Towards the use of cognitive load theory as a diagnostic tool in online learning

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This paper examines cognitive load theory in online learning. The central idea of the paper is that by identifying instances of cognitive load in online courses, educators can make practical adjustments in the design and teaching of courses in order to minimise the cognitive load experienced by learners and thereby increase the likelihood of successful cognitive processing. The presentation brings together current thinking in cognitive load theory and descriptions of key aspects of contemporary online learning to identify and describe of potential instances of cognitive load experienced by online learners.

Keywords: cognitive load theory, cognitive load, online learning, online teaching, learning design

Cognitive load theory (CLT) seeks to understand the cognitive effort required to complete a learning task relative to the capacity of the short-term memory (Sweller, 1988, 1994). It provides a framework for understanding practical implications for both learning design and teaching. CLT has supported the advancement of educational theory and practice by aiding in the explanation of a large set of experimental findings (see de Jong, 2010). The premise that underpins the application of CLT foreshadows a role for CLT as a diagnostic tool: By recognising and addressing instances of cognitive load in learning situations educators can potentially pre-empt cognitive overloads and thereby support learning.

This paper considers CLT in online learning and seeks to provide guidance in the identification and description of instances of cognitive load in online learning so that they can be addressed through design and teaching practices which specifically aim to reduce cognitive load. This paper is part of a wider body of work which is addressing two broad questions:

- How does cognitive load manifest in online learning?
- How can cognitive load be addressed through online educational practices?

Background: Cognitive Load Theory

CLT proposes that the short-term memory has a limited capacity and exceeding this capacity may hinder learning (Chandler & Sweller, 1991; Sweller, 1988, 1994). The theory attempts to resolve this issue by promoting educational practices that reduce the demands placed on the working memory and also by maximising the available resources of the working memory when processing information (Sweller, Van Merriënboer, & Paas, 1998).

CLT identifies three types of cognitive load: intrinsic, extraneous and germane loads (De Jong, 2010). Intrinsic cognitive load is the essential load associated with successfully performing a learning activity. While it has historically been considered *fixed* and not subject to influence, intrinsic load is increasingly viewed as potentially dynamic. When intrinsic load is viewed as a feature of the relationship between a subjective learner and a learning task, it can be influenced by manipulating the relationships between the learner, task and subject matter (Paas, Renkl, & Sweller, 2003). Germane cognitive load is associated with processing information, the development of schemas and the automation of information processing. Cognitive activities such as interpreting, differentiating and organising information are considered germane load (Richard E. Mayer, 2002). This load can be affected by the design of learning tasks. This type of cognitive load can be seen as both a necessary to the acquisition of knowledge (Ayers, 2006) and also a hindrance to learning when the addition of germane load exceeds the capacity of learners' working memory. Extraneous cognitive load is the load that is not associated with achieving the intended learning outcomes (De Jong, 2010). Extraneous load is generated as a consequence of the presentation of the learning material as the learner attempts to make sense of information presented to them. This form of cognitive load can be altered by changing the design and presentation of the learning tasks.

Two strategies are commonly used to address cognitive load. The first is to *reduce cognitive load*. Careful attention to instances of cognitive load and alteration to the design and presentation of instructional materials can reduce the levels of cognitive load (see, for example, Chandler & Sweller, 1991; De Jong, 2010; R E Mayer & Moreno, 2003; Paas et al., 2003). The second is to *increase the cognitive capacity* of the learner. CLT views cognition operating on parallel *controlled* and *automatic* pathways (Paas & Van Merriënboer, 1990; Sweller and Chandler (1994). The controlled pathway is conscious, slow and requires more effort. The automatic pathway is non-conscious, faster, and relatively effortless (Feldon, 2007). The effect of a particular automatized activity on cognitive load is present, but limited, reducing the load on working memory bypassing working memory (Mousavi, Renkl, & Sweller, 2004, p.319). The development of automaticity is a mechanism to increase learners' cognitive capacity by shifting cognitive processing from demanding controlled pathways to less demanding automatic pathways.

Focus

The ongoing work from which this paper is drawn is concerned with identifying cognitive load in online learning situations so that it can be addressed through design, delivery and facilitation practices. Of interest in this paper in the diagnostic role of CLT, which is applied here to identify aspects of online learning that have the potential to introduce additional cognitive load based on the nature of online environments and technology-mediated activity. Identifying key features of online learning which distinguish it from other learning situations, particularly placed-based contexts which may have been the subject of previous CLT research, has the potential to help online educators identify and address sources of cognitive load and thereby support and facilitate learning.

Identifying Cognitive Load in Online Learning

In terms of improving learning outcomes for networked learners, the focus of CLT is twofold: First, there is a responsibility for designers and teachers to identify and then address instances of cognitive load. By rationalizing the cognitive load that learners experience, educators have an opportunity to better structure and support learning processes. Second, there is an opportunity to support learners' cognition by supporting the development of automaticity in cognitive processes and thereby reducing the load learners' experience when confronted with complex tasks.

Steeples, Jones, and Goodyear (2002) describe an architecture for online (networked) learning environments in which the following are also situated: a) the learning environment, which is where learning activity takes place; b) learning tasks, which provide a specification for learner activity; and c) learner activity, which is the actual activity undertaken by learners as part of learning processes. These features of the online environments provide a framework to describe the sources of cognitive load that networked learners encounter.

Cognitive Load in Networked Learning Environments

Online learning environments present learners with a several potentially challenging features, including the use of mediating technologies; the demands of working in highly connected, media rich environments; a potentially unfamiliar social environment; and the demands of computer-mediated communication.

First, mediating technologies add multiple demands on learners' cognitive processing. For novice online learners, the use of multiple technology interfaces in computer operating systems, learning management systems, computer-mediated communications tools, social media platforms and content-specific computing applications create significant demands on learners' ability to make sense of and use a variety tools that comprise the learning environment. As highlighted by Morrison and Anglin (2005), the load of learning about technology concurrent with learning about subject matter should not be underestimated. Learners can be overwhelmed by loads introduced by the demands of navigating hypertext environments with complex non-linear relationships between information (Kalyuga & Liu, 2015; Zumbach & Mohraz, 2008) and the possibility of technical failure with one or more of the required technologies.

Second, online learners experience cognitive load managing large amounts of rich, multi-modal information in hypertext environments. The additional load is a result of complexity. When there is a potentially excessive number of elements or there are complex interrelationships between the elements (high element interactivity), working memory may be overloaded, impairing the acquisition and automation of schemas (Paas et al., 2003). For online learners engaged in high element interactivity, information processing is more difficult and requires more working memory resources. As Sweller (2010) suggests, "The more elements that interact, the heavier the working memory load" (p. 124). Therefore, there is the potential for online learners to experience overload when dealing with both the quantity and quality of information available; making choices about which information to use; and the management of that information for ongoing use.

Third, in addition to the more technical requirements of online learning, there are important social and cultural implications of mediating technologies. Technologies introduce social and psychological distance between participants in interactive exchanges (Riva, 2002). This distance creates a need for learners to reconsider the degrees of structure in their interactions; the type, amount and focus of their interactions; and the levels of autonomy they are required to exercise in managing their learning activity (Dron, 2007; Moore, 1972, 1973). Online learning environments are social spaces and online communication and social activity are learned skills. The presentation of self, the cultivation of online social presence, the acts of identifying, interpreting and responding to others' virtual presence and they operation of social-relational mechanisms which support the development of technology-mediated interpersonal relations all present new learning for novice online learners (Caples, 2006; Kehrwald, 2008; Murphy, 2004; Swan & Shih, 2005; Tu, 2002). Orienting to this new social space and overcoming the social and psychological distance introduced by technology adds cognitive load.

Fourth, computer mediated communication, which may be the only communication channel available to online learners, poses a risk of cognitive overload. Online communication requires familiarity with computer-mediated communications tools, often across different media. It requires a different set of communication skills, understanding of difference communication protocols, and interpretative skills. Researchers in online learning have documented the demands of technology-mediated communication including the need to learn to read and interpret online social cues (Kehrwald, 2008; Kreijns, Kirschner, Jochems, & Van Buuren, 2004; Murphy, 2004); the establishment of communication protocols (Palloff & Pratt, 1999, 2001; Preece, 2001); the development of social-relational mechanisms in online interpersonal interaction (Kehrwald, 2010; Murphy, 2004); and the pressure of goal-oriented online collaboration. As Kehrwald (2008) points out, online communication is a learned activity and thus it represents an additional load.

Notably, these sources of cognitive load are additional to the cognitive load associated with learning subject matter (Morrison & Anglin, 2005). The important implication of this point is that educational designers have a responsibility to mitigate the potentially massive additional load introduced by online learning environments.

Cognitive Load in Learning Tasks

Learning Tasks represent a critical opportunity to influence learner activity. Thus, they are a key mechanism to address cognitive load with attention to the presentation of information, the creation of supportive structure, anticipation of learners' needs and facilitation of productive learning activity.

The literature of CLT is rife with examples of extraneous load that emanates from presentation of information (Brunken, Plass, & Leutner, 2003; R E Mayer & Moreno, 2003; Moreno & Valdez, 2005). The presentation of information without attention to cognitive load theory frequently results in high levels of extraneous cognitive load (Chandler & Sweller, 1991). Given the variety of media and modes of presentation that are employed in online learning, the presentation of information is a potentially common source of extraneous cognitive load. Specific research has been undertaken investigating the relationship between cognitive load and multi-media. Of interest for online learning is the effect upon learning when multiple sources of data were concurrently being treated by the working memory. The use of text, video, audio, still imagery and interactive multimedia derived from a variety of sources and used in combination as part of comprehensive packages of learning materials presents a significant risk in terms of the introduction of cognitive load (Brunken et al., 2003; R E Mayer & Moreno, 2003; Moreno & Valdez, 2005).

An important aspect of schema acquisition in multi-media learning is the splitting of a learner's attention across mutually dependent information sources. Schema formation and learning can be negatively affected when even one more sources of data are used concurrently (Chandler & Sweller, 1991; Kalyuga, Chandler, & Sweller, 1999). Notably this occurs when the sources of information do not synchronize or support each other, and the learner is therefore required to search for semblances of connectivity between the data sources. Where text and diagrams are used, the *split attention effect* can be overcome by strategically placing the text at an appropriate position, in relation to the diagram, synchronizing both the text and diagram in a single integrated source of data, maximizing the reinforcing effect of the text+visual combination and supporting meaning making.

A further effect upon schema acquisition occurs when texts and diagrams are accompanied by an auditory source. This is the *modality effect*. Researchers such as Richard E. Mayer, Moreno, and Pressley (1998) found that the "multi-media learners can integrate words and picture more easily when the words are presented auditorily rather than visually" (p. 312). The modality effect affirms that when information is instructionally designed to minimize cognitive load and is presented from two differing sources, such as an auditory and visual source, schema formation and learning can be enhanced.

As with the use of mediating technologies, the presentation of learning tasks provides an opportunity for the introduction of, or, the mitigation of, additional cognitive load. As described by Steeples et al. (2002) learning tasks specify and elicit learner activity. Each task "needs to be sufficiently well-specified that the changes of the learner engaging in unproductive activity are kept within tolerable limits" (Steeples et al., 2002, p. 332). The focus on limiting unproductive activity highlights the potential for learning tasks to introduce additional cognitive load. When considered in combination with the presentation of information, the use of mediating technologies and the skills required for productive online communication, the presentation of learning tasks represents an opportunity to address a number of potential sources of cognitive load.

Central to the design of learning tasks is consideration of a learner's prior knowledge. Vygotsky (1978) suggests learners' schema acquisition benefits from tasks a) that provide them engagement sympathetic to their previous experiences and b) within their zone of proximal development. It is critical to understand the network of relations between a) the subjective learner, who has a unique perspective, based on experience and prior knowledge, b) the learning task, which mediates subject matter, introduces structure and influences activity and c) the online learning environment which provides a social and cultural context. Ideally, these relations support learning by giving the learner access to people, resources and tools which support learning. However, the complexity of these relations and learners' abilities to make use of the relations (based on their unique combination of experience, skills and prior learning) make it very difficult to cater to each individual. Designers need a repertoire of strategies to a) appreciate the complex relations present in online learning situations; b) identify and accommodate the diversity of learners in a given online learning situation and c) address instances of cognitive load arising in the learner-task relation. The design of learning tasks should acknowledge their past experiences and activate existing schema that can be recalled automatically. Using the principles of CLT to enhance the design of technology-enhanced learning while considering the prior knowledge of the learner, invites the reduction of cognitive load that may enhance the acquisition of schema.

Cognitive Load in Learner Activity

Learner activity is central to the identification of cognitive load; all cognitive load is predicated on learner activity. The nature of online learning activity presents potentially novel demands on learners' cognitive processing abilities including learners' efforts to *learn to learn online*.

Learning to learn online is a phenomenon which may be better understood through CLT. In his study of learning to learn online, Arbaugh (2004) highlights that "while most indicators of online learning quality and effectiveness increase significantly as students take subsequent online courses, much of this increase occurs between the first and second online course" (Arbaugh, 2004, p.179). While Arbaugh did not indicate causality between student perceptions and cognitive load, cognitive load offers possible explanations. Central to the notion of learning to learn online is learners' abilities to automate common learning activities, thereby freeing up capacity in their working memory. As learners orient themselves to highly-connected, media-rich online learning environments, they develop both skills and ways of working which become automatic as they gain experience. They become adept at navigating learning management systems; they develop habits for accessing and returning to key information; they adopt protocols for online communication and they quickly adapt to rationalise their study time in ways that are personally productive. While the initial learning curve may be quite steep for novice online learners, the automation of online learning activity reduces cognitive load as learners become more familiar with and more skilled at working in online environments.

The second factor is a shift from traditional roles in teaching-learning relationships to a more learner-centric arrangement with shared control, differing levels of learner autonomy and interdependence (see, for example, Garrison, Anderson, & Archer, 2000; Palloff & Pratt, 1999, 2001). This arrangement creates the possibility of a much wider range of roles that learners play in online learning that is potentially more open, more democratic, more participatory and even more emancipatory than other highly educationalised forms types of learning (Fox, 2002). However, with different or novel learning arrangements comes an associated need for learners to identify, understand and learn to act in new roles. So, in addition to learning about technology and its use in online learning, novice online learners must also learn to be productive in technology-mediated social environments and take on potentially new roles.

Conclusion and directions for future research

We believe CLT is a useful diagnostic tool to help online educators identify, understand and address difficulties experienced by online learners. Using CLT as a lens to identify and understand online learners' experiences has the potential to help educators refine their online educational practices and, by extension, support learning.

However, understanding of CLT in online learning is far from complete. Further work is needed to both understand the operation of NL environments and the application of CLT to activity in those environments. In order to help researchers continue the important work of applying CLT to online, we offer the following suggestions for further research:

- Revisit the application of key media-related research into CLT in the context of contemporary media applications, including social media.
- Continue efforts to understand the demands of learning to learn online as an entrée to improving success rates for new online learners, and
- Further explore the practical implications of CLT and refine notions of good practice in design, development, teaching and learner support in online learning.

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Please cite as: Kehrwald, B. & Bentley, B. (2018). Towards the use of cognitive load theory as a diagnostic tool in online learning. In M. Campbell, J. Willems, C. Adachi, D. Blake, I. Doherty, S. Krishnan, S. Macfarlane, L. Ngo, M. O'Donnell, S. Palmer, L. Riddell, I. Story, H. Suri & J. Tai (Eds.), Open Oceans: Learning without borders. Proceedings ASCILITE 2018 Geelong (pp. 434-439). https://doi.org/10.14742/apubs.2018.1953