FULL TEXT ARTICLE

Cognitive load in internal medicine: What every clinical teacher should know about cognitive load theory

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Abstract

Internal medicine is an appropriate example of specialties in which to teach learners clinical reasoning skills, decision-making, and analytical thinking, as well as evidence-based, patient-oriented medicine. During daily clinical work, general internists always encounter a multitude of situations that lend themselves to educating medical trainees in ambulatory and inpatient settings. Application of existing learning theories to teaching has been shown to optimize teaching ability and to maximize the efficiency of teaching efforts.

Cognitive Load Theory explains learning according to three important aspects: the types of memory (working and long-term memory), the learning process and the forms of cognitive load that affect our learning.

The aim of this paper is to show the main perspectives and implications of the Cognitive Load Theory on clinical educational practices. It is important to give the right amount of information in the most effective way to learners, thereby making this information more useful. This article presents a concise overview of the basis of the Cognitive Load Theory in its first part, and, in its second part, it exposes the practical applications of this theory with examples. This learning theory will encourage clinical teachers to reflect on how to foster learning in medical trainees in the more effective way.

Highlights

- CLT can explain why learners struggle to master complex concepts and develop expertise.
- The human cognitive system has a limited capacity that can retain only 7 elements of information.
- There are 3 types of cognitive load that explains the limited resources of the working memory.
- CLT can help clinical teachers maximize the efficiency of their teaching efforts.

1 Clinical vignette

Consider the following scenario: As the attending physician working with a student, you are seeing a 40-year-old man coming to the emergency department after a sudden loss of consciousness while playing tennis with a friend. The patient can recall the sudden onset of light-headedness and a tingling sensation across his forehead for a few seconds before he lost consciousness [1] *. When he regained consciousness, he had no nausea, diaphoresis, chest pain, or dyspnoea. He was not injured and had no bowel or bladder incontinence. Witnesses reported no tonic–clonic movements. At initial presentation, the patient had normal vital signs, and the physical examination was unremarkable.*

While the student is trying to summarize the anamnesis and the physical symptoms, you start to discuss the differential diagnosis of the syncope. After a rapid analysis of the case you already have some strong diagnostic hypothesis. The student, however, cannot follow your reasoning. Puzzled, as you have come to appreciate how smart he is, you advise him to read the chapter on syncope in Harrison [2] *tonight. The next minute your telephone rings and, while you are heading off to your next appointment, you reflect on what just happened and wonder how you could better support your students in their learning.*

2 Introduction

Finding the right moment and a suitable task to teach pre-and postgraduates trainees is not an easy endeavour on top of everyday clinical activity. As educators for the next generation, experienced physicians have the mission of sharing their knowledge and skills with students and young residents in the best possible way [3]. An internist's reality is often characterized by complex cases, which sometimes seem too intricate to explain to the learners, making it challenging to synthesize clear learning messages in the little time available.

Medical training is the fundamental process of enhancing the development and maintenance of professional skills and competencies of a physician. To maximize the efficiency of teaching efforts, it is important to pause and think about how learning in the clinical context should proceed: sustainable learning does not come without effort from both the learner and the teacher.

Application of existing learning theories to teaching has been shown to optimize teaching ability [4]. Cognitive load theory (CLT) is a well-established learning theory, which takes the limits of the working memory (i.e. our attention span) into account. Teachers have to understand that learners are easily affected by cognitive overload, which is the situation where the learner has to manage too much information or too many tasks simultaneously, resulting in the learner being unable to meaningfully process this information. According to the CLT, sustainable learning appears to be heavily dependent on at least three factors: First, the knowledge already possessed by an individual regarding a given issue (memory), second, the complexity of the new information to be learned and, third, the way that new information is presented in the teaching situation [5].

It is, therefore, crucial to address the factors that affect the capability to learn and that can help a novice to become a medical expert. The target audience of this article is the clinician with teaching responsibility but limited theoretical knowledge about recent learning theories and aims to highlight the main perspectives and implications of CLT on clinical educational practices.

3 Cognitive load theory

Cognitive Load Theory (CLT) was initially developed in the 1980s by John Sweller [6]. This theory explains learning according to three important aspects: the types of memory (working and long-term memory), the learning process and the forms of cognitive load that affect our learning.

The task of a clinical teacher is to support the students to learn professional activities that are characterized by the simultaneous and meaningful integration of multiple sets of knowledge, skills and behaviours. These specificities are likely to induce high cognitive load. Where information related to a specific clinical case cannot be integrated optimally with already existing individual knowledge, sustainable learning may need more mental effort and take more time. Consequently, an everyday task in the clinic may overload a learner. In this context, CLT helps clinical educators to understand why learners in the health professions have problems mastering complex concepts and developing expertise [7], and it also offers strategies to support clinical teachers to facilitate effective student learning.

3.1 Types of memory

Research shows that the human cognitive system has a limited working memory (WM) capacity [8]. The WM is responsible for the active processing of information in real time [9]. WM receives inputs from both the sensory system and long-term memory (see Fig. 1 (f0005)).

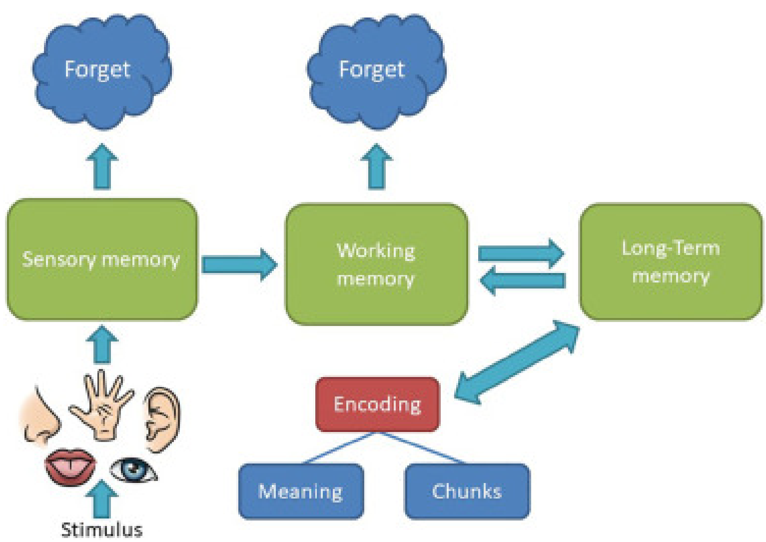

Fig. 1

Sketch of basic memory architecture (adapted from Baddely, 2014 [13]).

Long-term memory is the storage for permanent knowledge and skills. To this day, research assumes that long-term memory of a healthy person has few limitations, i.e. that, storage capacity is unlimited and memories are permanent [10].

The WM, in contrast, is limited as it can retain only in average 7 ± 2 elements or chunks of information [11] and can actively process no more than two to four items simultaneously [12]. The chunks of information can vary in size, according to individual experiences or training. It is important to be additionally aware that almost all information in the WM is lost within seconds if not promptly refreshed. In order to be transferred to long-time memory, new information needs to be encoded and related to knowledge already stored. This process is what is commonly referred to as 'learning' and is addressed in the next section.

3.2 Learning processes

The CLT explains learning as the process of organizing information into cognitive schemas in the long-term memory. A schema (chunk of organized information elements) can hold a huge amount of information, yet it is processed as a single unit in our WM. The formation of schemata is important to improve learners' understanding of a specific problem and to develop the ability to apply the information to future situations. The development of medical expertise implies restructuring our own knowledge into encapsulated concepts, which describe syndromes, groups of diagnoses or simplified causal mechanisms [14].

Consider the example at the beginning of this paper: the differential diagnosis of syncope, although complex, can be recalled from the long term memory almost automatically as a unique element by the WM of an expert who has organized his/her knowledge in a structured schema. Conversely, a novice will have to work with unstructured information elements ranging from pathophysiology aspects to clinical signs. His/her WM will struggle (eventually being overwhelmed) to organize his/her knowledge into a few meaningful sub-units, such as vascular conditions, cardiac conditions, central nervous system conditions and so on.

According to the CLT, such schemas of knowledge can be automated if they are repeatedly retrieved and used with success. Automation is a further process that increases the information processing capacity by reducing cognitive load; in fact, automated schemas can free WM because they bypass the WM and are processed subconsciously [15]. The ability to perform a task without significant mental effort is a characteristic of proficiency and allows the expert to perform multiple tasks at the same time and still process new and relevant information [16].

Therefore, two important points for the learning process can be retained:

1. Experts should support the construction of clinical schemas by making their own schemata of knowledge explicit to the students. This requires that the experts have to step back and deconvolute their knowledge contained in a schema. The elements of the deconvoluted schema should then be re-built together with the student.

2. Novices should see many and varied patients and be supported in their reflections on the clinical cases they see. This encourages the elaboration of their own schemata of knowledge. *Repetita iuvant* said the Romans already more than two thousand years ago!

3.3 Types of cognitive load

The cognitive load theory identifies three types of cognitive load that explains the limited resources of the working memory in different ways:

1. Intrinsic cognitive load: refers to the characteristics of the learning task and the effort it imposes on the learner to construct adequate and rich schemata. The intrinsic cognitive load increases with the complexity of the information being attended to. It depends on the number of elements and the relationship between the elements that must be processed simultaneously.

Dealing with a poly-morbid patient can represent an example of high intrinsic cognitive load: the more pathological elements the patient presents the more effort the learners will make to retain and understand the information in its entirety as well as any interrelationship.

2. External or extrinsic cognitive load: refers to the load imposed by the learning environment and the way the information is presented. Background noise, a chaotic environment or inadequate instructional design (e.g. chaotic explanation, overloaded slides, no clear logical relations between information elements, or weak association with learners existing knowledge) tend to prevent learners from effectively building new knowledge. Extraneous cognitive load increases when much information is presented simultaneously. A good learning environment for novice learners seeks to reduce irrelevant information and provides a structured, step by step instruction.

One of your students presents a case of glomerulonephritis to the specialist of nephrology. Your nephrology colleague utilizes the case as an opportunity to speak about his latest research on the immunopathological changes of podocytes in vivo *, the increase of glomerular interferon-gamma and the deficiency of membrane-associated guanylate kinase inverted 2. All at the same time.*

3. Germane cognitive load: refers to the capacity of working memory to make sense of information, i.e. to process the given information meaningfully. It is the load associated with the mental effort necessary to reorganize information in order to construct good schemas and interact with storage in the long-term memory. Without meaningful processing of the information, learning cannot occur.

The CLT assumes that these types of cognitive load interact and that each learner has an individual maximum cognitive load (i.e. the germane cognitive load span is specific to an individual). As shown in Fig. 2 (f0010) , it is important to adapt the difficulty of a task to the level of the learner (complicated information for an early learner may be easily assimilated by an advanced student). Hence, the clinical teachers should try to decrease the external load, then decompose a complex task into manageable units for a novice learner. This will leave free working memory in the learner to promote the construction of own schemas.

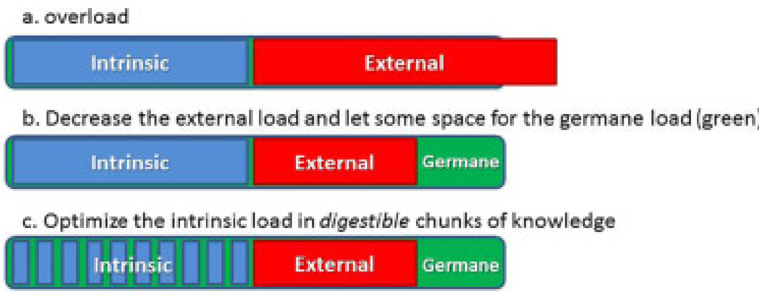

Fig. 2

How to optimize cognitive load: mind the overload (a.), reduce external load (b.) and simplify the information into blocks (c.). This will provide the learning capacities of the learners (germane load) with more space to operate.

4 Recommendations for practical application

Above, we have indicated that the CLT offers interesting perspectives on how to improve learning and help re-design clinical teaching. Its aim is to facilitate the germane cognitive load, which results from the optimization of the intrinsic load while also minimizing the extrinsic cognitive load. The teacher should adapt the education design and pitch this accordingly to the level of the learners, in order to enable them to build new knowledge based on their actual level of expertise [17]. The learning task itself should have the right degree of complexity, not being too complex for a beginner nor too simple for an advanced learner. The later refers to the so-called expertise reversal effect, which indicates that principles that work well for novice learners don't necessarily work well or even have negative effects for more expert students [18].

In the following tables, some strategies to manage the intrinsic load (Table 1 (t0005)), to reduce extrinsic load (Table 2 (t0010)) and optimize the germane load and avoid the expertise reversal effect (Table 3 (t0015)) are presented and related to example clinical situations:

Table 1

Strategies derived from the CLT to manage intrinsic load.

Technique	Description	Example
Isolated elements	When a task contains too many interrelated elements, overload should be avoided by presenting the most critical elements first and helping the learners to develop schemas to combine the elements	*When confronting students with a patient presenting a complex history, the anamnesis and its diagnostic implications could be discussed before beginning the physical examination. This would help students isolate the different elements of the clinical picture.*

Technique	Description	Example
Simple to complex	Increase the complexity gradually. By failing to differentiate complexity, we may under-load some learners and overload others [19]	*As a resident progresses during his/her training, encourage him/her to treat increasingly complex patients with more autonomy: patients with multiple comorbidities, higher acuity and higher-risk treatment*
Low to high fidelity	Starting in a high-fidelity environment (i. e. situations very similar to reality, which include many details and distracting factors) too early may overload students with too many elements, which therefore hinders learning and may even induce misconceptions [20]	*Students learn how to interview patients by practicing first with standardized patients (actors taking the role of a patient in a safe training situation), before proceeding to contact with real patients under direct supervision, and then finally interacting with real patients without direct supervision.*

Table 2

Strategies derived from the CLT to reduce external cognitive load.

Technique	Description	Example
Provide worked examples	Worked examples are composed of an introduction to a formulated problem, a task and a demonstration of each step needed to accomplish the task successfully [21]. Recent research has shown that the ideas behind worked examples are very useful to learning in the medical context [22]	*While analyzing the laboratory values of a patient, the senior resident provides a step-by-step demonstration of how to calculate the anion gap in the arterial blood gas-analysis. Then the students have the possibility of doing the same calculations on their own.*
Provide problem completion tasks	Provide the learners with a partially solved problem and ask them to perform the remaining steps [23]	*The resident is informed that the next patient has a liver cirrhosis and is asked to do a history and a physical exam*
Provide Goal-free learning tasks	Assign learners tasks that have a non-specific goal and encourage them to extend their knowledge base without being stressed by the job of finding a definitive solution.	Ask your learners to *find as many etiological explanations for these symptoms as you can as opposed to: Which illness is indicated by the symptoms of this patient?*

Technique	Description	Example
Combine modalities wisely	Present information using modalities that can be processed in parallel (e.g. auditory, visual) [24]. Overloaded visual information (e.g. pictures explained by text) cannot be processed in parallel, visual information and auditory information can.	*While explaining a patient-case to your student, use graphic diagrams* (i.e. *24-h blood pressure profile*) *to analyse the data and trends* [25]
Avoid unnecessary Redundancy	All redundant information that is not required for learning increase the extrinsic load.	*Clinicians frequently receive notification of the identical information* via *a page, a separate call from the lab, a flag in the lab page and an email. These well-intentioned notifications create a noise making it difficult to process other data* [26] *. For the clinical teacher, it is essential to recognize this and to point out the essentials*
Avoid split attention	When students are required to split their attention between multiple elements that must then be mentally integrated, the resultant working memory load interferes with learning [27]	*In the case of the syncope: while the student is trying to summarize the anamnesis and the physical characteristics, it is not appropriate for the educator to start discussing the differential diagnosis of the syncope. It is better to pause and leave the student enough time to process the different elements before beginning with a new task,* i.e. *discussing the differential diagnosis.*

Table 3

Optimizing the encoding and the learning process by monitoring germane cognitive load.

Technique	Description	Example
Offer variability	Illustrate tasks or problems using multiple/variable examples, from different perspectives	*Reviewing a patient case, the resident is asked how management would be different if some variables* (*age, gender, comorbidities,* etc.) *would change* [28]

Technique	Description	Example
Encourage Imagination before performing a procedure	Ask the learners to imagine or explain how to perform a procedure rather than just refer them to a textbook and let them read	*The attending physician asks the resident to explain each step of a lumbar puncture before practicing the procedure. So the expert can see if any of the steps were difficult to imagine clearly. If this proves to the case, these steps are revised.*
Encourage self-explanation and reflection	Ask the learners for their rational/explanation why a certain decision was taken. It will help them reflect and develop reasoning skills	*As a clinical teacher you prompt the resident to give the rationale behind a medication choice. The resident should be able to explain the risks or benefits of such medication by pondering side effects and the expected effects of the treatment in the specific clinical situation*
Fading guidance	Learning is promoted when the initially provided guidance is gradually decreased as the learner progresses and is able to take on more responsibilities	*In the case above of the lumbar puncture: we can first provide a step-by-step guidance, then feedback and finally no supervision at all*

5 Discussion

With this paper we aim to provide clinical teachers with access to a recent learning theory and its application to enhance learning. We intend to bridge the gap between clinical work and training, and summarize key outputs from the medical education literature. While the target audience of this article is clinical teachers in internal medicine working with students and young residents, the principles of CLT can be used in other medical specialties and other teaching settings.

The cognitive architecture as described by CLT and its relevance for clinical teachers is presented here. Learning in the clinical setting requires the simultaneous integration of information into meaningful schemas, which are integrated sets of knowledge elements related to patients and situations. In our opinion, the CLT offers principles that can easily be applied as guidance for clinical teaching, even though this theory was initially developed for teaching and learning classical knowledge (e.g. math), rather than applying it to complex procedures. Recent research [29 30 31] and our examples presented here show that the CLT principles are easily applicable for clinical teaching; individual clinical teachers can apply these principles, which are also well suited for faculty development, and hopefully will encourage discussion on clinical teaching in general. Of course, our initial examples can be extended with countless other scenarios.

Clinical teachers should be aware of the differences in clinical reasoning between themselves (as experts) and the novices they are teaching to. In fact, research in clinical reasoning has shown that experts have different representations of knowledge [32] i.e. highly organized schemata. That is why it is important for the clinical teacher to make their schemata of knowledge explicit to the novice trainees. Research has shown that schema-based instruction is associated with improved retention of structured knowledge and diagnostic performance among novices [33].

Moreover, it is important to adapt clinical teaching to the progress of learners and to consider the expertize-reversal effect: trainees need to be provided with an optimal (not too much, not too little) amount of work that should challenge learners, but not exceed their capacity. In a safe learning environment, learners should be able to seek help when the work exceeds their capacities, without this being perceived as a weakness [34].

Analyzing a teaching event through the lens of CLT will facilitate the clinical teacher to find the most appropriate instructional designs. It is important to note that, to be effective, such education will rely on both learners' and instructors' motivation and engagement, as well as effective communication between learners and instructors. For example, it has been shown that perceived supervisor disengagement and lack of confidence have been associated with higher levels of external cognitive load [35]. Clinical teachers should assume the same role for their learners as trainers for athletes or musicians. Athletes are usually supported by trainers or coaches who try to structure practice activities to improve individual performance and provide informative feedback [36].

Hence, CLT shows that the responsibility on learners' progress also rests with the clinical teacher. When students have just completed their undergraduate medical education and start working as residents, they are often overwhelmed by the complexity of the working environment and rely on help from clinical supervisors to accomplish their tasks. Even a motivated and bright learner is not in the position to make use of consolidated clinical knowledge at the beginning of his/her postgraduate education. These limitations can be bridged when clinical teachers possess basic understanding of how knowledge is attained by trainees and how this process can be supported.

6 Conclusion

When the working memory of the learner is overloaded, learning is hindered and the resulting clinical performance is impaired. This can cause errors and eventually harm patients.

Returning to the clinical vignette presented at the beginning of this manuscript, cognitive load theory can be used as a framework to guide a useful teaching session with our learners. First, the adequate amount of time and space should be found to discuss the case and to reduce the external cognitive load. Second, the educator's schema of syncope (with all its elements) needs to be explicit to the student. In doing so the complexity is reduced and the intrinsic load lowered. This should enable the learners to meaningfully process the information within their individual germane cognitive load capacity. In turn they can build their own schemata of the differential diagnosis of syncope.

Thus cognitive load theory can be used to derive practical techniques to foster learning in medical trainees. We encourage clinical teachers to reflect on how these can be applied to their own teaching situations.

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