persuading learners to use their written history taking before verbal reporting
	Split-attention	The physical integration of verbal and pictorial information sources can enhance learning, compared to their physical separation	Combining sources of information in ward round can avoid split-attention to the learners
	Problem Completion	Providing a not complete problem and asking learners to complete it	Novice learners of nursing can see the whole chain of a wound suturing and then complete the last part of this chain
	Worked example	Providing at least a demonstration for learners to show a typical problem-solution way	Showing a typical physical examination to novice learners and stop to explain each step
	Redundancy	Teachers must avoid extra not required information to learners	Teachers must avoid extra specific and detailed information related to patient's disorder to novice learners
Germane load optimization	Contextual learning	Providing a different version of a task randomly	Providing a chance to the students to work in special clinics with special diagnosis and then working in not special clinics to screen patients
	Variability	Variability of task and problems for increasing the number of interacting elements related to intrinsic load	Presenting the variable age, setting, gender, and comorbidity of medical diagnosis of a disease to the students
	Visualization	Asking students to imagine a concept or procedure	Visualizing detail steps of a wound suturing by nursing students after learning it and before repeating that
	Self-explanation	Asking the students to explain the task or procedure for themselves	Before breaking bad news, chief resident self-explain related to this topic

CLT=Cognitive load theory

names of medicine, or having large group debates, as opening activities. It was also mentioned that providing students with lecture notes, can be helpful. "Notes Page" presentation view is a feature of PowerPoint, dividing in half a standard 8.5" 11" page, where the presentation slide appears at the top and the notes section at the bottom. Topic categorization can be helpful in this case which focuses on five concepts: (a) drug categorization and action mechanism, (b) adverse effects that are medication specific or worrying, (c) important contraindications, (d) nursing factors such as infusion rates, injection sites, and laboratory tests, (e) patient instruction aspects including dietary limitations, monitoring education, and data regarding safety. Such learning strategies create an active learning environment concentrated on students' needs. The lecture notes provide the learners with the chance to listen to lectures actively with no stress regarding major topics when note-taking; if needed, students were able to directly do note-taking on the lecture notes that were printed, where they identified whether or not the information was "need to know" or "nice to know." Learners were further involved in reviewing at the start of the class, and as the semester progressed, even began to ask for their favorite activities. It was indicated by the instructor that the learning activities conducted to creating a "fun, engaging, and student-centered environment".[26]

Cognitive load theory in novice and experienced learners and "expertise reversal effect"

Research has shown, teaching that is properly designed for amateur learners are not the same as instructing learners who are more experienced. Instructional design for novices must assess the audience with regard to their prior knowledge and what they do not know yet. Underlying knowledge is to be taught prior to supplying one or multiple advanced knowledge to the students. Audio-visual presentations are more effective compared with presentations relying on one. Information is to be instructed in a manner that can be integrated by the students. Consider the potential impact of visual representations on different learners. Novice learners spend a lot of their cognitive resources analyzing the graphic, with limited resources remaining to connect and link the representations. Even when attempting to connect the representations, they more often focus on surface features, and not to the underlying pertinent features.[41]

On the other side, learners are considered experienced once they have automated most of their schemas and have deeply fathomed their field of the study.[4,8] Such learners are able to rapidly generate ideas and maintain a methodical thinking process utilizing schema or pattern. Recognizing the patterns conduces to learners quickly specifying problems and suitable solutions, while analytical skills and the methodical thinking process aid them in identifying specific problems and coming up with solutions. In longer running programs, the instructional design that used to apply to novice learners no longer impacts learners having more advanced prior knowledge, known as "expertise reversal effect."[4] Such anomaly has led instructional designers to employ a different strategy when designing materials for advanced learners. Instructional design for advanced learners is to be "adaptive, individualized instruction, based on authentic tasks, that gradually allows learners to take control over the process." Students ought to specify areas with room for improvement and create activities and learning that can address such items. Students become abler to self-monitor and identify more areas for improvement as they start being more active in learning. Instructional design generates activities enabling students to imagine, self-explain, or partake in future states because of such activities aid students in gaining experience from their mistakes and challenges. Jigsaw activities, peer teaching, and other activities provide advanced learners with more opportunities to explore the material. A LMS is useful for recording student progress. Voice thread and other such programs give students the opportunity to finish these activities and utilize instructor and peer feedback and discussion.[8,23,27]

Medical and health sciences curriculums and cognitive load theory

Task complexity, task fidelity, and instructional support are the three dimensions of devising curricula and materials in a medical setting. Task fidelity is the progression of learning tasks which start with low risk attempts such as material learning through lecture or text, and progression to simulated environments, and finish with actual scenarios and patients. Tasks are to gradually become more complex and skills required to aid learners will have more advanced knowledge and self-regulation skills. Teaching support differs among various stages of complexity and is to be gradually reduced as students workup their ways to becoming experts. At all levels, instructional support ought to provide students with practice chances and observe their cognitive load.[21]

To achieve learning, educators at the University of Calgary's Faculty of Medicine made use of the concept of worked examples. Using developed schemes, these educators provided the medical students with the experience of experts. They evaluated the pros and cons of the old medical curriculum to review and devise a novel one. By 1991, the Clinical Presentation Curriculum (CPC) was prepared comprised of 120 clinical presentations. Worked examples encourage the development of diagnostic knowledge. In one study, amateurs studying the worked examples of electrocardiograms gained better results in the retention test. CPC possibly offers a suitable approach to training, but it rather focuses on clinical education than on basic sciences or preclinical work.[21]

On the other side, a curriculum that establishes problem-based learning (PBL) strategy in the teaching-learning process, is not based on CLT and is suitable for hypothetic deductive clinical reasoning. In comparison, CPC is more appropriate than PBL for novice learners in the case of CLT.[2,42] It is to be noted that a complete PBL use in medical education is not recommended, but it could be effectively employed as a supplementary strategy to facilitate the research and self-study of senior students.[2] Moreover, minimally or partially guided teaching can positively influence supervised senior students because the formation of schemas (increasing expertise) is able to decrease the ICL.[2,42] Pretz, on the other hand, holds that holistic intuitive approach better suits amateurs dealing with everyday challenges, while analytical strategies are more suitable for experts.[43] Such arguments encourage health professional educators to make use of novel research where both analytical reasoning (AN) from system 2 of thinking and nonanalytical (schema or script) reasoning (NA) from system one are utilized. As demonstrated by Norman and Eva, interventions with the objective of having sheer amateurs to employ both types of processes over the diagnosis of electrocardiography illustrate slight but persistent effects. Similarly, one studyhas shown that promoting NA reasoning results in slight achievements with facile challenges, while encouraging AN reasoning leads to enhancements with challenging problems, highlighting the correlation between content and process.[42] According to Rencic, a mnemonic checklist like SEA TOW (is a Second idea required? Is this a pattern recognition diagnosis which is "Eureka"/pattern? Is there an Anti-evidence refuting my diagnosis? Did I Think about my thoughts (metacognition)? Am I Overconfident? What else can I be missing?) Can encourage careful reflection on the challenging and complex diagnostic process. This metacognitive strategy possibly conduces to recognizing the need to decelerate and prevent early closure errors.[44] It seems that although interactive factors are increased in this approach by slowing down the mind and thinking analytically (increasing ICL), it can be helpful for medical error reduction in both novice and advanced learners.[20]

Challenges of cognitive load theory

"Measurement" challenges (how to measure different types of cognitive loads), along with "construct" challenges (types of cognitive loads), are associated with CLT studies. Instruments only measuring the overall cognitive load have limited theory testing and application.[34] In the early 1990s, Paas introduced the primary cognitive load rating scale measure. There exist alternatives to the Paas scale such as secondary tasks which necessitate the students to get involved in a task secondary to the primary task. The indication is an increase in working memory load exerted by the first task may reduce the performance on the second task.[45,46]

Moreover, based on the qualities shared between the concepts of metacognition and germane load (e.g., monitoring the understanding and adapting action in actual time), future cognitive load measuring instruments should explore the inclusion of metacognition concepts. So far, there has been no literature published on the measurement of cognitive load subtypes during medical tasks.[34] Some studies have indicated that intrinsic and ECLs are interdependent, possibly with a nonlinear and heavily context-dependent relationship. Hence, their measurements are completely context-dependent. Another challenge is that it not possible to measure germane load right after a learning activity as there is little time for schema development or automation; therefore, there is a weak association between learning outcomes and GCL factors. Further, regarding the challenges of emotional states on CLT, it is known that positive emotions are related to more profound processing, yet it is not clear what approaches are able to most efficiently modulate emotional influences on working memory resources. Based on CLT, the extraneous load is associated with external sources including noise in the background or the manner of information presentation. However, it is noteworthy that a learner's self-consciousness caused by teacher's observation in a medical clinic, anxiety, inner thoughts, fatigue or other internal factors possibly conduce to extraneous load, thereby "consuming" working memory resources. Extraneous load approaches have concentrated on decreasing or discarding the sources, some of which may be inevitable (e.g., some kind of interruptions or distraction that is internally generated). The main question is that are there "teachable" skills – possibly, skills associated with concentration maintenance or mindfulness – able to effectively decrease the working memory influence of a certain distraction? or is it necessary to teach the students regarding problem-solving skills?.[47-51] Young *et al*. fostered an idea about second-generation handover practices which is concerned with internal distraction sources and the clinician's capability to deal with the distractions. He mentioned that approaches such as mindfulness, deep breath, or attention control are to be tested, as they may enhance the capability of a clinician to prevent distractions such as inner anxiety or outer noise, thereby reducing extraneous load and improving the performance. This is a new strategy for controlling the extraneous load; instead of managing the external factors, such interventions deal with the clinician's experience that can lessen the effect of distractions such as internal ones.[12,26]

Another challenge is that learner goal, teacher objectives, and approaches to human sensory processing should be included in the CLT model. Such augmentations are crucial because of the weak correlation between cognitive load and instructional design concerning self-controlled learning environments.[46]

Cognitive load theory from cognitive sciences view

There are various opinions about the impact of cognitive load on the ability of attention and concentration. Some believe that as cognitive load increases, distraction increases due to limited executive resources of the human brain. Others believe that relevant cognitive load can reduce distractibility by inhibiting peripheral processing.[52] Bottleneck theory emphasize that human information processing shows its limits in multitasking scenarios (doing two or more new tasks at the time). However, CLT can reduce occurrence of such incidences by reducing constrains that create bottleneck for learning.[8,31,53]

As was already mentioned, CLT is on the basis of human memory model, which is created by Shiffrin and Atkinson, and is associated with sensory, working, and LTM. Sensory memory contains the exact sensory copy of what was briefly presented (i.e., <0.25 s). Working memory, for a short period, maintains an input material which is more processed (i.e., <30 s), only able to process certain pieces of material. Finally, LTM is the storehouse for a learner's whole knowledge for a long time.[54]

Working memory is only able to maintain very few data elements that are independent at one time (7 ± 2), and is not able to process more than 2–4 elements actively at a certain time. This type of memory is regarded as the "bottleneck" for the processing of data,[55] and is the result of the correlation between myriad element processes, such as attention, prospection, perceptual, and LTM representation.[56] The function of working memory is altered over time with a trajectory that is U-shaped and inverted which can be changed for the better by training. An overloaded working memory impairs performance, and leads to errors, and possibly, entails patient harm.[56,57] However, it is to be borne in mind that capacity is augmented via "chunking" pieces of data into more convoluted units.[58] A well-accepted idea is that the constraints originate from the difficulty associated with maintaining various active representations separated from each other with minimal interference in neural activity. Humans are able to process more elements when they are distributed between the two channels, because working memory contains channels that are half independent for visual and auditory data.[8]

Although neural activity which is constant in tasks of working-memory is considered as resulting from reentry via circuits that are recurrent, its exact mechanism is yet to be understood, but possibly involves rapid plastic changes at synaptic levels. Therefore, despite the fact that working memory possibly involves short-term plasticity, it does not seemingly need structural changes like a synthesis of new protein, because it functions via recruiting already present ion channels and synapses. During working memory, several brain regions interact such as "executive" regions existing in the prefrontal cortex, parietal cortex, and basal ganglia, along with regions specific for the process of especial representations to be held, such as the fusiform face area responsible for visage data maintenance. Human consciousness can monitor the items in the working memory.[56] Findings from functional magnetic resonance imaging have confirmed the frontoparietal circuitry's role in working memory. This coordinated activity is supported by the superior longitudinal fasciculus (III); a white matter tract which connects the Brodmann area 9 / 46 with the supramarginal gyrus (BA40). Recent studies indicate the role of networks and their relationships such as Default Mode Network and task-based networks can have an impact on performance.[59]

Another important issue in CLT which is related to cognitive sciences is visualization. Visualization (creating pictures or images) is one of the useful techniques to optimize germane load.[8] It would be applicable in teaching-learning according to CLT because images can cue memories.[60] Visualizing involves both the early and higher-order visual thalamus-cortical pathways of the human brain,[61] and develops and refines internal demonstrations of solid and convoluted objects and their relative spatial position. The neuronal networks assembling the information and constructing memories do not concern the source (either created from within) of the inducing inputs so long as the necessary cellular and circuit signaling processes are available. Networks of "mirror neurons" in the brain possibly conduce to such procedures. Visualization processes further gain access to neural circuits that are engaged in sensory, motor, executive, and decision-making pathways in the brain.[62]

Discussion

In different settings of health science education, high levels of cognitive load can influence the performance and learning of trainees in a negative manner. In this systematized review study, we collected and categorized previous studies to five main categories called by "Various types of cognitive loads," "Aim of CLT," "Strategies to managing Cognitive Load," "CLT in novice and experienced learners and "expertise reversal effect," Medical and Health Sciences Curriculums and CLT," "Challenges of CLT."

CLT is specifically pertinent to complicated learning settings, in which there exist high levels of element interactivity, referring to when the components of a task cannot be independently processed, yet, for learning to occur, need to be processed with regards to one another.[5] The workplace environment can conduce extraneous overload and negatively affects the ability to engage in activities that promote germane load and learning. Intrinsic load must not be too high (overwhelming a student's working memory) or too low (inducing boredom or apathy). Common examples of extraneous loads are environmental distractions or suboptimal instructional design (e.g., unnecessarily having to look for information). Concerns about external or internal problems, competing demands, and self-induced time pressure are among the internal distractions also contributing to extraneous load which is always should be considered and minimized. Germane load, the third kind of cognitive load, refers to when learners freely employ cognitive processes so as to generate or modify cognitive schemas (organized patterns of data retrievable as a single unit and maintained in LTM). An important issue is that instructional designing including interleaved practice compared with blocked practice or prompting generative processes such as self-explaining or elaborating are among the approaches to promoting germane load.[5,8,12,27,34] In contrast to the intrinsic load which is not typically controlled by the learner, the capability of controlling or modulating the germane load primarily lies with the student. Increased levels of intrinsic and extraneous load decrease the space for the formation of the schema; therefore, the increase in the levels of either can affect the learning and performance in a negative way. It was suggested different cognitive load strategies according to the literature in this article.

Another issue is that as the complex and automatized schemas are forming, instructional designing must consider "expertise reversal effect." Instructional design for advanced learners is to be "adaptive, individualized instruction, based on authentic tasks, that gradually allows learners to take control over the process." Peer teaching is such a good technique for advanced learners.[5,8]

A major obstacle to completely understanding the implications of CLT for health professions education workplaces are measuring the cognitive load, particularly cognitive load subtypes. Current debate revolves around whether to conceptualize germane load as the subset of intrinsic load or as the third kind of cognitive load different from intrinsic and extraneous loads.[34]

Transferring cognitive patterns (schemas) to learners during a CPC have positive and negative points according to CLT and were compared to problem-based learning in previous literature.

Finally, as CLT mostly concern about human memory architecture, it seems that CLT's effects for workplace learning might be enhanced if considered besides the context of other learning theories.[5]

Among the limitations of this study was including only English language articles which indicates that missing some studies is possible. It was also limitation related to the uncertainty of the quality of articles. Furthermore, we considered four main databases and the nonuse of some other databases can be mentioned as our limitations. On the other hand, we tried to include a proper range of studies by systematic and hand searching and discuss CLT from the lens of cognitive neuroscience.

Conclusions

CLT was developed according to human memory architecture, evolutionary educational psychology. Although its various subtypes are a challenge in this theory, intrinsic, extraneous, and GCLs are mostly considered. Instructional designing generated by CLT can optimize learning through reducing the extraneous load, fitting the intrinsic load to the learner's developmental stage, and promoting germane load. A variety of strategies are suggested according to CLT to optimize learning. Teaching that is properly designed for amateur learners is not the same as instructing learners who are more experienced. CPC and PBL curriculums were comparing according to CLT. There are some challenges related to CLT, especially in measurement of subtypes. There are various opinions about the impact of cognitive load on the ability of attention and concentration. Some believe that as cognitive load increases, distraction increases due to limited executive resources of the human brain and the other believe that relevant cognitive load can reduce distractibility by inhibiting peripheral processing. Mental imagery (visualization) is one of the useful techniques to optimize germane load as it processes further gain access to neural circuits that are engaged in sensory, motor, executive, and decision-making pathways in the brain.

Acknowledgments

This study, registered under the code No. 397540 and ID code of (IR.MUI.MED. REC.1397.170) confirmed by the Ethics Committee, was part of a research project conducted to obtain a PhD degree in Medical education from the Isfahan University of Medical Sciences.

Financial support and sponsorship

This study was financially supported by the Research Deputy of the Isfahan University of Medical Sciences.

Conflicts of interest

There are no conflicts of interest.

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