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Cognitive Load Theory: Applications in Medical Education

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Cognitive Load Theory

Applications in Medical Education

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Abstract

This article examines how cognitive load theory can help instructional designers in medical education design material and content to best suit their audience. Through the examination of schema construction, working and long-term memory, biologically primary/secondary knowledge, and novice and experienced learners, this article proposes instructional design best practices. This article separates these best practices into three categories: activities, pre-lecture resources, and teaching strategies, which can be applied to either novice learners or experienced learners.

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Introduction

Context

Cognitive load theory (CLT) is, perhaps, one of the more scientific educational theories in the lexicon of education professionals, which makes the concept especially appealing to the medical education community; however, many medical education professionals lack a clear understanding of its basic concepts and how these concepts may affect their audience or learners. Cognitive load theory seems to lie beneath many of the techniques and strategies used in education such as micro-learning, formative/summative assessments, and teaching to different learning styles (among many others). Yet, CLT has not been as thoroughly studied in professional contexts. Professionals need to conduct research into the best methods for them; this is due to the fact that the instructional design field has very different audiences, resources, and topics. Unfortunately, institutions and companies do not often support this research, or time may not allow for the research to be conducted. This, regrettably, creates a gap in how existing research relates to the specific audiences that instructional designers and technical communicators encounter. CLT is often mentioned when professionals discuss the most effective methods to communicate concepts to an audience, and during conversations about different techniques, such as micro-learning. A great deal of curiosity about cognitive load theory exists among professionals in the instructional design field, which is my professional area of expertise. I have spent the entirety of my professional career in the education field—initially as a high school teacher, and currently as senior instructional design specialist at Mayo Clinic. The goal of this article is to explore CLT as a general concept and CLT as it relates to materials presented to post-secondary students in a medical institution. The cognitive load on students in a medical education setting is extremely high due to the workload placed on students and the advanced concepts that they study. The ultimate goal will be to help instructional design professionals and technical communicators in the medical education field communicate with their audience and improve their audience's educational experience. As this paper progresses, implications of CLT in medical education will be highlighted in short sections culminating with a proposed list of best practices in Appendix A.

To provide a brief history and introduction of the topic, CLT can be traced back to the 1950s, but the concept was really defined in the 1980s and 90s by John Sweller, an Australian psychologist. The theory, briefly, is concerned with the effort dedicated to learning new information and whether instructional design can have a positive effect on the effort needed to learn the new material. There are three types of cognitive load: intrinsic, extraneous, and germane. These types of cognitive load will be explored, along with other concepts, later in this article.

Methods for Literature Review

This literature review will consist of sources that describe and define CLT, identify strategies for novice and experienced learners, and identify implications and best practices for using CLT in a medical environment. To conduct the search for sources, Minnesota State University, Mankato’s MavScholar feature was utilized to find scholarly articles, books, and more. Initially, searches were for descriptive or defining articles. These searches returned a number of useful articles—the most useful of them were three articles written by John Sweller. After these defining and descriptive articles, which will help readers understand core concepts, were found, efforts were made to further specialize and refine the search criteria. The next round of searches was for studies and research conducted in an educational setting. Not surprisingly, studies and research conducted in an educational setting on CLT were not hard to come by. After reviewing this research, the content showed that learners in higher education are split into two categories—novice learners and experienced learners—and these are the themes that will be explored in the second section. The final step in finding sources for this article, was to look for CLT research that pertains to a medical or medical education environment. These sources were more elusive; however, they were not terribly difficult to find. In a manner consistent with the other two sections of this article, results were narrowed down to five sources for analysis in this article.

In total, over twenty sources were reviewed for use in this article, and this number was ultimately trimmed down to fifteen. Of these fifteen sources, six of them fell into the “defining/describing” theme, five fell into the “novice/experienced learner” theme, and five sources fell into the “medical education” theme. As is the case with any research article, the neat five/six sources for each section strategy was altered as information from sources ultimately was a better fit elsewhere in this article. The sources used in this article were chosen due to their potential application to the medical education field and similarly to the typical medical education professional and student (for example, studies on elementary students were not included). As each source was reviewed, the following questions were asked:

1. Is this source credible?
2. How does this source define or expand on CLT?
3. Does this source contain actionable information?
4. Is there a relation to medical education?
5. What instructional design methods may be used to test the findings of this source?

As was mentioned previously, this article will concentrate on defining and descriptive articles, differentiating between novice and experienced learners, and implications and best practices in a medical education environment. The defining and descriptive section will include three articles by John Sweller and two articles that build upon his research. The novice/experienced learner section will explore strategies for reaching novice learners and experienced learners. Finally, the medical education section will examine implications for cognitive load in a medical education setting, and best practices for instructional designers and medical education professionals. Each section and subsection will examine the methods used in the study or article and implications for the instructional design and technical communication field.

Defining and Describing Cognitive Load

Foundational Research

John Sweller has contributed the bulk of foundational research in CLT. His research in the 1980s and 1990s is considered seminal to the field of cognitive load research. This is evidenced by the number of papers that he has authored or coauthored and the number of articles that cite his work. Continuing themes in Sweller's work include the three types of cognitive load (intrinsic, extraneous, and germane), schema construction and automation, working memory, and long-term memory—specifically how these functions affect the learning of new concepts and information (Sweller, 1994; Sweller, 2016; Sweller, van Merriënboer, & Paas, 1998). This section will explore these concepts and their implications for the medical education instructional design community.

Three Types of Cognitive Load

Intrinsic cognitive load is the level of difficulty associated with a topic, concept, or information being taught. The level of difficulty can change according to the topic. For example, the intrinsic load of learning basic addition will be very different from the load associated with advanced algebra. Intrinsic load is generally considered not to be influenced by instructional design; although, topics can be segmented or chunked into more meaningful pieces. Prior knowledge may also reduce intrinsic cognitive load. When a learner can relate the new information presented to something they already know about, intrinsic cognitive load may be reduced (Sweller, 1994).

Extraneous cognitive load is affected by how the information is presented by instructional designers and technical communicators. The goal of instructional design is to reduce the extraneous cognitive load on learners. So for example, if an instructor were describing the Golden Gate Bridge to students, using a visual medium such as a photograph, illustration, or video would reduce the extraneous cognitive load more than a verbal description of the bridge. The type of activity created by instructional designers can have a positive or negative affect on learners depending on the level of intrinsic cognitive load. For instance, if there were a high level of intrinsic cognitive load, the instructional designer would not want to create an activity with limited or no feedback, as this would increase the extraneous cognitive load (Sweller, 1994).

Germane cognitive load describes the effort taken to process and construct schemas. John Sweller defines schemas as, "a cognitive construct that organizes the elements of information according to the manner with which they will be dealt" (1994, p. 296). It is the goal of instructional design to increase the germane cognitive load thereby making it easier for students to process and construct schemas. Germane cognitive load is sometimes referred to as the good kind of load. While the goal of instructional design is to reduce extraneous cognitive load, making the learning too easy will reduce long-term learning and retention. Managing germane cognitive load can be a balancing act of providing information and content to the learner, but providing limited feedback and guidance so the transfer of learning can take place (Sweller, van Merriënboer, & Paas, 1998).

Schema Construction and Automation

One of the foremost concepts within CLT is the learners' acquisition of new schemas. John Sweller's article from 1994, "Cognitive Load Theory, Learning Difficulty, and Instructional Design" explores how the difficulty behind learning a concept can be determined; Sweller contends that schema acquisition and automation are the foremost tools for learning. This article concentrates on intrinsic cognitive load, which is constant and the level of which depends on the material. This article also explores element interactivity, which is the degree to which elements in the individual schemas interact. Because of this interaction, schemas must be learned simultaneously, and the more element interactivity that exists between schemas, the higher the intrinsic cognitive load will be. On the other hand, if schemas can be learned in succession, rather than at the same time, intrinsic cognitive load will be lower. For instance, a child learning to tie their shoes could do so by learning several different knots. Sweller's theory is that their learning will be improved if the learn these knots in succession (first mastering one knot before learning another method) than if they tried to learn multiple knots at the same time. Sweller suggests that extraneous cognitive load can interfere with learning in a negative way when there is high element interactivity, and that redesigning content when there is low element interactivity often will not have much effect. Element interactivity can be a useful concept to describe the difficulty of learning material (1994).

Implication in Medical Education

The intrinsic cognitive load in the medical education field can be extremely high due to the complicated concepts and high workload placed on students and learners. Sweller's article from 1994 indicates that instructional design in this area could be improved by concentrating on successional learning. That is, if instructional design concentrates on teaching one concept or schema in a series and achieving mastery before moving on to the next, the learners' intrinsic cognitive load will be lower.

Working and Long-term Memory

CLT also examines the role of working memory, or short-term memory, in learning and schema acquisition. In their 1998 article, John Sweller, Jeroen van Merriënboer, and Fred Paas describe the importance of working memory and long-term memory as it pertains to CLT. They start by comparing working memory to consciousness, specifically that human consciousness is capable of monitoring the items in the working memory. They go on to note that working memory is capable of holding about seven items at a time. Additionally, humans typically are processing these items in some way, which reduces the number of items capable of being held in working memory to two or three. When learning new concepts, the working memory can quickly become overwhelmed if occupied with anything beyond simple cognitive activities (1998).

In his 2016 article "Working Memory, Long-term Memory, and Instructional Design," John Sweller expands on the concept above by discussing "biologically primary and biologically secondary knowledge." Biologically primary knowledge is knowledge that human beings have acquired over countless years and ages—knowledge that we have evolved to acquire. Examples include recognizing facial features, navigating to a known location, and listening and speaking. Learning these skills occurs unknowingly and effortlessly, and does not apply to working memory limitations. On the other hand, biologically secondary knowledge consists of information we need for social and cultural reasons, and must be learned with the assistance of primary knowledge. Biologically secondary knowledge includes nearly every topic taught in educational institutions (2016). Unfortunately, for instructional designers within the medical education field, this would include nearly every topic or concept they need to train or teach.

A partner or counterpart to working memory, long-term memory is also a core concept of CLT. Long-term memory is not a function that human beings are aware of until it has been filtered through their working memory. On multiple occasions, Sweller discusses the concept of "novice-expert differences," and how they may come in to play in the learning process. Sweller describes how an expert chess play may look at a chessboard, see it as a single entity, and be able to see their best possible move based on the position of the pieces on the board. This is in contrast to the novice chess player who will see a chessboard, pieces, moves, and strategies as separate entities. Because of their prior knowledge and expertise, experts are better able to quickly adapt their strategy based on board configurations. Novice players need to gain this ability through practice, and as they gain experience, they are better able to adapt, as the experts are (Sweller, 1994; Sweller, van Merriënboer, & Paas, 1998).

Implication in Medical Education

Instructional designers in medical education can provide this experience to the learners by communicating concepts and providing repeated, alterable simulated practice for learners. This may come in the form of case-study practice, simulation center practice, and self-directed learning.

Contributing/Expanding Research

Although he has continued to contribute to the subject of CLT, the bulk of John Sweller's research and contributions occurred in the 1980s and 1990s, and a great deal of research has been conducted into CLT since. Some of this research has contributed to defining and expanding upon CLT, while some has raised questions to its validity.

One example of research that proposes some alterations to the theory is Gerjets and Scheiter's paper, "Goal Configurations and Processing Strategies as Moderators Between Instructional Design and Cognitive Load: Evidence from Hypertext-Based Instruction," (2003) which investigates CLT, and proposes some augmentations to the theory based on evidence from hypertext-based instruction. Gerjets and Scheiter investigate the relationship of instructional design and cognitive load; specifically how the role of goal configurations and processing strategies can play between the two. Gerjets and Scheiter argue that teacher goals, learner goals, and processing strategies should be incorporated into the CLT model. The authors assert that these augmentations are necessary due to the weak link between instructional design and cognitive load in self-controlled learning environments (2003).

Implication in Medical Education

Although analyzing learners, writing measurable objectives, and determining outcomes is considered by many to be a best practice in instructional design, Gerjets and Scheiter argue that these items should be represented within the CLT structure as well. While the inclusion of these factors in the accepted structure of CLT may not be within the scope of the average instructional designer, instructional designers and technical communicators can make efforts to build these items in to their workflow processes and procedures to better analyze and plan their work.

Kalyuga's 2009 article, "Instructional Designs for the Development of Transferable Knowledge and Skills: A Cognitive Load Perspective," reviews several other articles and seeks to analyze their messages and results as they pertain to developing flexible, transferable skills and expertise. The article focuses on CLT as it relates to developing a profound understanding and transferable skills as well as higher-level thinking and self-regulation. This article examines how instructional design support and self-regulation skills might increase learners' abilities to transfer their own knowledge and skills. The article concludes that a more thorough understanding of how germane cognitive load increases learning is needed, as well as a way to measure cognitive load levels and cognitive process levels (2009). Kalyuga's research here harkens back to Sweller's research on working and long-term memory where he describes the novice-expert differences as they relate to chess. Sweller described how novice players gradually improved in adapting their play through practice and experience (Sweller, 1994; Sweller, van Merriënboer, & Paas, 1998). Kalyuga's article suggests that perhaps illustrations that may reduce extraneous load can also hurt actual learning due to the fact that may reduce the actual experience of learning by giving learners a diagram, which tells them how to do something but takes away the actual experience of learning the process. Kalyuga identifies this as a concept that should be investigated further (2009).

Implication in Medical Education

This finding may have a significant impact on instructional design as it pertains to workforce training. Often, instructional designers include process flows, instructions, procedures, and illustrations as a basic element of their job; however, results indicate that instructional designers should be putting more effort into designing activities that help the learners create these items for themselves.

One example of research that raises questions of validity in the accepted understanding of CLT is the 2007 article "A Reconsideration of Cognitive Load Theory." In this article, Schnotz and Kürschner review some central, theoretical problems with CLT based on empirical studies conducted on the subject. For instance, some of the empirical findings become questionable because the findings are subject to interpretation. This article reviews these issues by analyzing the theoretical differences between the different types of cognitive load. The article finds that the reduction of cognitive load can occasionally reduce, rather than enrich, the learning process. The authors include Vygotsky's concept of the zone of proximal development and research on implicit learning in their analysis (2007). Schnotz and Kürschner challenge multiple core concepts of CLT (e.g. fixed intrinsic load), but perhaps the most interesting argument they make is that the reduction of cognitive load is not always beneficial to learning. This is similar to Kalyuga's findings that reducing extraneous load may be harmful to the learning process, Schnotz and Kürschner find that making learning too easy by reducing extraneous and intrinsic load ultimately hurts the learning process (Kalyuga, 2009; Schnotz & Kürschner, 2007). As mentioned above, these findings provide ample justification for further research into the pros and cons of reducing extraneous load, as well as which instructional design practices ultimately may benefit learners.

Cognitive Load in Novice and Experienced Learners

John Sweller identified two different types of learners—novice learners and experienced learners. Sweller maintained that the difference between the two is that novice learners have not yet acquired the schemas that an expert has (Sweller, 1994; Sweller, van Merriënboer, & Paas, 1998). In medical education, there is a stark contrast in the skill sets of those entering programs (such as a Ph.D. program) as novices and those leaving the programs as experts, making this differentiation especially important. In this section, we will examine how CLT in educational settings may differ when considering novice and experienced learners.

Novice Learners

Many, if not most, learners that instructional designers will reach are individuals with limited knowledge of the subject matter. Michelle Cook (2006) discusses the visual representation of information in science classrooms and how design elements are critical to understanding these visual representations. The article combines empirical evidence in instructional design practices and includes theoretical ideas related to cognitive load to argue that instructional design can reduce the amount of cognitive load on novice learners. Cook's article also describes how outside influences, such as prior knowledge and individual differences, affect what effect a visual representation will have on learners' cognitive load. The article seeks to fully explore the potential impact visual representations have on learners, who may exist anywhere on a spectrum that ranges from novice to expert. Cook notes that novice learners:

> Expend much of their cognitive resources interpreting the graphic and are left with few resources to link the representations. Even when novices attempt to interconnect representations, they often concentrate on surface features with no awareness of the underlying relevant features (2006, p. 1078).

This finding could have a significant impact on how instructional designers in a medical education setting create content for novice learners such as new residents. Instructional design, in this case, should teach the underlying knowledge first before supplying one or multiple graphics to residents. Instructional design in this situation would need to analyze the audience to determine what prior knowledge is present and what the audience does not yet know. Cook's article also notes that presentations that include both audio and visual cues are more effective than presentations that rely on one or the other. She also notes that the information should be presented in a way that helps students integrate the information (2006).

Implication in Medical Education

Perhaps instructional design can implement interactive infographics, which include text, pictures, and pop-up information. For example, when a student hovers a mouse cursor over a specific area of an illustration or picture, a supplementary video could open to explain that area in more detail.

Russell and Hannon reached similar conclusions in their 2012 study that examines digital instructional content and its ability to support learners with varying learning abilities and provide learning opportunities for greater numbers of learners. Yet, digital instructional content often fails to address variation in student abilities. Universal Design for Learning ascertains that students should be provided with a variety of ways to represent and express knowledge. Russell and Hannon's study takes high school chemistry and seeks to understand the influence student-centered, technology-based instructional design has on cognitive load. Their results show that when interactivity is low, high intrinsic cognitive load leads to poorer performance and increased workload; furthermore, that reducing extraneous cognitive load can help increase performance and reduce workload for tasks that include high interactivity (2012).

Implication in Medical Education

These findings further the assertion made in the previous paragraph that materials for novice users should incorporate multiple forms of media and that this media should be presented in such a way that users are able to learn the underlying relevant information before moving on to integrate other concepts.

One possibility for the media presented to students may be in the form of pre-lecture resources to help create prior knowledge. Michael Seery and Roisin Donnelly (2012) conducted a study of 49 freshmen university students in a chemistry course. Students were provided with pre-lecture resources that introduced important concepts from the upcoming lecture as well as a quiz covering the material. The research found that the pre-lecture materials helped to reduce the extraneous cognitive load on students while they were in class. The study also found that summative test results showed no difference in scores between the students with prior chemistry knowledge and without prior chemistry knowledge (2012).

Implication in Medical Education

Seery and Donnelly's research provides empirical evidence that shows the benefits of addressing underlying relevant information through pre-lecture materials before integrating other new concepts in the form of a formal lecture. Lecture remains a common method of imparting new information to learners in the medical education field, as it does in other higher education settings, so there is ample opportunity for instructional designers to work with faculty to develop materials of this nature.

In a 2014 article, Kaylor reviews CLT and instructional design from the perspective of a medical education—making note of the emphasis placed on testing outcomes and the struggle of educators to maintain student-centered learning environments. The article describes how CLT and instructional design are used in an undergraduate course on pharmacology for nursing. Over the course of an academic year, CLT was used to introduce four learning strategies into the course: opening class with a review activity, giving students access to the lecture notes, using a "top 5" approach to learning (e.g. students were asked what five things they think they should remember about a certain drug), and identifying "need to know" vs. "nice to know" information. The study found that the implementation of these learning strategies promoted an atmosphere of active learning and an environment that focused on students' needs. Qualitative feedback was obtained from students' summative course evaluations at the end of each semester. The evaluation found that the lecture notes allowed students to actively listen to lectures without fear of missing important topics while taking notes, and allowed them to take notes directly on the printed lecture notes if needed, where they could identify if the information was "need to know" or "nice to know." Students also were engaged in the review activity at the beginning of class and even started requesting their favorite activities as the semester progressed. The instructor noted that the learning activities helped to create a "fun, engaging, and student-centered environment" (2014, p. 110). Instructional designers in a medical education setting can work with faculty members to develop materials and activities similar to these that would promote an active learning environment.

Experienced Learners

Often, with programs that have a long duration, such as a Ph.D. program, one can see what has been termed the "expertise reversal effect." This effect refers to the fact that in longer running programs, instructional design that worked for novice learners does not have an effect on learners with more advanced levels of prior knowledge (van Merriënboer & Sweller, 2010). Because of this anomaly, instructional designers must take a different approach when designing materials for expert or experienced learners.

Several of these approaches are discussed in a 2005 article. Authors Gog, Ericsson, Rikers, and Paas examine how CLT has been effective when paired with instructional design in the initial or novice phase of skill acquisition. However, the "expertise reversal effect" has caused experts in CLT to start examining how instructional design should be altered as learners' knowledge increases. Gog et al. seek to understand how expertise is developed, and how expert performance research and the theoretical framework of deliberate practice have helped advance the understanding of advancing expertise. This article examines how specific activities and principles can help instructional designers create formats for mastery levels. For example, the authors identify that instructional design for experts should be "adaptive, individualized instruction, based on authentic tasks, that gradually allows learners to take control over the process" (2005, p.77). As students move from novice learners to expert learners, evidence finds that they should start shaping their own learning. Students should be identifying areas where they can improve and creating activities and learning that addresses these items. As students start taking a more active role in their learning path, they will become more capable of self-monitoring and identifying further areas for improvement. Some possible first steps in this approach would be for instructional design to create activities where students self-explain, imagine, or anticipate future states as these activities can help students learn from their mistakes and difficulties (2005).

Implication in Medical Education

This information is especially pertinent to a formal medical education setting because students typically enter this setting as novice learners but leave as experts. There is ample opportunity in core courses for methods like peer teaching, jigsaw activities, and other activities that would give these experienced learners more opportunity to explore the material. The implementation of these methods into a rich e-learning environment such as a learning management system is possible to record student progress. Programs such as VoiceThread could offer students the chance to complete these activities and allow for peer and instructor feedback and discussion.

Cognitive Load in a Medical Environment

A number of studies have been conducted in a medical education setting, such as Kaylor's work discussed in the last section; conversely, this section will concentrate more on what lessons CLT can teach those of us in the medical education field. This section will first examine the implications of CLT in medical education and then examine best practices.

Cognitive Load Implications in Medical Education

Instructional designers and medical education professionals should be aware of CLT's implications to the learners in their environment. These professionals must be able to provide materials and activities that will aid novice learners in the acquisition and automation of schemas, and provide the experience necessary to turn these novice learners into experienced learners and experts in their fields (Young, van Merriënboer, Durning, & Ten Cate, 2014). For the novice learners, instructional designers and medical education professionals must remain cognizant of the limitations of working memory, which is capable of holding a limited number of information elements at one time (Young & Sewell, 2015). Learning should be chunked out so that students' working memory is not overloaded, as this will have a negative effect on their progression from novice to expert. Novice learners should be supplied with multiple visual representations, which will aid in the construction of schemas, and practice opportunities that will aid in the automation of schemas (Cook, 2006; Sweller, 1994; Sweller, van Merriënboer, & Paas, 1998). After moving learners into the "experienced learner" category, they should be capable of quickly generating ideas while maintaining a methodical thinking process. The ability to recognize patterns will aid these learners in quickly identifying problems and the appropriate solutions, while a methodical thinking process and analytical skills will help them identify unique problems and create solutions. After learners have automated most of their schemas and have developed a profound understanding of their field of study, we can consider them to be experienced learners (Young, van Merriënboer, Durning, & Ten Cate, 2014).

Best Practices

A fair question to ask may be, "what does all of this research tell us?" What actionable items can we come away with as an instructional designer or technical communicator? In "Cognitive Load Theory in Health Professional Education: Design Principles and Strategies," Jeroen van

Merriënboer and John Sweller (2010) discuss fifteen instructional design best practices and guidelines that help learners decrease the extraneous cognitive load that can be reduced by including goal-free tasks, examples, completion tasks, varying sources of information, presenting content in multiple ways, and reducing redundancy. Intrinsic load can be managed by ordering information and tasks in a simple to complex continuum. Germane load can be enhanced by increasing variability over tasks, including interference during practice of skills, and asking learners to provide their own explanations of concepts (2010).

Implication in Medical Education

A number of these principles can be directly applied to the medical education field. To decrease the extraneous load on students and employees, instructional designers can incorporate more activities that drive learners towards an unspecific goal. For example, designers could implement an activity that asks students to think of as many examples as they can of why community members may be uncomfortable with the institution's research practices. Instructional designers can work with faculty members to include the worked example and completion principle together in courses. For instance, instruction for suturing may include a video of someone completing a suture for the students to critique followed by guided practice using pigs' feet. The medical education's workforce may be able to utilize the split attention principle in that we can provide "just in time" materials to them in the shape of user guides, walkthroughs, and simulations. To utilize the modality principle, instructional designers can replace reading assignments with video lectures and examples. Finally, to utilize the redundancy principle, instructional designers can reduce and remove redundant sources of information and combine sources together using eLearning software and learning management systems. To help increase germane cognitive load, medical education staff can implement multiple case-study examples to utilize the variability principle. The contextual interference principle can be utilized in labs—faculty could randomize the tasks they ask students to complete as they move through the semester.

In their 2016 article, "Twelve Tips for Medical Curriculum Design from a Cognitive Load Theory Perspective," Leppink and Duvivier identify three dimensions to consider when designing curriculum and materials in a medical education setting: task fidelity, task complexity, and instructional support. Task fidelity is considered to be the progression of learning tasks. Leppink and Duvivier suggest that these learning tasks begin with low risk endeavors such as learning the material through a text or lecture, progress to simulated environments, and end with real patients and scenarios. Task complexity considers working memory limitations and cognitive overload. They argue that tasks should gradually increase in the complexity level and skills needed to help students further develop their knowledge and self-regulation skills. Finally, instructional support should be different at the different complexity levels and should gradually decrease as students move from novices to expert. Instructional support should provide students with practice opportunities at all levels and monitor the students' cognitive load (2016).

Implication in Medical Education

Instructional designers and medical education professionals can provide learning activities and materials in line with Leppink and Duvivier's suggestions in many different ways. To help students avoid cognitive overload, instructional designers can work with faculty members to ensure that introductory undergraduate courses concentrate on learning the basics through text, lecture, discussion, various forms of media (infographics, videos, etc.), and low risk simulations (such as practice on medical dummies). As students progress, so should the complexity of the learning tasks. More experienced learners should be given access to simulated tasks in computer models, a simulation center, or practice on cadavers in a slightly more realistic, but still lower risk, environment. Finally, at the end of their education and residency, students should work with real patients. Instructional designers and medical education professionals can work with faculty to ensure that students receive an appropriate level of support at every stage of their education.

Conclusion

CLT has received an increase in visibility in medical education over the past few years, and with that increased visibility has come a desire to fully understand what CLT means for medical education's students and faculty. CLT's long history and abundance of available research make it a perfect fit for adoption within the medical education community. This article has examined core concepts such as intrinsic, extraneous, and germane cognitive loads; the construction and automation of schemas; and the role and limitations of working and long-term memory. We have reviewed novice-expert differences and have identified strategies for reaching both audiences. Finally, CLT's implications and best practices within the medical education field were examined, identified, and expanded upon. Ultimately, the prior research in CLT was used to identify instructional design strategies for use within the medical education field.

How can CLT help instructional designers and medical education professionals create materials appropriate to their audience? Professionals within these fields should always keep the analysis of learners, development of measureable objectives, and determination of outcomes as best practices. However, instructional support should differ at different complexity levels and should gradually decrease as students move from novice learners to experienced learners. A number of proposed activities, resources, and strategies were proposed here, and these proposed items must be strategically tested within the learner group that would most benefit from them. The table in Appendix A shows some of these proposed items.

Further research should be conducted within the medical education field to further define how the implications and best practices identified here can improve medical students' cognitive load levels and learning experiences.

Appendix A

<table>
<tr><th>Novice Learners</th><th>Experienced Learners</th></tr>
<tr><td>

- Activities
  - Case Study practice
  - Simulation practice
  - Activities that develop schemas
  - Interactive infographics, video
  - Review activities

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- Activities
  - Simulation practice
  - Self-directed learning
  - Activities that develop schemas
  - Interactive infographics, video
  - Review activities
  - Student created activities that pertain to student identified areas of improvement
  - Peer teaching, jigsaw

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- Pre-lecture resources
  - Lecture notes
  - Top 5 activities
  - Need to know vs. nice to know

</td><td>

- Pre-lecture resources
  - Lecture notes
  - Top 5 activities
  - Need to know vs. nice to know

</td></tr>
<tr><td>

- Teaching Strategies
  - Include the worked example and completion principle together in courses
  - Utilize the split attention principle in that we can provide "just in time" materials to them in the shape of user guides, walkthroughs, and simulations
  - Replace reading assignments with video lectures and examples
  - Reduce and remove redundant sources of information and combine sources together using eLearning software and learning management systems
  - Begin with low-risk endeavors such as learning the material through a text or lecture, progress to simulated environments

</td><td>

- Teaching Strategies
  - Progressive instruction that allows learners to take over the process
  - Activities that drive learners towards an unspecific goal
  - Progress to simulated environments, and end with real patients and scenarios
  - Tasks should gradually increase in the complexity level and skills needed to help students further develop their knowledge and self-regulation skills

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References

Cook, M. P. (2006). Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science Education, 90*(6), 1073-1091. doi:10.1002/sce.20164

Gerjets, P., & Scheiter, K. (2003). Goal configurations and processing strategies as moderators between instructional design and cognitive load: Evidence from hypertext-based instruction. *Educational Psychologist, 38*(1), 33-41. doi:10.1207/S15326985EP3801_5

Gog, T. v., Ericsson, K. A., Rikers, R. M. J. P. & Paas, F. (2005). Instructional design for advanced learners: Establishing connections between the theoretical frameworks of cognitive load and deliberate practice. *Educational Technology Research and Development, 53*(3), 73-81. doi:10.1007/BF02504799

Kalyuga, S. (2009). Instructional designs for the development of transferable knowledge and skills: A cognitive load perspective. *Computers in Human Behavior, 25*(2), 332-338. doi:10.1016/j.chb.2008.12.019

Kaylor, S. K. (2014). Preventing information overload: Cognitive load theory as an instructional framework for teaching pharmacology. *The Journal of Nursing Education, 53*(2), 108. doi:10.3928/01484834-20140122-03

Leppink, J., & Duvivier, R. (2016). Twelve tips for medical curriculum design from a cognitive load theory perspective. *Medical Teacher, 38*(7), 669-674. doi:10.3109/0142159X.2015.1132829

Russell, A., & Hannon, D. (2012). A cognitive load approach to learner-centered design of digital instructional media and supporting accessibility tools. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 56*(1), 556-560. doi:10.1177/1071181312561116

Schnotz, W., & Kürschner, C. (2007). A reconsideration of cognitive load theory. *Educational Psychology Review, 19*(4), 469-508. doi:10.1007/s10648-007-9053-4

Seery, M. K., & Donnelly, R. (2012). The implementation of pre-lecture resources to reduce in-class cognitive load: A case study for higher education chemistry. *British Journal of Educational Technology, 43*(4), 667-677. doi:10.1111/j.1467-8535.2011.01237.x

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295-312. doi:10.1016/0959-4752(94)90003-5

Sweller, J. (2016). Working memory, long-term memory, and instructional design. *Journal of Applied Research in Memory and Cognition, 5*(4), 360-367. doi:10.1016/j.jarmac.2015.12.002

Sweller, J., van Merriënboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296. doi:1022193728205 van Merriënboer, J., & Sweller, J. (2010). Cognitive load theory in health professional education: Design principles and strategies. *Medical Education, 44*(1), 85. doi:10.1111/j.1365-2923.2009.03498.x

Young, J. Q., & Sewell, J. L. (2015). Applying cognitive load theory to medical education: Construct and measurement challenges. *Perspectives on Medical Education, 4*(3), 107-109. doi:10.1007/s40037-015-0193-9

Young, J. Q., Van Merrienboer, J., Durning, S., & Ten Cate, O. (2014). Cognitive load theory: Implications for medical education: AMEE guide no. 86. *Medical Teacher, 36*(5), 371-384. doi:10.3109/0142159X.2014.889290