From Theory to Practice: The Application of Cognitive Load Theory to the Practice of Medicine

Adam Szulewski, MD, FRCPC, MHPE, PhD, Daniel Howes, MD, FRCPC,
Jeroen J.G. van Merriënboer, PhD, and John Sweller, PhD

Abstract

Cognitive load theory has become a leading model in educational psychology and has started to gain traction in the medical education community over the last decade. The theory is rooted in our current understanding of human cognitive architecture in which an individual's limited working memory and unlimited long-term memory interact during the process of learning. Though initially described as primarily a theory of learning, parallels between cognitive load theory and broader aspects of medical education as well as clinical practice are now becoming clear. These parallels are particularly relevant and evident in complex clinical environments, like resuscitation medicine. The authors have built on these connections to develop a recontextualized version of cognitive load theory that applies to complex professional domains and in which the connections between the theory and clinical practice are made explicit, with resuscitation medicine as a case study. Implications of the new model for medical education are also presented along with suggested applications.

Cognitive load theory (CLT) has emerged as one of the leading models in educational psychology over the last few decades.[1] Its success is due, in part, to its generalizability across domains, including medical education.[2] Rooted in theory, the end goal of CLT has always been to improve learning at the individual student level.[3] Recently, CLT has started gaining traction outside the classroom in complex professional domains,[4] and there is every reason to suggest that it can also be applied to medicine. Though CLT has relevance across medical specialties, its applicability is particularly evident in the practice and teaching of resuscitation skills.

Resuscitation medicine is a field of medicine that spans specialties where physicians care for patients who are acutely ill and require emergent intervention (e.g., patients suffering from cardiac arrest, multisystem trauma, shock). In general, physicians involved in resuscitation medicine rely on crisis resource management skills to lead teams of health care providers in challenging high-stakes environments that are characterized by stress, uncertainty, and incomplete information where decisions must be made rapidly.[5] A failure to act appropriately in a short time period can have potentially fatal consequences for patients, a situation which regularly places heavy demands on physicians' cognition. This cognitive burden makes this field of medicine an ideal case study for the application of CLT.

The intention of this paper is to make explicit connections between theoretical CLT concepts and their practical application in clinical work. We hope that this will improve clinicians' appreciation for the cognitive processes at play when they are making important decisions for their patients, often under time pressure and in messy clinical environments. We feel that the connection we are drawing has the potential to improve both teaching and the practice of complex professional fields, like medicine. At the same time, there is the potential for the field of CLT to be moved forward and enriched by an understanding of how it is being applied in real-world settings.

In this article, we first review CLT in general, then discuss how its principles can be applied to medicine, using resuscitation medicine as a case study. We conclude with the introduction of a recontextualized version of CLT that has practical applications to clinical medicine and other related professional domains. By introducing this new framework, our goal is to provide a shared theoretical foundation and lexicon for the ongoing study of CLT in clinical practice.

CLT Background

CLT is a theory of education that is grounded in an understanding of human cognitive architecture from an evolutionary psychology standpoint. Based on Geary's work,[6–8] it is assumed that knowledge can be categorized into biologically primary knowledge and skills, such as acquiring a native language, that we have evolved to acquire, and the biologically secondary knowledge and skills that we acquire for cultural reasons. Educational institutions were established to deal with biologically secondary knowledge and skills. Most biologically primary knowledge consists of generic cognitive skills such as general problem solving, while most biologically secondary knowledge consists of domain-specific skills such as knowing how to multiply out a denominator in algebra.[9]

The cognitive architecture used by CLT applies to biologically secondary rather than primary knowledge. That architecture allows us to acquire novel information either by a random generate-and-test procedure during problem solving or, more commonly and more efficiently, by obtaining information from other people or learning resources. Novel information must be processed

Please see the end of this article for information about the authors.

Correspondence should be addressed to Adam Szulewski, Department of Emergency Medicine, Queen's University, 76 Stuart St., Kingston, Ontario, Canada K7L 2V7; telephone: (613) 549-6666, ext. 7660; email: adam.szulewski@queensu.ca; Twitter: @Adam_Szulewski.

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in a working memory with limited capacity and limited duration before being transferred for storage to long-term memory with no known limits on capacity or duration. Lastly, once information is stored in long-term memory, it can be transferred back in unlimited amounts for unlimited periods of time to working memory to generate appropriate action.[1] Appropriate triggers from the environment determine which stored information is transferred back to working memory.

Based on this architecture, processing novel, biologically secondary, domain-specific information in working memory can generate a cognitive load that is reduced through learning if that information has been stored previously in long-term memory for later use. At a conceptual level, cognitive load during learning can be divided into 3 basic elements: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. Intrinsic cognitive load refers to the relative complexity of information specific to a task and person. Extraneous cognitive load is due to suboptimal conditions for information presentation. The sum of intrinsic cognitive load and extraneous cognitive load is thought to represent the overall cognitive load that can be measured experimentally. Germane cognitive load refers to the working memory resources dedicated to processing intrinsic cognitive load and is related to the construction and automation of mental schemas that relate information elements to each other.[10]

From an educational perspective, the main principle of CLT is for educators to minimize extraneous cognitive load, thereby optimizing germane cognitive load within the limits of available cognitive capacity. If the sum of intrinsic cognitive load and extraneous cognitive load exceeds working memory capacity, then a state of cognitive overload results, which leads to poorer learning outcomes. See Figure 1 for an overview of these concepts.

Beyond Traditional Notions of CLT

Though initially described as a theory of learning that could be applied to optimize instructional design, more recently, researchers and educators have started to draw parallels between CLT and the domains of medical assessment and[11,12] medical simulation,[13] as well as medical professional practice.[14,15]

CLT has recently been expanded to include 2 new constructs: working memory depletion[16,17] and affect (e.g., emotion, stress, uncertainty) as factors that can influence cognitive load.[18]

The addition of the working memory depletion effect expands on the previously held notion that working memory has a fixed capacity. Building on changes to the testing effect with changes in test timing, Leahy and Sweller[17] showed that working memory resources can be depleted with cognitive activity and later restored with periods of cognitive rest. Related to this, Chen et al[16] found that learning that was spaced by temporal gaps between learning episodes was superior to identical, massed learning with no gaps between learning episodes. After massed practice, learners obtained lower scores on a working memory capacity test, higher ratings of cognitive load, and lower test scores than after spaced practice.

Affective factors (like emotion, stress, and uncertainty) are thought to contribute to extraneous cognitive load in traditional educational models.[1] Therefore, the goal of education should be to minimize these factors in an effort to optimize learning (by maximizing germane cognitive load). What has started to become clear, however, is that though emotion, stress, and uncertainty likely detract from learning in a traditional classroom setting and, therefore, contribute to extraneous cognitive load (see Figure 2A), these factors are inherent to the practice of complex skills in many real-world professional settings. As a result, in such settings, these factors may instead contribute to intrinsic cognitive load (see Figure 2B).[1] In an empirical study, in which the types of cognitive load were measured in physicians working in a busy urgent care center, measures of overall cognitive load, intrinsic cognitive load, and acute stress were highly correlated with one another, suggesting that stress is an element of clinical work that is inherent to the work itself.[15] This finding lends evidence to the model whereby emotion, stress, and uncertainty contribute to intrinsic cognitive load (as opposed to extraneous cognitive load) in certain professional domains.

In training individuals within professional domains like resuscitation or emergency medicine, minimizing these affective factors risks inadequately preparing trainees for their professional work. Take, for example, this case that a lead physician may face:

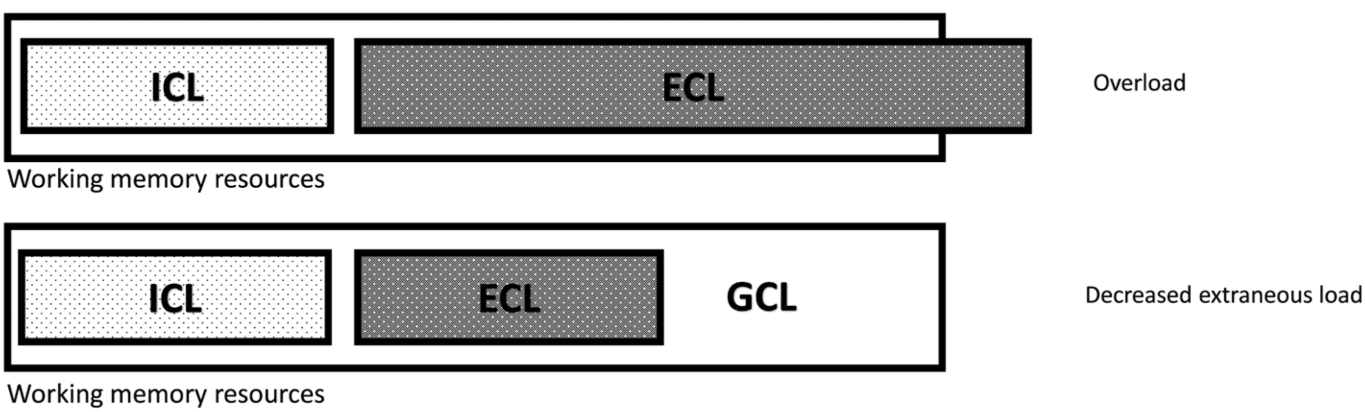

Figure 1 Traditional conceptualization of cognitive load theory. The 2 black rectangles incorporating ICL, ECL, and GCL represent available working memory resources. Abbreviations: ICL, intrinsic cognitive load; ECL, extraneous cognitive load; GCL, germane cognitive load.

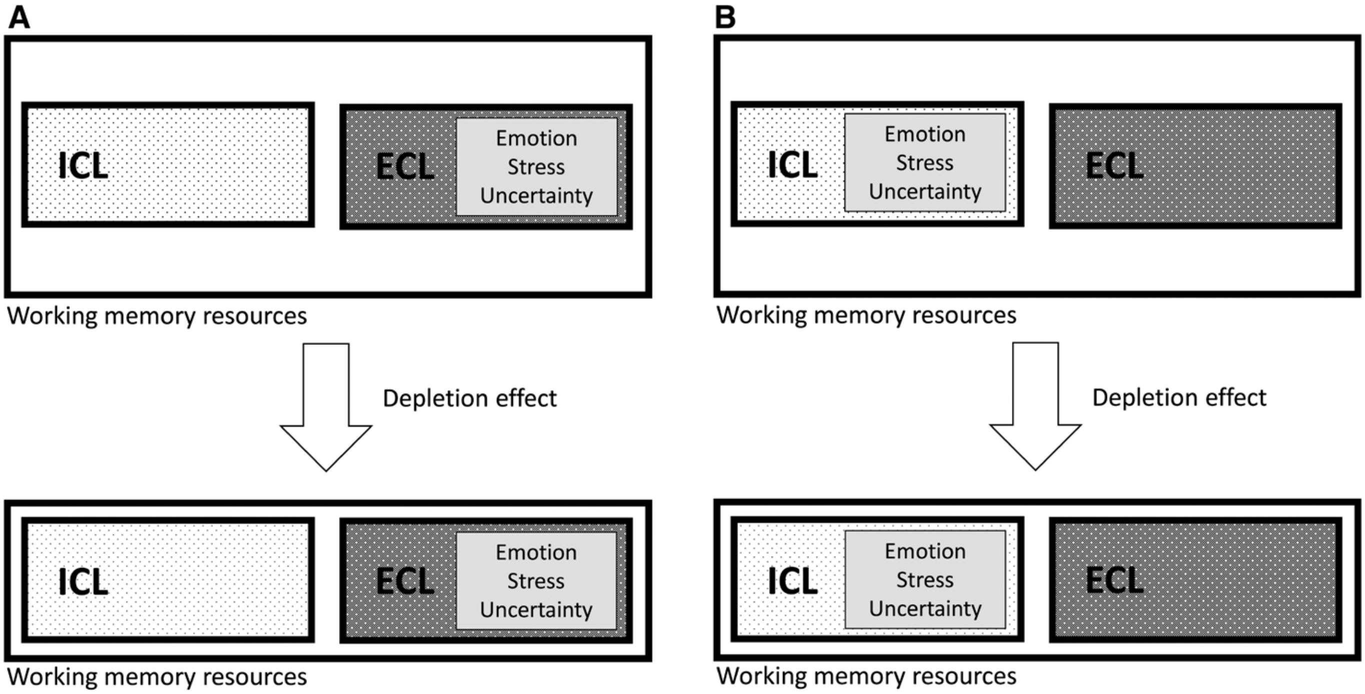

Figure 2 The working memory depletion effect and the contribution of affective factors to cognitive load in traditional educational settings (A) and in complex professional domains (B). With cognitive effort, working memory (the black rectangle) is thought to decrease in capacity through the depletion effect. Affective factors (e.g., emotion, stress, uncertainty) are thought to contribute to extraneous cognitive load in traditional educational settings (A) and to intrinsic cognitive load in complex professional domains (B) where these factors are inherent to professional tasks. Abbreviations: ICL, intrinsic cognitive load; ECL, extraneous cognitive load.

> A 14-year-old boy arrives in the emergency department at 3 AM after being involved in a snowmobile accident. He was the helmeted driver of the vehicle, which was traveling at approximately 100 km/h. The trauma team (led by the physician) is assembled when the patient arrives. The team consists of a number of residents, each representing different specialties, most of whom the physician leader does not know. The patient has a low blood pressure and high heart rate, suggesting he is in shock. He also has an obviously broken leg with no pulse. He is confused and only moaning in response to painful stimuli. As the patient arrives, a code blue is called overhead, and the anesthesia resident on the trauma team must immediately leave the trauma bay to deal with this cardiac arrest on the ward. Within 5 minutes, the patient's worried parents arrive in the emergency department, asking for an update. There are 11 other patients in the emergency department waiting to be seen.

Because stress, emotion, and uncertainty are factors influencing cognitive load that are inherent to the work of being an emergency physician, it seems more accurate to consider them as part of intrinsic cognitive load, as opposed to extraneous cognitive load. Simply stated, they are factors that are par for the course in emergency medicine. For many factors, whether they are considered intrinsic or extraneous depends on how one defines the role of the person performing the task. If the role of the physician is to care for the trauma patient, the other waiting patients are extraneous. If the role of the physician is to oversee all of the medical care in the emergency department, these waiting patients are intrinsic to the physician's job.

In a study based on a modified cognitive task analysis of expert trauma team leaders, physicians described the ability to handle uncertainty and to maintain a defensive pessimism as aspects of their cognition integral to managing a resuscitation case.[19] This finding supports the argument that these affective factors are intrinsic to the nature of the professional task itself, as opposed to being external factors needing to be minimized.

During physician training, the extent to which these affective factors should be minimized probably depends on the learner's level of expertise. Early in training, these elements may overload or distract the student, reducing learning. Eventually, with increased expertise, physician trainees should be exposed (in a graded fashion) to emotion, stress, and uncertainty during their training and be taught strategies to deal with these real-world challenges if they are to be adequately prepared for their eventual professional roles. One way to accomplish this change in exposure to the affective components of resuscitation medicine is by gradually increasing the number of realistic clinical challenges in physician simulation training (e.g., time delays, lack of personnel, needing to troubleshoot malfunctioning equipment). Appropriate training can be realized by applying a design approach like the Four Component Instructional Design model and sequencing exposure of learning tasks in a simple-to-complex and a low-to-high fidelity fashion. At the same time, learners should be provided cognitive supporting strategies (including modeling examples provided by the instructor).[2] This new proposed approach to the delivery of simulation education contrasts with the current approach in which strategies for dealing with affective factors are often ignored, equipment and personnel are predictably available, and delays rarely exist—often because instructor to learner ratios are low and simulation lab time is a limited resource.[20]

CLT Terminology Applied to the Clinical Context

The terminology used in CLT has been well defined in an educational setting. We believe that direct parallels exist in the clinical realm. In a clinical setting, intrinsic cognitive load refers to a physician's cognitive work related to the clinical task in question. Depending on one's perspective, the term may refer to the management of an individual patient or to a larger task (e.g., managing all patients in a section of an emergency department). This load is made up of both the intrinsic load proper and affective components (emotion, stress, uncertainty). Extraneous cognitive load, in a clinical setting, is understood to refer to distractions and interruptions that are not related to the task in question. Examples include overhead pages about patients in other areas of the hospital and loud conversations between staff in adjacent care areas. Germane cognitive load, as it is described in the original CLT model, refers to the working memory resources dedicated to processing intrinsic cognitive load (i.e., for schema construction and automation). In an environment where clinical work (as opposed to learning) is the main goal, germane cognitive load likely plays a more limited role.

When the cognitive demands of both intrinsic and extraneous cognitive loads overwhelm working memory resources, a state of cognitive overload ensues. Cognitive overload (sometimes referred to as "helmet fire," a term used by aviation's fighter pilots) refers to the reduced ability to perform or make decisions during difficult cases when working memory resources are overwhelmed by heavy intrinsic and extraneous cognitive load. Finally, the idea of working memory depletion is related to the idea of *decision fatigue* that is often discussed in medical circles and is well described in the literature.[21–23]

These theoretical ideas are clarified with concrete examples in Chart 1, which lists the aspects of the clinical case presented in the previous section within the recontextualized framework.

Expertise and Its Influence on Cognitive Load

The nature of expertise in medicine has been widely studied but remains incompletely understood. This is due, in part, to the inherent complexity and lack of standardization of many real-world medical encounters.[24] Nonetheless, we have recently started to uncover some of the tacit elements of expertise development in this field that are particularly relevant to the discussion of CLT. It is known that domain experts make decisions differently than novices.[25] To be accurate, our recontextualized model of CLT needs to take expertise factors into account.

The first factor tied to expertise development in medicine is that of long-term working memory and the creation and automation of cognitive schemas.[26] This factor is encapsulated in the ability of experts to use environmental cues to retrieve information from long-term memory and transfer that information to working memory to generate action that is appropriate for the environment.

Thus, long-term working memory refers to the ability of content experts to hold onto a comparatively larger amount of domain-specific information in their working memories than novices can. Though the capacity of working memory is the same for novices and experts, each unit of an expert's working memory contains more relevant information. This is thought to be due to the creation and automation of information-rich cognitive schemas in the long-term memory of experts that allow these complex schemas to be rapidly shuttled back and forth between working and long-term memory, thus imposing a relatively low burden on working memory resources.[27] In addition, making decisions becomes cognitively easier once the decision maker has the experience of having made similar decisions in the past.[28] The ability of experts in resuscitation medicine to decrease their intrinsic cognitive load based on domain-specific content knowledge is more or less a given. A study comparing higher- with lower-performing residents in resuscitation-based simulation examinations found that the number of cognitive processes dedicated to anticipating changes in clinical course and contingency planning (related to affective factors like clinical uncertainty) was greater for the higher-performing than for the lower-performing physicians.[29]

Experienced physicians may also have developed strategies to regulate their emotions, thus allowing them to stay calm during stressful circumstances.[30] Other studies have found that individual mental rehearsal before a medical team enters a medical simulation improves team performance.[31] The cognitive mechanism by which this occurs is unclear, but it is plausible that by priming long-term memory with mental rehearsal, schema retrieval may become optimized. These examples suggest that at least some strategies for dealing with affective aspects that contribute to intrinsic cognitive load may come from schemas stored in long-term memory that become more readily accessible via a long-term working memory mechanism.

Chart 1

Factors Within Each Domain of Cognitive Load Theory That the Lead Physician in the Presented Case[a] Must Consider

Intrinsic cognitive load		Extraneous cognitive load
Intrinsic load proper	**Affective component**	
• Decision making related to patient management • Special considerations in pediatric trauma • High-risk traumatic mechanism • Addressing time-sensitive priorities (fractured leg with no pulse, decreased level of consciousness) • Leading a team of ad hoc physicians and allied health care professionals	• Patient is a critically ill child. • Physician leader does not know levels of expertise of the ad hoc team of physicians on the trauma team. • Source of hemorrhagic shock is unclear. • Parents are present in the resuscitation bay.	• Simultaneous code blue called overhead • Multiple other patients waiting to be seen • Noise from a busy emergency department

[a]A 14-year-old boy arrives in the emergency department at 3 AM after being involved in a snowmobile accident.

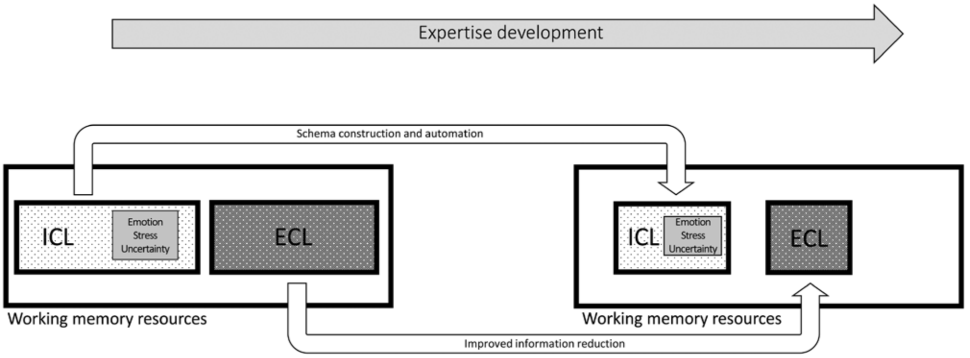

Figure 3 The effect of the development of expertise on cognitive architecture. As physicians develop expertise, they are able to decrease the relative contribution of intrinsic cognitive load (via long-term working memory/schema construction and automation) and extraneous cognitive load (via improved information reduction). These changes, in turn, free up working memory resources and improve clinical performance. Abbreviations: ICL, intrinsic cognitive load; ECL, extraneous cognitive load.

The second element of expertise development in medicine related to CLT is that of information reduction. Information reduction refers to the ability of domain experts to disregard task redundant stimuli in their environments, instead focusing on information relevant for the task at hand.[32] For example, in the case of a patient suffering from a ruptured abdominal aortic aneurysm, a domain expert would know to deprioritize analyzing the electrocardiogram (often provided in the initial workup of all critically ill patients but irrelevant in this case) and instead focus on calling the vascular surgeon to arrange an emergency operation. A medical student, on the other hand, may spend more time systematically analyzing the electrocardiogram in an effort to extract any potentially useful cues. The student may, for example, close the frame too soon (i.e., prematurely make a decision) and diagnose acute coronary syndrome because of diffuse ST segment depression on the electrocardiogram, instead of considering that this finding is more likely related to profound blood loss and resultant demand ischemia in this clinical context. This difference in the amount of time spent focusing on relevant versus redundant stimuli has been confirmed in at least one resuscitation-based simulation study[20] and confirmed in another that analyzed the cognitive processes of expert trauma team leaders in a clinical context.[19]

Both long-term working memory/schema creation and automation and improved information reduction have implications in the recontextualized version of CLT for professional work. First, by capitalizing on long-term working memory, experienced physicians develop strategies that allow them to decrease the relative contribution of intrinsic cognitive load on their overall cognitive load. This is done by having constructed and automated mental schemas to deal with both the complexity (element interactivity) of the case itself and by dealing with the emotion, stress, and uncertainty that a case may present. Experienced physicians also have the ability to decrease their extraneous cognitive load by knowing what they can safely deprioritize (via information reduction), effectively freeing up working memory. See Figure 3 for details.

Putting It All Together

A model that unifies the concepts outlined in this paper is presented in Figure 4. It brings together the idea of working memory depletion and the concept of emotion, stress, and uncertainty as aspects of intrinsic cognitive load, as well as cognitive changes associated with expertise development. Our hope is that this model will provide clinicians and researchers with a shared theoretical framework for the application of CLT in clinical practice. With ongoing reflection and study, an appreciation for the cognitive processes that we have introduced in this article may help to improve clinicians' awareness of situations in which they are becoming cognitively overloaded and to identify any underlying causes. This increased awareness has the potential to optimize aspects of clinical performance and decrease medical error related to cognitive overload.

Limitations of the New Model

Though the recontextualized model of CLT as presented is thought to apply to complex professional domains, it has certain limitations. To begin, the model does not account for changes in working memory capacity due to age.[33,34] It also does not account for the collective working memory of a team whereby working memory capacity is thought to increase as a result of collaboration amongst team members.[35]

Further, the model does not directly address affective factors that might influence a physician's working memory that are not related to the physician's work itself. For example, stress and emotions related to a physician's marital problems or having to care for a sick relative would likely affect a physician's work as well.

It is also worth noting that a related body of literature on executive functions exists that outlines an alternative theoretical framework around the type of top-down cognitive processes discussed in this paper. One of the main differences between that framework and that of CLT is the definition of working memory. In some (but not all) executive function models, working memory is considered to be 1 of 3 subcomponents of executive functions (the other 2 being cognitive inhibition and cognitive flexibility).[36] In the CLT model, working memory is defined more broadly and is thought to encompass the entirety of one's cognitive processes. Both models have their merit; however, for the purposes of this paper, we have chosen to use the broader definition of working memory used in CLT.

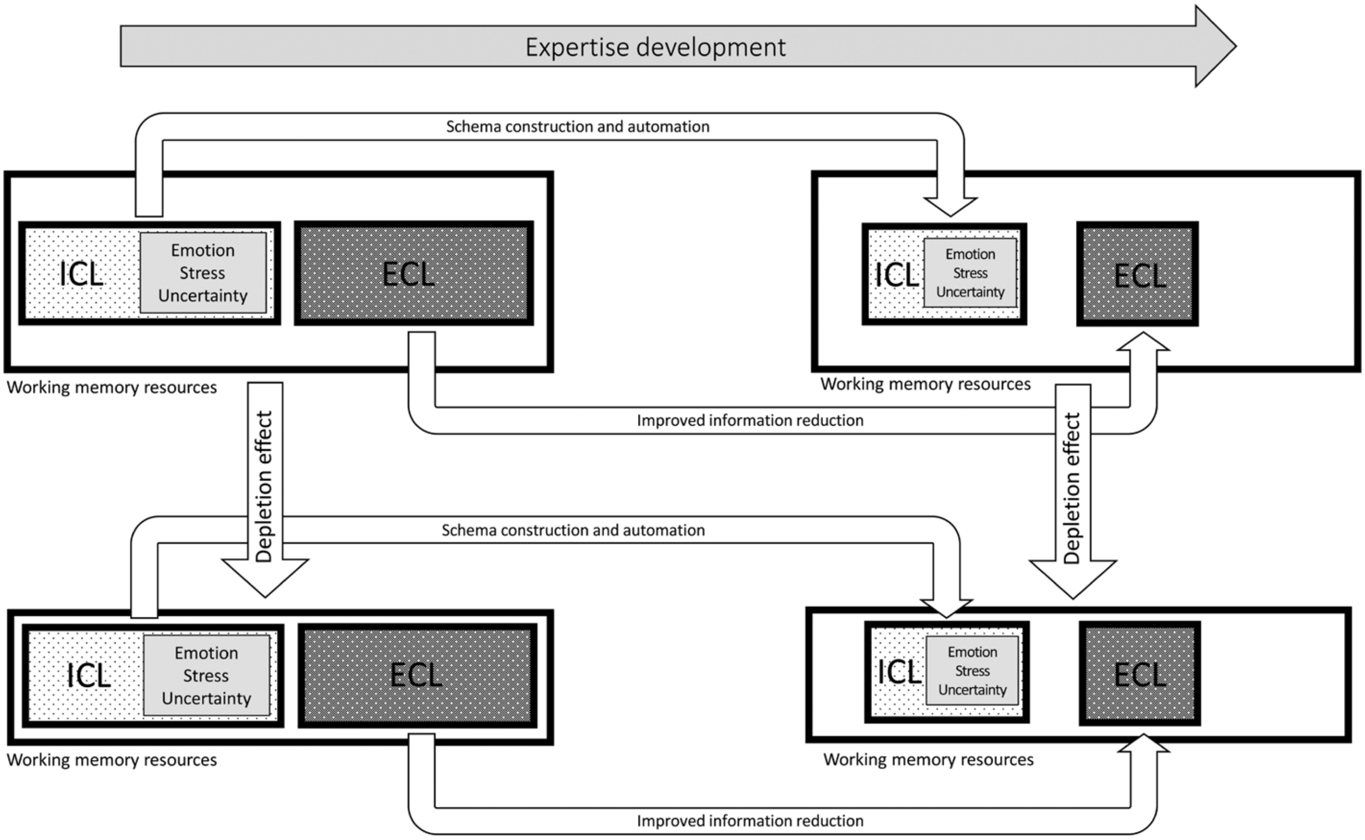

Figure 4 Complete recontextualized cognitive load theory framework for complex professional domains. Abbreviations: ICL, intrinsic cognitive load; ECL, extraneous cognitive load.

Future Directions

Our attempt to more directly bridge CLT and clinical work in this manuscript represents a first step. There are a multitude of research avenues that could stem from these ideas. For example, creating a framework for more clearly identifying which specific factors, in which specific circumstances, impose intrinsic versus extraneous cognitive load on physicians during their day-to-day roles would be useful. Medical educators could use this information to better prepare their learners for authentic clinical tasks. Practitioners could use this information to learn to mitigate certain distractions while identifying and eliminating others through system changes. Another line of research that stems from this work is the study of whether teaching physicians to compartmentalize (in the manner presented in this paper) the various stimuli to which they are exposed might lead to an improved ability to identify and prioritize salient aspects of a complicated clinical encounter and appropriately deprioritize others. In so doing, they could reduce their cognitive load for a given task.

Conclusions

Though initially described as principally a theory of learning, there are clear parallels between CLT and the work of professionals in cognitively complex fields, like resuscitation medicine. In this paper, we have attempted to bridge the gaps between CLT as a theory of learning with the application of CLT in these types of professional domains. We have done this by discussing the parallels between theory and practice and have built upon some new advances in CLT. Our new recontextualization represents only an initial model that will become stronger in future iterations as others empirically test our hypotheses and expand upon the model presented here.

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A. Szulewski is associate professor, Departments of Emergency Medicine and Psychology, Queen's University, Kingston, Ontario, Canada; ORCID: https://orcid.org/0000-0002-3076-6221.

D. Howes is professor, Departments of Emergency Medicine and Critical Care Medicine, Queen's University, Kingston, Ontario, Canada.

J.J.G. van Merriënboer is professor, School of Health Professions Education, Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, the Netherlands.

J. Sweller is emeritus professor, School of Education, University of New South Wales, Sydney, Australia.

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