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Cognitive Load Theory: Implications for Nursing Education and Research

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This article provides an overview of cognitive load theory (CLT) and explores applications of CLT to health profession and nursing education research, particularly for multimedia and simulation-based applications. The article first reviews the 3 components of cognitive load: intrinsic, extraneous, and germane. It then discusses strategies for manipulating cognitive load variables to enhance instruction. Examples of how CLT variables can be modulated during instruction are provided. Lastly, the article discusses current applications of CLT to health profession and nursing education research and presents future research directions, focusing on the areas of multimedia and simulation-based learning.

Keywords: cognitive load, multimedia and simulation education

Résumé

Théorie de la charge cognitive : répercussions sur la formation et la recherche en soins infirmiers

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Le présent article offre un aperçu de la théorie de la charge cognitive (TCC) et explore les applications de la TCC dans la recherche sur la formation des professionnels de la santé et des soins infirmiers, plus particulièrement les applications multimédias et fondées sur la simulation. L'article revoit tout d'abord les trois types de charge cognitive : intrinsèque, extrinsèque et germane. Il examine ensuite les stratégies permettant de manipuler les variables de la charge cognitive en vue d'améliorer l'enseignement. Des exemples montrant comment les variables de la TCC peuvent être modulées pendant l'enseignement sont fournis. Enfin, l'article discute les applications actuelles de la TCC dans le domaine de la recherche sur la formation des professionnels de la santé et des soins infirmiers et présente les orientations futures de la recherche, l'accent étant mis sur les secteurs de l'apprentissage multimédia et fondé sur la simulation.

Mots-clés : charge cognitive, apprentissage multimédia et fondé sur la simulation

Students in nursing and health education programs acquire a body of knowledge, skills, and attitudes during their education in preparation for future practice. One goal of an educator, therefore, is to create an environment of instruction where learning can take place. Cognitive load theory (CLT), derived from an understanding of human learning and memory, is explored extensively in the cognitive and education psychology literature and may be beneficial for nurse educators when designing and implementing instruction. The purpose of this article is to provide an overview of CLT and to discuss the impact of cognitive load on working memory and learning. The article will also explore how CLT has been applied in health profession education, particularly for multimedia and simulation-based applications. Finally, the implications of CLT on nursing education and research will be discussed.

Working Memory, Cognitive Load Theory, and Learning

For the purposes of this review, we present an operational definition of learning as the student's acquisition of knowledge, skills, or attitudes (Van Merriënboer, Kirschner, & Kester, 2003) that results in changes to long-term memory (Norman, 2013) and that produces an observable knowledge, behaviour, or action outcome. Central to this definition of learning is that a student receives information through multiple sensory pathways (e.g., visual, auditory inputs through pictures, words, and sounds) and creates visual and auditory representations within the cognitive system (Mayer, 2002). These representations are processed within the structures of working memory with the goal of transferring and storing the information into long-term memory.

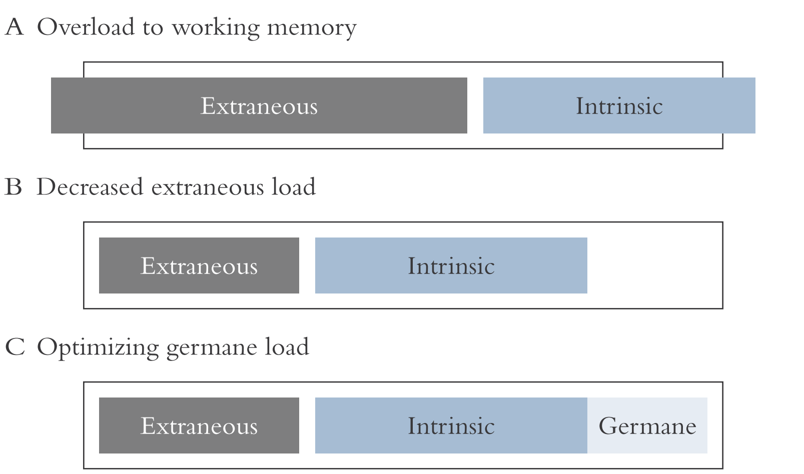
There are three assumptions about the cognitive architecture of working memory and long-term memory. The first is that working memory is constrained and limited. Our understanding around limited working memory was first detailed by Miller (1956), who stated that an individual is capable of retaining only "seven plus or minus two" units of information at any point in time. Thus, if the quantity of information presented exceeds the capacities of a learner's working memory, then the information cannot be retained. In contrast, the second assumption is that there is virtually unlimited long-term memory, and working memory and long-term memory structures can interact. Therefore, inasmuch as information processing within working memory can be retained in the infinite stores of long-term memory, information can be brought forth from long-term memory to interact with and facilitate working memory processes (Schnotz & Kürschner, 2007). The final assumption is that the cognitive load imposed on a learner's working memory during instruction can be modulated. Thus, the student's cognitive load can be increased or decreased, impacting information processing in working memory (Mousavi, Low, & Sweller, 1995).

Our understanding of CLT is historically rooted in John Sweller's (1988) work on understanding learners' problem-solving strategies. Sweller terms the cognitive resources required for complex problem-solving "cognitive processing capacity" and argues that the cognitive load imposed on a learner during problem-solving can interfere with learning. In other words, the cognitive work required to figure out how to solve a problem can interfere with one's ability to learn the actual principles that the problem is intended to teach. Given a learner's limited working memory, it is helpful for nurse educators to understand the components of cognitive load that can impact student learning.

In CLT, there are three components of cognitive load: intrinsic, extraneous, and germane (Van Merriënboer & Sweller, 2005). Intrinsic cognitive load describes the actual learning goal or task and is directly related to the quantity and complexity of the learning material. Along with the learning goal or units of information provided during instruction, intrinsic cognitive load considers the inherent difficulty of the learning goal and the learner's level of expertise in the subject matter. One measure of intrinsic cognitive load is its degree of element interactivity, which describes the number of separate components in the learning goal that would need to be held simultaneously in working memory (Leahy & Sweller, 2005). The greater the complexity of the learning goal, the greater the intrinsic cognitive load (Paas, Renkl, & Sweller, 2003). Extraneous cognitive load is attributed to features of instruction that are not necessary for learning and that therefore impose a burden on the cognitive processing ability of working memory (Sweller, Van Merriënboer, & Paas, 1998). CLT assumes an additive model for the intrinsic and extraneous cognitive load variables such that, for any particular learning task or goal, the sum of the intrinsic and extraneous load must not exceed working memory capacity (Sweller, 1994). Germane load describes the processing that promotes automation of information into long-term memory, thus facilitating learning (Paas & Van Merriënboer, 1994). Germane load has been described elsewhere as "generative cognitive processing" (Mayer, 2010) that allows the learner to "make sense of" and understand the presented material. Germane load, while increasing the overall cognitive load of the learner, is identified as distinct from extraneous load in that the instructional approaches promote, rather than detract from, understanding of the learning material. Figure 1 depicts the additive nature of the cognitive load variables. Based on these CLT principles, nurse educators must seek to keep intrinsic cognitive load within the limits of the student's working memory and to decrease extraneous cognitive load in the instructional design. Instructional design that facilitates learning, the germane load component, can then be incorporated if the extraneous load is decreased.

Identifying the appropriate amount and type of cognitive load imposed on a learner during instruction is a significant factor in the success of an educator's instructional intervention (Paas, Tuovinen, Tabbers, & Van Gerven, 2003). Poorly designed learning goals that require complex processing of multiple ideas or skills and that exceed the capacity of a learner's working memory lead to cognitive overload and decreased learning (Doolittle, McNeill, Terry, & Scheer, 2005). Either too much learning material (or material that is too complex) (high intrinsic load) or poorly designed instruction that includes unnecessary information or instructional features (high extraneous load), or a combination of both, can lead to an overload in working memory (see Figure 1, A). Instructional design can be optimized to decrease extraneous cognitive load (Figure 1, B) such that the additional working memory capacity could be used for germane cognitive processing (Figure 1, C).

Figure 1 ***Optimizing Learning by Adjusting Cognitive Load***



Source: Adapted from Van Merriënboer and Sweller (2010).

Manipulating Cognitive Load to Optimize Working Memory

Given the nature of the three components of cognitive load, it is possible to construct instructional materials for nursing students that optimize the cognitive load imposed on working memory and facilitate long-term retention.

Approaches to Adjusting Intrinsic Cognitive Load

The first variable, intrinsic cognitive load, describes the inherent nature of the learning task at hand and the student's expertise in the subject matter. Therefore, modifying intrinsic cognitive load necessarily involves changing the learning task by either adding or subtracting the amount and complexity of the material to be learned. If a learning goal remains unchanged, the intrinsic cognitive load is considered unchangeable.

Approaches to Minimizing Extraneous Cognitive Load

The cognitive and educational psychology literatures contain many studies of strategies for minimizing extraneous cognitive load. Even a basic survey of these strategies can yield significant applications for nursing education. This review will not provide a comprehensive overview of all strategies that have been explored to minimize extraneous load but will highlight a few strategies.

The Worked Example Effect was one of the first reported strategies for minimizing extraneous cognitive load. Research compared students who were provided with explicit details regarding the steps necessary to solve a problem and students who were not provided such details and were therefore required to figure out what those steps might be on their own (Sweller et al., 1998). Through seeing worked examples, students were able to focus on the particular learning goal in the instructional session rather than expending cognitive resources attempting to solve the problem in an unsystematic or trial-and-error manner. Another approach to minimizing extraneous cognitive load is the Split Attention Principle (Ayres & Sweller, 2005). Studies by Ayres, Sweller, and others have found that students who were required to focus on multiple disparate objects at once (e.g., a diagram and text description that were separated on a page) experienced increased extraneous cognitive load compared to students who focused on objects that were integrated (e.g., a text description placed next to the appropriate part of a diagram) (Chandler & Sweller, 1991). This principle was applicable not only for visual information but also when there was competing auditory information during instruction. In one study, learning and retention significantly decreased when students received instruction that included narration and accompanying background music in comparison to students who received the narration without background music (Moreno & Mayer, 2001). A third strategy for reducing extraneous cognitive load is the Modality Principle (Low & Sweller, 2005). Even as working memory is limited, the learner's visual and auditory pathways within working memory can function synergistically to process instructional material. For example, if a diagram has accompanying text, educators can decrease extraneous cognitive load by converting the text into an auditory narration while maintaining the diagram in the visual format. Through the Modality Principle, instructional design is optimized when visual and auditory processing pathways can both be engaged.

Approaches to Fostering Germane Load

Germane load is the cognitive load resulting from activity in working memory that facilitates learning beyond simple task performance (Schnotz & Kürschner, 2007). While extraneous cognitive load interferes with learning by unproductively overtaxing working memory, germane cognitive load promotes acquisition and automation of information into long-term memory (Paas et al., 2003). Therefore, efforts both to decrease extraneous load and to increase germane load during instruction are advocated, with the goal that the total cognitive load does not exceed working memory capacity (Van Merriënboer & Sweller, 2005). Paas and Van Merriënboer (1994) discuss the Variability Effect, whereby increases in the variability of learning tasks may contribute to increased cognitive load but result in improved learning outcomes. This would seem to contradict the previous examples highlighting the negative effects of increased extraneous cognitive load on learning. Indeed, the initial explorations of CLT variables focused on intrinsic cognitive load and strategies for decreasing extraneous cognitive load. The concept of germane load was introduced later, when researchers discovered that some forms of instruction that ostensibly increased cognitive load were found to be beneficial for learning. Another strategy for fostering germane learning processes was to encourage students to make active comparisons and to articulate the differences across examples from different categories (Gerjets, Scheiter, & Schuh, 2008). This approach, while increasing cognitive demands on the learner, facilitated, rather than detracted from, learning. Another study explored both providing worked examples (to decrease extraneous cognitive load) and prompting students to identify underlying principles illustrated by the examples of instruction (to enhance germane load). In this study, worked examples were gradually phased out as the learners improved their understanding of the instructional materials and were then encouraged to articulate the underlying principles for the worked examples (Atkinson, Renkl, & Merrill, 2003). This instructional approach was found to significantly improve learning and transfer. The results are consistent with those of other instructional approaches that attempt to facilitate germane cognitive load by asking students to provide self-explanations of the principles highlighted in the instructional material (Chi, Bassok, Lewis, Reimann, & Glaser, 1989).

Defining what constitutes extraneous cognitive load versus germane cognitive load can be difficult. Depending on the learning goal, the instructional design, and the level of learner expertise, factors contributing to extraneous load in one group of learners may serve to facilitate germane load in another group (Paas, Renkl, & Sweller, 2004). Therefore, instructional strategies that increase the cognitive load on working memory may end up contributing to extraneous or germane load. Determining which form of cognitive load is attributable to the instructional design may at times be done post hoc (De Jong, 2010).

Measurement of Cognitive Load Variables

Sweller (1988) proposed a few strategies to measure cognitive load variables given that direct measures were not available; intrinsic cognitive load could be correlated with the number of units of information a learner was required to hold in working memory or with the degree of complexity in the instructional material. Two decades later, Schnotz and Kürschner (2007) reiterated that there was no definitive way to measure cognitive load variables beyond the general estimating approaches employed in the literature. Three strategies the authors highlight are as follows: asking learners for subjective ratings of perceived cognitive load, measuring physiologic parameters, and applying performance-based measures. While elaboration of the three approaches described by Schnotz and Kürschner is beyond the scope of this review, it is helpful to know that quantitative measures of cognitive load are beginning to appear in the literature (Leppink, Paas, Vleuten, Gog, & Merriënboer, 2013). Such measurement scales may be useful in instructional design and evaluation of instructional variables.

Current Applications of Cognitive Load Theory in Education Research

The principles of CLT and its applications to health profession education research have been discussed with increasing frequency over the past several years, especially with respect to CLT and multimedia learning (Cook et al., 2012; Grunwald & Corsbie-Massay, 2006; Mayer, 2010; Van Merriënboer & Sweller, 2010). Multimedia learning in health profession education includes any approach that incorporates visual, auditory, and/or multisensory experience(s) into the instructional design. Therefore, with the increase in multimedia applications and other learning technologies such as high-fidelity simulation, there has been a concomitant increase in discussion regarding how these learning aids might impact on cognitive load and working memory. The literature on health profession education research includes studies that call for the application of CLT principles to instructional design, studies that have used CLT as the framework for instructional design, and review articles providing support for how to apply CLT to health profession education.

The literature calling for the application of cognitive load principles to instructional design includes studies with virtual patients and the use of computer animations in medical education (Cook, 2009; Ruiz, Cook, & Levinson, 2009). The authors highlight the need to evaluate technology- and multimedia-based instruction through the lens that these more technologically sophisticated instructional formats might hinder learning by placing increased extraneous cognitive load on the learner. They challenge an unquestioning uptake of learning technologies and multimedia applications that do not adequately consider the instructional aims, the learner characteristics, and the evaluation metrics from a cognitive load perspective.

Other health profession education studies have applied the principles of CLT to the instructional design (Holzinger, Kickmeier-Rust, Wassertheurer, & Hessinger, 2009; Stark, Kopp, & Fischer, 2011) and illustrate how CLT offers a useful framework for evaluating the effectiveness of instructional designs and approaches. Holzinger et al. (2009) evaluated the effectiveness of a hemodynamics simulation instructional group in comparison with a text-based instruction group and a group who received the simulation instruction with additional feedback and support. The learning benefit occurred only when additional instructional feedback and support were provided to the simulation-based learning group; otherwise, the simulation group did not demonstrate improved learning outcomes in comparison with the text-based instruction group. Because a fourth intervention group (text-based instruction with instructional support) was not included, it was difficult to ascertain whether these same learning benefits would persist if the additional support were provided to students in a text-based learning environment. The authors interpreted the findings through the lens of CLT and interpreted the simulation-only instruction format as resulting in cognitive overload, but providing the additional support of instruction with the simulations facilitated learning and processing of hemodynamics instruction. Furthermore, simulation-only instruction could be seen as contributing to excessive extraneous cognitive load, but providing the additional feedback and support during instruction could facilitate germane processing.

Stark et al. (2011) explored the variables of example format and feedback in managing the cognitive load of medical students receiving hypertension and hyperthyroidism instruction. Results suggest that offering students erroneous examples with feedback that elaborated on the correct responses improved student performance, whereas erroneous examples without the elaborated feedback resulted in decreased performance. Furthermore, there was a greater positive learning effect of elaboration feedback when the difficulty of the learning domain increased (i.e., from instruction in hypertension to instruction in hyperthyroidism). Such studies demonstrate the ways in which CLT, and evaluation of instructional design with the goal of minimizing extraneous cognitive load and facilitating germane load, can contribute to nursing education and research.

Several review studies have highlighted the contributions that CLT-based approaches can make to health profession education, from general overviews discussing CLT as a potential framework (Patel, Yoskowitz, & Arocha, 2009; Rikers, Van Gerven, & Schmidt, 2004; Valcke & De Wever, 2006), to specific applications in the development of anatomy animations in medical education (Khalil, Paas, Johnson, & Payer, 2005a, 2005b). Discussion of CLT for the design of instructional material in health profession education includes strategies that reduce extraneous cognitive load, facilitate germane cognitive load, and incorporate learner expertise into instructional approaches (Van Merriënboer & Sweller, 2010).

Applications of Cognitive Load Theory in Nursing Education and Research

Currently, there are no known studies employing CLT as a framework for the design and evaluation of nursing education and research. General areas such as cognition and decision-making in nursing practice are explored and many other frameworks are discussed in the literature. For example, high-fidelity simulation and other multimedia applications are being incorporated into nursing education with enthusiasm and rapid acceptance. Frameworks used to guide the development of simulation-based learning include behavioural, constructivist, and experiential learning approaches (Kaakinen & Arwood, 2009) and focus on instructional design within a paradigm similar to that in a study by La Rochelle et al. (2012) evaluating an authenticity-based or context-based approach to instruction. The underlying premise of these approaches is that students learn best when placed in authentic learning environments that closely approximate clinical settings, because this optimizes learner motivation and emotional engagement. As stated in the study by La Rochelle et al. (2012), evaluating these learning modalities through the lens of cognitive load imposed on learners would allow educators to consider how best to use these applications and modalities in nursing education. Some have called for reconsideration of frameworks such as constructivist or experiential learning approaches (Kirschner, Sweller, & Clark, 2006). Others in simulation-based nursing education have called for a similar reconsideration (Sanford, 2010; Schiavenato, 2009). Therefore, application of CLT to nursing education research presents a promising avenue for exploration.

Implications and Future Directions for Nursing Education Research

This article has provided an overview of cognitive load theory and presented principles that have been explored in cognitive and education psychology. CLT as a framework for instructional design and evaluation is the subject of increasing attention in health profession education research, particularly within the realm of multimedia and simulation-based learning applications. Nurse educators and researchers can contribute to nursing education research by applying CLT principles to evaluate instructional design and educational effectiveness.

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