Literature Review of Cognitive Load Theory and Implications for e-Learning

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Abstract

The scope of this paper is the application and impact of cognitive load theory in the context of e-Learning. Specifically, it seeks to answer the question of what are the characteristics of individual learning styles, motivation, and limitations on the ability to process new information that determine the effectiveness of online instruction and the acquisition of learner knowledge? The introduction provides a vocabulary to help frame the discussion. Next, the research is examined to provide insight to differences in learner cognitive styles affecting the design of instruction. Cognitive load is discussed in the context of research into managing cognitive load in online learning, through use of an online learning assessment tool to personalize learning. The paper concludes with a set of twelve research-based heuristics suggested by Morrison and Anglin (2005) for managing cognitive load in e-Learning.

Introduction

Technology has become increasingly pervasive in the development and delivery of instructional content via electronic means. Learning in this context is variously referred to as e-learning, Internet learning, distributed learning, networked learning, tele-learning, virtual learning, computer-assisted learning, Web-based learning, and distance learning. In most cases the instructional systems design (ISD) process model used is based on one or more educational theories. Increasingly, greater attention is being paid to learning theory particularly with regard to individual learner attributes, characteristics, styles, and motivation levels. This paper provides a contemporary review of the literature, with a focus on knowledge acquisition using online learning. Given the terms used above to describe online learning, several assumptions are made with regard to learners which include: an implied separation of time and space between the learner and tutor or instructor, that the learner uses a computer to access the learning materials, that the learner uses technology to interact with the tutor and other learners, and that feedback and support are provided to learners. As suggested, this creates a shared responsibility for learning by the learner and the tutor (Ally, 2004).

The predominant learning theories considered in this review are cognitivist and constructivist based. According to Ally (2004), cognitive theorists believe that learning involves memory, motivation, and thinking, with reflection playing an important role in learning. Learning is largely an internal process, with the amount learned dependent on preexisting knowledge, the processing capacity of the learner and the amount of effort expended during the learning process. Constructivist theorists on the other hand, believe that learners interpret information and the world according to their personal reality, and that they learn by observation, processing, and interpretation, before converting new information into personal knowledge.

In recent years, there has been considerable discourse with disagreement around the role of computer technology and the degree to which it influences learning (Clark, 2001; Kozma, 2001). The topic has become a `chicken or egg' debate given the vast amount of coverage afforded it, and will not be considered in detail here. The conclusion most often drawn is that instructional design plays a larger role in the effectiveness of the content and the ability to affect learning, than does the media selection itself (Schramm, 1997). This does not suggest, however, that if you build it they will learn. Rather, the ability of the learner to acquire knowledge is partially dependent on a set of factors that are separate from the instructional content. Effective instruction needs to be authentic, meaning that the learner should learn in the context of the workplace or other application environment, situated in order to connect with prior knowledge on the part of the learner, and anchored to promote transfer through application of the knowledge for problem solving. Learners also need to be engaged by being able to focus their attention and cognitive effort on learning. In this regard, learner engagement is essential to learning success (Herrington, Oliver, & Reeves, 2003).

Different learning styles should be considered when designing online instruction, particularly for activities and learner support. As an example, concrete-experience learners prefer specific examples in which they are involved with the content. Reflective learners prefer to observe or follow a worked example before taking any action on their own. Information may be presented in different modes (e.g., text/visual or audio) to accommodate different learning styles. Motivation provided should be both intrinsic (learner driven) through activities to help guide the learner, and extrinsic (instructor and performance driven) to ensure that objectives for learning are achieved (Keller, 1983).

Cognitive Styles

Cognitive style refers to the way an individual organizes and processes information. Cognitive styles are generally considered to be fixed characteristics of an individual. Cognitive strategies on the other hand, provide methods of coping with information that are incongruent with an individual's preferred style. In a study conducted by Pillay and Wilss (1996), two cognitive style groups consisting of four styles were used: Wholist-Analytic and Verbal-Imagery dimensions (Riding & Cheema, 1991). Each represents a continuum of style.

Individuals along the Wholist-Analytic continuum tend to process information in wholes or parts. Those along the Verbal-Imagery dimension tend to represent information verbally or in mental images. These styles are not absolute and indeed, most individuals are bi-modal, intersecting the two (e.g., a Wholist/Verbaliser or Wholist/Imager.) The position of an individual on the Wholist/Analytic dimension does not affect their position on the Verbal/Imager dimension. An understanding of cognitive styles is important because styles affect the way individuals process and acquire information, make decisions, solve problems and respond to other people in social situations. Wholists organize information into chunks to form an overall perspective of the given information. Analytics, by contrast, view information in conceptual groupings focusing on one grouping at a time. Verbalisers process information as words or verbal associations, whereas Imagers relate information better with mental images or pictures. Members of each group can make use of other modes by conscious choice; however, this requires additional processing, imposing extraneous cognitive load which may hinder learning (Sweller, 1989). It follows that designing online instruction suited to the learner's cognitive style, reduces extraneous cognitive load. Unfortunately, much of instructional content is designed based on experts' preferred cognitive styles, which may be in contradiction with the learner's preferred style. The study conducted by Pillay and Wilss (1996), relied on an experimental design involving eight groups and four sets of instructional materials in accordance with the four cognitive styles. The instruction was taken from a second year computer-based nursing course, and all students were assessed to determine their preferred cognitive style. During the study, 26 learners in different groups completed lessons matched to their preferred style and mismatched with other styles. The groups were tested at the end of each lesson using identical test items. Overall, the matched groups attained higher test scores than the mismatched groups for the same questions. One of the conclusions drawn is that whereas online instruction has increased accessibility to a broader audience, learners may be at a disadvantage in terms of cognitive accessibility. The study provides preliminary information to suggest that there may be an interaction between online instruction and individuals' preferred cognitive style. The conclusions indicate a need for further research in replicating this study and by designing additional studies around online instruction that can be tailored to individual cognitive styles to promote learning through reduced extraneous cognitive load.

Cognitive Load

Heo and Chow (2005) conducted a study to determine the impact of an online learning tool on learning and assessment, by minimizing cognitive load. As a point of reference, cognitive load may be intrinsic, extraneous, or germane. Intrinsic cognitive load is related to the complexity of the material. Extraneous cognitive load is due to the design of the instructional materials. Germane cognitive load is the mental processing that allows learning to take place. It is desirable to decrease intrinsic and extraneous cognitive load, while increasing germane cognitive load. In the study, online graduate students studying programming learned new material through the use of worked examples and online quizzes. The study was intended to show that student learning can be enhanced through design of the learning environment to control and reduce cognitive load when presenting new information.

Worked examples provide a critical component to the learning process in programming courses to help in linking conceptual knowledge with pragmatic knowledge for problem solving. Learners were exposed to fundamental programming techniques and underlying concepts through practice with code examples. This technique helps to facilitate transfer of knowledge into practical solutions through assignments and small projects (Heo & Chow, 2005). Instructors serve as coaches by bringing in other resources within the performance context in an effort to facilitate student learning, rather than serving as broadcasters of knowledge. Learners are self-directed in this environment and the content is personalized in ways that work most effectively for them. This environment has been difficult to replicate online, resulting in lectures and examples that tend to be functionally and visually static, organized around the delivery media rather than the knowledge representation and learning tasks of the student. Sequencing of online examples are typically followed by additional explanations and descriptions, creating a split-attention effect for learners and invoking a situation where every learner receives the same amount of description for a specific code. By dealing with the issue of split attention, extraneous cognitive load is reduced, potentially increasing overall learning effectiveness.

The study looks at the impact of using an experimental tool, Online Learning and Assessment Tool (OLAT), to enhance learning by reducing cognitive load. There were three different hypotheses that were tested in the study: 1) Students receiving tool-facilitated feedback on their work will gain enhanced understanding from their mistakes, thus their test performance over time will improve beyond that of control group students; 2) Students receiving tool-facilitated descriptions in code examples will develop a better understanding of the examples, thus their test performance over time will improve beyond that of control group students; and 3) Students receiving both tool-facilitated descriptions and feedback will show the greatest improvement in performance over time (Heo & Chow, 2005). In essence, the tool allows for personalized self-directed learning by embedding descriptions in examples and integrating feedback within the lesson. There were 24 students who participated in the study over a six-week period. Student performance increased by students using the tool over those in the control group, as evidenced in questions on lecture material and in quiz scores. Findings in the study findings suggest that the tool intervention facilitated a decrease in the overall extraneous cognitive load associated with students learning new material. This was a key finding since intrinsic cognitive load was assumed to be high due to the nature of the content. An added finding was that participants in the tool group required less time for preparation than did members of the control group in studying examples of code. This suggests that learners could obtain the same amount of knowledge, if not more, in less time when the tool-facilitated lectures were provided in both lectures and in assignment feedback.

Research-based Heuristics for Managing Cognitive Load

The Association for Educational Communications and Technology (AECT) published a special issue of Educational Technology Research and Development in which Morrison and Angler (2005), provided a set of twelve heuristics for managing cognitive load in the design of e-Learning materials. While each of the heuristics is supported by empirical research in the context of the study it references, application of the heuristics should be done with care, subject to the recommendations provided for future research into each subject area.

The first heuristic is:

1. A strategy requiring initial learning of technology skills, then particular content area concepts, will enhance learning for students with a low level of technology skills.

This heuristic is based on the study by Clarke, Aryres, and Sweller (2005), which, based on cognitive load theory, considered the impact of timing of learning spreadsheet technology skills when learning basic math concepts. Two sequencing strategies were examined: 1) learning spreadsheet skills, and then math skills in sequence; and 2) studying spreadsheet skills concurrent with math concepts. A subjective measure of cognitive load was also included in the study. Further research is recommended on concurrent and sequential sequencing strategies for math and technology, and also in other content areas such as history.

The next two heuristics are:

2. Exploratory practice results in greater involvement than do worked examples for experienced students.

3. Students with no prior knowledge will have less efficiency with exploratory practice than with worked examples.

Paas, Tuovinen, Van Merrinëboer, and Darabi (2005), consider motivation as an external variable in problem-based learning and in worked examples, for planning and optimizing instructional materials. Using worked examples for experienced students can serve as a de-motivator, lowering performance levels as compared to experienced learners presented with problems to solve using tools provided. Future research considering cognitive load theory and motivation should focus on authentic environments, measures that can be adapted to e-Learning, and the effect of cognitive load in a variety of conditions affecting motivation.

The next two heuristics are:

4. Presenting two integrated nonredundant external representations (verbal and visual) in contrast to one (verbal or visual) will result in higher student performance levels and require less mental effort by learners.

5. Strategies for interactivity that involve the learner in the process of understanding (schema development) prior to feedback will enhance transfer learning.

Moreno and Valdez (2005), examined cognitive load and learning affects of dual-code and interactivity as two multimedia methods to promote meaningful learning. The hypothesis used to test for dual code learning is that deeper learning occurs when the student is presented with dual representation (verbal and nonverbal) of a causal system than students presented with only one representation. The hypothesis used to test for interactivity is that students will learn more when asked to organize the steps in a causal scientific system than students presented with a set of preorganized causal chain steps. The research reported in this study can be extended in future studies through replication and by including content from disciplines other than math and science.

The next heuristic is:

6. For learners with high learning prerequisites, inclusion of animated pictures that can be manipulated will enhance learning and allow for cognitive processing that would otherwise not be possible.

Schnotz and Rasch (2005), conducted an experiment to examine the effects of animation in e-Learning materials by considering two functions of animation: enabling and facilitating, as both are assumed to reduce cognitive load. Animations are said to have an enabling function if they reduce the cognitive load of tasks in order to allow additional cognitive processing that would otherwise be impossible (increased capacity). Animations have a facilitating function, on the other hand, if they reduce the cognitive load of tasks that could otherwise be solved only with high mental effort (decreased effort). Learners with high prerequisites were more effective in learning using animations that allow for manipulation designed to enable cognitive processing. Learners with low prerequisites did better with simulation type animations intended to reduce cognitive load. Based on the findings of this study, recommendations are for additional research to further confirm the relationship between animation function, learning prerequisites, and germane cognitive load.

The next three heuristics are:

7. Adding verbal annotations to text can improve recall and transfer performance.

8. Selection and organization-level annotations can enhance comprehension.

9. Providing more than one type of annotation results in a decrease in performance.

Wallen, Plass, and Brünken (2005), investigated the use of text annotations to support development of schemata as a strategy for managing intrinsic and extraneous cognitive load. Specifically, the experiment looked at how much is enough with regard to text annotation, before it has a detrimental effect on learning through increased cognitive load. This study extends the discussion of cognitive load research beyond message design. Consequently, there are several recommendations for further research. One is a study to investigate effectiveness and effect on cognitive load of embedding annotations within the text verses presenting them adjacent to the text. Another area for study is a comparison of active learning strategies involving passive annotations to determine if there are differences in performance and cognitive load. Further studies investigating the effect of instructional strategies on cognitive load should include objective measures of cognitive load rather than merely suggesting that such strategies result in and increase (Morrison & Anglin, 2005).

The next two heuristics are:

10. Designing deliberate practice strategies to enhance germane cognitive load can lead to the development of expertise.

11. The effectiveness of deliberate practice is enhanced if the learner is motivated.

Van Gog, Ericsson, Rikers, and Paas (2005), examine several issues related to the design of instructional materials for advanced learners. Effects identified in cognitive load research including: worked-example effect, split-attention effect, redundancy effect, and modality effect produce different outcomes depending on the expertise and prior knowledge of the learner. Instructional strategies for expert learners can incorporate reflection, feedback and other elaboration strategies to enhance learning from errors. The study considers that in addition to being motivated to practice, learners must also be engaged in a mindful way to make effective use of feedback for error correction and development of schemas. The reversal effect on learning occurs when the same materials are used for all learners. In an example given, the use of integrated text and graphics reduces the split-attention effect for novice learners, though may create a redundancy effect for expert learners leading to an increase in cognitive load.

Additional research is warranted to determine the extent of the expertise reversal effect when designing materials for different levels of learners. This leads to better understanding of how experts use schemas to solve problems.

The final heuristic is:

12. Making adaptive decisions based on performance and a subjective measure of cognitive load my result in more efficient learning.

Kalyuga and Sweller (2005), have extended research in the use of adaptive models in instructional technology by introducing cognitive load as an adaptive variable. Cognitive efficiency is calculated and applied to adapt instruction for each learner, through rapid measure of semantic knowledge and a subjective measure of the learner's cognitive load. The study and suggested heuristic provide an alternative to designing one form of instruction and relying on time as the individualization factor. Implementation of this approach requires at least two levels of difficulty in the learning materials, and a rapid assessment method to adjust the learning based on the individual learner's measure of cognitive difficulty. Additional research is recommended to apply this approach in other knowledge domains (the current study involved algebra studies by tenth grade students.) Another area for development in future research is the development of an objective measure of cognitive load.

Conclusion

For online learning, or e-Learning, to be effective requires consideration of a number of factors related to learner characteristics, given the inherent separation in time and space between when the instructional content is delivered and when it is received by the learner. This paper has sought to provide a review of the current literature to provide insight into cognitive styles, differences between novice and expert learners, and strategies for managing cognitive load. A set of twelve heuristics was introduced to manage cognitive load in e-Learning, which are all grounded in research. The heuristics should be viewed as tentative, however, until they can be validated through replication of the studies and application to other knowledge domains.

A critical area not specifically addressed in this paper warrants mention due to the growing body of literature that has begun to emerge about the nature of online learning. That is, the impact of e-Learning on pedagogical models and practice. Whereas development of any educational environment is a complex task, many educators are experiencing an especially difficult time changing the ways in which they teach. Many have never personally experienced online learning, yet are now being asked to develop e-Learning content. Not only must faculty members develop and design their activities and interactions in new ways, they may be often at a loss without the ability to recognize when students are puzzled (Schrum and Hong, 2002). Administratively, the traditional hierarchy is flattened, with power and control over how and when learning occurs being redistributed. Clearly, the challenges facing educators extend beyond the need to be comfortable with the reliance on technology to support their courses.

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