Understanding and Identifying Cognitive Load in Networked Learning

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Abstract

This paper considers cognitive load theory (CLT) in the context of networked learning (NL). It aligns with NL practitioners' efforts to understand and eliminate barriers to learning in NL situations. The ideas presented are based on the premise that by recognising and either minimising or eliminating instances of unnecessary cognitive load in NL situations educators can improve learners' abilities to acquire and develop schema and, in doing so, educators can support learning in NL situations. The presentation brings together current thinking in cognitive load theory and descriptions of key aspects of NL to identify and describe of potential instances of cognitive load experienced by networked learners.

The paper is structured in three main sections: The first section provides the background to our exploration of CLT in the context of NL. It includes an overview of CLT and its development; an overview of NL; and a definition of the problem this paper seeks to address, namely, that NL situations include a number of instances of cognitive load which may not be present in other (e.g., face-to-face; on-campus) learning situations. The second section explores common features of NL and identifies potential sources of cognitive load in NL situations. It is organised according to key features of the 'architecture' of NL: the learning environment; learning tasks and learner activity. By identifying potential instances of cognitive load, the presentation provides a basis for, firstly, understanding cognitive load in NL; and, secondly, addressing it. Key sources of cognitive load referenced in this paper include the presentation of information in NL situations; the use of mediating technologies; the demands of managing information in connected environments; the load associated with technology-mediated social activity, including computer-mediated communication; the presentation of learning tasks; and the demands of 'learning to learn' in NL situations. The third section of the paper identifies a potential research agenda to guide further explorations of CLT in NL including: research into technical aspects of NL to improve the presentation of information and computer interfaces; research into the use of instructional design techniques sympathetic to CLT and specifically targeting NL and engagement tasks; research to understand learning to learn online in NL from a CLT perspective.

Keywords

cognitive load theory, cognitive load, networked learning, online learning, online teaching.

Introduction

Cognitive load theory (CLT) focuses on human cognition and the limitations of short `term memory. Briefly, CLT seeks to appreciate the cognitive effort required to complete a learning task relative to the capacity of the short term memory (Sweller, 1988, 1994). CLT has developed to provide a framework for understanding practical implications for both the design of learning situations (sometimes called 'instructional design' or 'learning design') and the support and facilitation of learning (often called 'teaching'). As de Jong (2010) points out, CLT has supported the advancement of educational theory and practice by aiding in the explanation of a large set of experimental findings. The premise that underpins the application of CLT is: By recognising and addressing (reducing or eliminating) instances of cognitive load in learning situations educators can improve learners' ability to acquire and develop schema and, in doing so, support learning.

ISBN 978-1-86220-337-2

This paper considers CLT in NL and seeks to provide guidance in the identification and description of instances of cognitive load in NL so that they can be addressed through design and teaching practices which specifically aim to reduce cognitive load in NL situations. This inquiry was initially guided by three broad questions:

- How does cognitive load manifest in learning (in general)?
- How does cognitive load manifest in in NL (in particular)?
- How can cognitive load be addressed through NL practices?

This paper addresses the first two questions. The presentation is structured in three main sections: The first section provides the background to our exploration of CLT in the context of NL. It includes an overview of CLT and its development; an overview of NL and a definition of the problem this paper seeks to address, namely, that NL situations include a number of instances of cognitive load which may not be present in other (e.g., face-to-face; on-campus) learning situations and therefore need to be identified and understood so they can be addressed. The second section explores common features of NL and identifies key sources of cognitive load in NL situations, thereby providing a basis for, firstly, understanding cognitive load in NL and, secondly, addressing it. While the identification of an extensive set of practical suggestions for addressing cognitive load is beyond the scope of this paper, the third section identifies a potential research agenda to guide further explorations of CLT in NL.

Background

Cognitive Load Theory

CLT postulates 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 the issue through the development of instructional techniques that are designed to reduce the demands placed on the working memory and maximising the available resources of the working memory when processing information (Sweller, Van Merriënboer, & Paas, 1998).

CLT suggests three types of cognitive load: intrinsic, extraneous and germane cognitive loads (de Jong, 2010). Intrinsic cognitive load is the essential load associated with achieving intended learning outcomes in specific learning task. It is the cognitive load that is necessary to acquire the skills and knowledge associated with the task. Once considered relatively ‘fixed’ and not subject to influence, intrinsic cognitive load is now viewed as more dynamic than previously understood. As a feature of the relationship between the subjective learner and the task, intrinsic cognitive load can be altered through careful attention to the relationships between the learner, task and subject matter (Paas, Renkl, & Sweller, 2003). Extraneous cognitive load is the load that is evoked that is not associated with the intended learning outcomes (de Jong, 2010). Extraneous cognitive 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. Germane cognitive load is the load associated with processing information, the development of schemas and the automation of information processing tasks. This load can be also be manipulated by the instructional design of tasks. Skills such as interpreting, differentiating and organising information are considered germane load (Mayer, 2002). This type of cognitive load can be seen as beneficial to the acquisition of knowledge and may enhance the learning process (Ayers, 2006). It can also hinder learning when the addition of germane load exceeds the capacity of learners’ working memory. As germane load is induced by learners’ efforts to process and comprehend, it can be altered through the design of materials and activity (Brunken, Plass, & Leutner, 2003).

Significant in the development of CLT has been the investigation and clarification of the term 'load' within a CLT paradigm. Recent work highlights two variations of the notion of load. The first variation centres on the learner and defines cognitive load in terms of effort that is exerted by the learner within the context of a learning task. The second variation centres on the task itself and defines load in terms of the complexity of the learning activity and the instructional constraints of the context (de Jong, 2009; Paas, 1994). Although these two views of load are related, it is important to differentiate between them to be able to identify cognitive load in NL.

Various tools have been developed to measure the multi-dimensional nature of cognitive load (Brünken, Plass, & Leutner, 2003; Daneman & Carpenter, 1980; de Jong, 2010). Both analytical and empirical methods have been developed. Analytical methods draw upon expert opinions or analysis of tasks and provide a subjective framework of data. Empirical methodologies use introspective rating scales, psycho-physiological data (heart rate), pupil dilation, electroencephalography (EEG) to assess cognitive load (Paas et al., 2003). Some measures such as the NASA-TLX, have been developed to quantify mental demand, as well as physical demand, temporal demand, performance and frustration (Sweller, Ayres, & Kalyuga, 2011). CLT researchers have in general focused upon introspective scales to rate mental effort (Paas, 1992) or task difficulty (Ayres, 2013). In particular, the use of a self-perceived reporting scale such as a Likert scale has become a common methodology (Ngu, Chung, & Yeung, 2015; Paas & Van Merriënboer, 1993).

Two strategies are commonly used to address cognitive load. The first strategy 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). Educational design is considered broadly in this paper, including the overall conceptualisation of the learning process, the sequencing of learning tasks, the design of individual tasks and the presentation of both learning materials and tasks. Consideration of cognitive load in each of these stages of educational design and development can help reduce cognitive load.

The second strategy is to increase the cognitive capacity of the learner in order to maximise the acquisition schema. CLT draws upon dual-process theories to explain cognition operating on parallel ‘controlled’ and ‘automatic’ pathways (Paas & Van Merriënboer, 1990; Sweller and Chandler (1994). The controlled pathway is conscious, slow and requires relatively more effort. The automatic pathway is faster, non-conscious and relatively effortless (Feldon, 2007). In automatic processing, the effect of a particular automatized activity on cognitive load is present, but limited, reducing “working memory load by effectively bypassing working memory” (Mousavi et al., 2004, p.319). The development of automaticity, which results from experience, represents an opportunity to increase a learner's cognitive capacity by shifting cognitive processing from labour-intensive controlled pathways to relatively low-effort automatic pathways.

Networked Learning

As described by Jones and Steeples (2002), NL is “learning in which information and communication technology is used to promote connections: between one learner and other learners; between learners and tutors; between a learning community and its resources” (p. 2). As the name implies, NL seeks to leverage the power of networks to facilitate learning as an active, social process.

The network component of NL refers not only to technology, but also to social structures (i.e., ‘networks’) (see Fox, 2002) in which relationships are structured by “networked logic” and the accompanying notions of culture, production and experience (Castells, 1996). Networked learners rely on connections with both resources and people (Steeples, Jones, & Goodyear, 2002) because both are necessary for efficient and effective learning (Collins & Berge, 1996)

The learning component of NL is informed by socially-oriented learning theories, such as situated learning, situated cognition, socio-cultural approaches and community-based learning models (Jones & Asensio, 2002). Learning in this context is inherently active and learners’ energy and attention is focused on production within connected community (or network) structure. Learning is a process of developing individual and shared understandings that inform changes in attitudes, beliefs, capabilities, knowledge structures and skills. Learning activity is facilitated by the connectivity provided by the network. Knowledge is embodied in practice, which is socially reproduced, supervised and modified over time (Brown & Duguid, 2000). Notably, networked practices may represent a significant departure from more ‘traditional’ didactic, teacher centric approaches which remain commonplace on university campuses. The learner-centric orientation, and the associated attention to the learner, learner activity and learner experience (Jones & Steeples, 2002) in NL implies a different set of roles for course participants than in more traditional approaches (Hammond, Trapp, & Bennett, 2002). The change in roles is not without its inherent conflicts related to power relations associated with the practicalities of assessment and educational administration (Trehan & Reynolds, 2002). Understanding NL practice requires a careful unpicking of potentially new systems of activity. Moreover, extrapolating findings of educational research drawn from non-networked contexts requires a careful analysis of contextual factors including the social and cultural systems in both contexts in order to support decisions about the transferability of findings.

Defining the Problem

We are concerned with identifying cognitive load in NL situations so that it can be addressed through attention to practical aspects of design, delivery and facilitation. Of interest in this paper are aspects of NL that have the potential to introduce additional cognitive load based on the nature of NL environments and networked activity. Identifying key features of NL 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 NL practitioners identify and address sources of cognitive load and thereby support and facilitate learning. In this paper, we are only concerned with identifying and understanding cognitive load in NL. The practicalities of addressing instances of load are described in a separate paper.

Discussion: Identifying Cognitive Load in Networked Learning

CLT provides a lens for understanding and addressing challenges that confront learners in NL situations. 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, reduce, or eliminate instances of cognitive load. By rationalizing the cognitive load that learners experience, educators have an important opportunity to structure and support learning processes with less cognitive load. 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 et al. (2002) describe an architecture for NL which centres on an educational setting in which the following are also situated: a) the learning environment, which may include both physical and virtual spaces in which 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 in response to tasks. These features of NL architecture provide a framework to describe the sources of cognitive load that networked learners encounter. We consider 'NL environments' to refer to the broad technical and social context for NL. Learning tasks are conceived as discrete units of specific learning activity (as opposed to 'learning' in general). While there is clearly overlap amongst the learning environment (the 'where' of learning activity takes place); the specific learning tasks (what we ask learners to do) and the learning activity (what learners actually do), we have separated our analysis of the application of CLT to NL according to 'broad' (course wide) considerations and task-specific considerations when distinguishing between the learning environment and learning tasks.

Cognitive Load in Networked Learning Environments

When contrasted with place-based learning environments, NL environments present learners with a number of challenging features. These include the use of mediating technologies, the demands of operating in highly connected, media rich environments, a potentially unfamiliar social environment and the demands of computer-mediated communication.

First, the use of mediating technologies represents a source of cognitive load as technologies add manifold demands on learners' cognitive processing. NL environments, by definition, rely on the use of technology to not only connect learners, but also to mediate activity. For novice 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 of technological 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 multiple additional 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, learners have the additional cognitive load of managing large amounts of rich, multi-modal information that is associated with highly connected networked 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 ability to acquire and automate schemas (Paas et al., 2003). Network learning situations that have low element interactivity are less difficult to process and require less working memory resources. For network learners that engage in high element interactivity, the task is more difficult (in terms of information processing) and requires more working memory resources. Where a learner is processing several elements simultaneously such as a rich, multi-modal task, larger amounts of working memory are required. As Sweller (2010) suggests, 'The more elements that interact, the heavier the working memory load' (p. 124). Therefore, there is the potential for network learners to experience overload when dealing with both the quantity and quality of information available, making discerning choices difficult about which information to use and the management of that information for ongoing use.

Third, in addition to the more 'technical' requirements of NL, there are important social and cultural implications of mediating technologies. Technologies 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 (Moore, 1973). 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 networked 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 to learning the intended subject matter.

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 in order to keep learners effort and attention oriented toward the intended learning outcomes, educational designers have a responsibility to mitigate the potentially massive additional load introduced by NL 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 et al., 2003; Mayer & Moreno, 2003; Moreno & Valdez, 2005) As described by Chandler and Sweller (1991), the presentation of information without careful attention to cognitive load theory frequently results in high levels of extraneous cognitive load. Given the wide variety of media and modes of presentation that are employed in NL, 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 NL 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; 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. Research suggests that 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 effect is known as the 'modality effect'. Researchers such as 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. A key consideration in the design and presentation of learning task goal of optimising the relationship between the demands of the task and the cognitive load that is produced when learners

Central to the design of learning tasks is consideration of a learner's prior knowledge. As suggested by Vygotsky (1978), to successfully acquire schema, learners benefit from tasks that that provide them engagement sympathetic to their previous experiences and within their 'zone of proximal' development. More specifically to NL, it is critical to understand the network of relations between a) the subjective leaner, 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 NL community which provides a social and cultural context for activity. Ideally, these relations support learning through the development of a network of connections which give the learner access to people, resources and tools which support learning. However, the complexity of these relations and learner's 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. NL designers need a repertoire of strategies to a) appreciate the complex relations present in NL situations; b) identify and accommodate the diversity of learners in a given NL 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 technologically-based 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 because all cognitive load is predicated on learner activity. The very nature of NL activity presents potentially novel demands on learners' cognitive processing abilities including learners' efforts to 'learn to learn' in on the network through the acquisition and automation of skills which support highly connected learning in networked environments.

Learning to learn online (or in NL) is phenomena 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 in NL is the idea of automaticity and learners' abilities to automate common learning activities thereby freeing up capacity in their working memory. As learners orient themselves to highly-connected, media-rich NL environments, they develop both skills and ways of working which become automatic as they gain experience. While the initial learning curve may be quite steep for novice networked learners, the automation of NL activity reduces cognitive load as learners become more familiar with and more skilled at working in NL environments.

The second factor is a shift from more traditional roles in teaching-learning relationships to a more learner-centric arrangement with shared control, and 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 may play in NL that is potentially more 'open', more democratic, more participatory and even more emancipatory than other, more highly educationalised forms types of learning (Fox, 2002). However, with these new, 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 application in NL, novice networked learners must also learn to be productive in technology-mediated social environments and take on potentially new roles as they participate in NL.

Conclusion and directions for future research

We believe CLT is a useful tool to help NL practitioners identify, understand and address difficulties experienced by networked learners. Using CLT as a lens to identify and understand learner experiences in NL environments has the potential to help NL practitioners refine their NL practices and, by extension, support learners. However, understanding of CLT in NL 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 NL, we offer the following suggestions for further research:

First, further research with CLT and technical aspects of NL is needed. Research investigating specific methods applying CLT principles to reduce the levels of cognitive load associated with the presentation of information in highly connected rich-media networked environments will help address what is potentially the most significant area of extraneous cognitive load—the presentation of information. Further work with the development of computer interfaces can provide a mechanism to benefit large numbers of networked learners by simplifying their learning about and interactions with mediating technologies. As suggested by Kaluga and Luia (2015), “With this (CL) theory, the technology-based learning environments could be better matched to the nature of human cognition (p. 4).”

Second, research into the use of instructional design techniques sympathetic to CLT and specifically targeting network learning and engagement tasks, also may provide further insight into improving the learning outcomes of network learners. In particular, the identification of either the split attention or modality effect, and levels of element interactivity provide a basis to improve the on-line network learning experience.

Third, questions specific to network learning such as: What particular germane skills are more likely to benefit network learners and enhance their learning may provide insight into the maximising the development of cognitive processing. While germane load can be generalized as the processing of the information, researching whether the development of schemas and the automation of information processing tasks, are their skills, specific to network learners that could benefit from CLT principles.

Fourth, further work is needed to understand learning to learn in NL from a CLT point of view. Understanding cognitive load experienced by novice learners informs the development of environments and tasks which address extraneous load and support automaticity, which improves learners’ cognitive capacity.

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ISBN 978-1-86220-337-2