Exploring Prior Knowledge and Cognitive Load Theory and Implications on Learning

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Cognitivist theories have been evolving since the 1930’s with the work done by Bartlett (1932) and his studies on the topic of remembering where he states that schema is built on past experiences and organized to be recalled later. Additional work with cognitivism, by Miller (1956), showed that learners using their short-term memory can only recall 7 ± 2 numbers effectively without straining their memory capacity. Further studies have been done looking at schema of humans and how schema integrates with learning. The evolution of cognitivist theory has paved the way to cognitive load theory (CLT) during the 1980’s. According to Clark, Nguyen and Sweller (2006), “Cognitive Load Theory is a universal set of learning principles that result in efficient instructional environments as a consequence of leveraging human cognitive learning processes” (p. 7). Cognitive load has been very important in everyday instruction for the learner and the instructor. As a learner, CLT has its effects on working memory, but an instructor can control the cognitive load on a learner by altering instruction and utilizing prior knowledge of the learner.

Due to the evolvement of technology, it is even more important now to pay attention to Cognitive Load Theory and how it impacts the learner and instruction negatively and positively, especially with e-learning. The researchers cited in this article will look at how cognitive load impacts working memory, what factors increase or decrease cognitive load for the learner, why prior knowledge of the learner is important and how instructional designers can best utilize cognitive load theory into their design of instruction and materials for instruction and the e-learning environment.

In order to understand cognitive load theory (CLT), the role memory plays in learning needs to be reviewed. Driscoll (2005) states that in a cognitivist view, the human learner acts as a processor of information similar to a computer (p. 74). Information has to be processed in stages before it can be stored permanently in human memory. Three types of memory stages exist: sensory as the initial stage, short-term or working memory as the second stage, and long-term as the third stage.

Sensory memory deals with the senses such as visual and auditory. Information is held in this stage for split seconds of time before it's forgotten or processed further. Next, working memory and short-term memory is the next processing stage that holds information for 5-30 seconds, dependent on the number of items, and information is only held for a limited amount of time, or forgotten (Peterson & Peterson, 1959). If a learner is to store information for long periods of time, the information from short-term memory has to process to long-term memory and it can hold unlimited information (Driscoll, 2005, p.75). In order for information to be stored into long-term memory, it must be encoded first in the short-term or working memory. Learners need to allocate their resources to working memory, and instructional sources can cause an overload within working memory. For this reason working memory is vital to learning and will be the main concentration when talking about CLT.

Three types of cognitive load exist: intrinsic, extraneous, and germane and each plays a part in the learning process. Intrinsic cognitive load (ICL) is "connected with the nature of the material to be learned" (Bannert, 2005, p. 139). Or as defined by Sweller and van Merrienboer (1998), "intrinsic cognitive load through element interactivity is determined by an interaction between the nature of the material being learned and the expertise of the learner" (p. 262), and cannot be altered. Examples of intrinsic cognitive load are when the learners are reading words in a sentence or sentences in a paragraph, or the numbers presented in a math problem such as 2x + 2y=18. Extraneous cognitive load (ECT) is in control of the instructional designer and is directly related to instructional design and the materials associated with it. This causes increases in the number of elements that must be processed simultaneously in the learner's working memory (Wong, Leahy, Marcus, & Sweller, 2012, p. 450). Of course ECL is not relevant for the learning process, and it's unnecessary for cognitive load. ECT takes up unnecessary space in the working memory that can be used for schema construction and learning. Instructional designers can control and alter ECL to reduce working memory. Poorly designed instruction significantly increases the cognitive load for the learner. And, if a learner has both high intrinsic and extraneous cognitive load, it taxes the working memory. ECL is information that is "nice to know" but is not a "need to know" basis. Examples include: long text with sounds, multiple types of information given at one time, and conventional problems. Conventional problems are not related to real life examples. For example, ?-60=120, and students would just work the problem with no examples. In worked problems, the instructor would provide examples and models on how to solve the equation first before the students solve the equation. The last type of cognitive load is germane cognitive load (GCL) and is explained as extra information that contributes to learning and helps develop schema. GCL can be altered and it does increase cognitive load. An example of GCL would be helpful tips or definitions in social studies textbooks that are framed off from the normal reading columns. For example, if a fourth grade student is reading about the Robert E. Lee and the Civil War from the textbook then Robert E. Lee would be in bold print in the text and a box would be framing the word Robert E. Lee with the definition outside of the text. All three types of cognitive load are accumulative to working memory.

Cognitive Load Theory Impacting Learners in E-Learning

It is obvious to understand how cognitive load can affect a learner in a face-to-face situation with information and materials given by the instructor. With the infusion of technology in the classroom, cognitive load is given a new dimension to learning by adding audio, visual, abundant text and interaction. Merrienboer and Ayres (2005) explain that “if intrinsic load is high, extraneous cognitive load must be lowered; if intrinsic load is low, a high extraneous cognitive load due to inadequate instruction design may be harmful, because the total cognitive load is within working memory limits” (p. 8). Animations and statics (isolated pictures) used in e-learning can also increase cognitive load and should be used with careful consideration. Hegardy, Kriz, and Cate (2003) showed that animations fared no better than static diagrams to produce higher levels of learning. An instructor would need to look at their current audience of learners in order to make this evaluation. For example, an experience learner that has existing knowledge on the subject being shown would be in more favor of an animation to produce learning outcomes than static diagrams since it wouldn’t tax their working memory. However, a less experienced or novice learner would find animations taxing to their working memory and would fare better with static diagrams. In studying the effects of math content on the learner, Kalyuga (2008) stated learning was not increased for expert learners when using static diagrams compared to animations. Another way to compare static pictures and animations is by adding the length of time a picture or pictures would be shown or the length of animation, and how it impacts learning. Is it best to show a series of pictures, or a long or short animation? This is definitely something to consider when designing e-learning. Wong et al. (2012) researched the length of animations compared to short and long animations, and found that shorter animations were superior to static graphics in not increasing cognitive load. It is interesting to know that in this same study, static showed superior over longer animations. Of course as an instructor, one would have to know the learners’ background knowledge to either reduce or increase cognitive load in working memory.

Another way of studying how illustrations affect learning is comparing how illustrations impact learning when they are either instructor or learner generated. Depending on who controls or implements the illustrations, changes the cognitive load. A study done by Schwamborn, Thillman, Opfermann, and Leutern (2011) with science content and novice learners, with the illustrations being generated by the instructor, resulted in comprehension and understanding of materials led to cognitive load being lessened. However, if the learner generated the illustrations, it resulted in greater cognitive load that interfered with the learning of the content.

In addition when looking at interaction of videos, auditory, and text one needs to consider the best format to reduce cognitive load and free working memory. An instructor would need to realize if it would be best to introduce the video with text or video with auditory. An instructor that uses various interactions in e-learning results in splitting the attention of the learner, and increasing the cognitive load. For example, a learner might be reading text on a computer screen at the same time a video is playing. If the learner is tuned into just reading the text, then that learner is missing the other source (the video) for information, thus creating the split-attention effect. Plus, if information is presented to the learner in a video format and that same information is presented on the same screen in text format, a redundancy effect occurs. For example, a student wanting to know about how molecules react in a chemical reaction connects to a video on Youtube.com. While the video is playing, the text for the video is displayed below the video. If the student is tuned into the video, then the full attention is not on the text. Or while the student is reading the text then parts of the video are being missed on molecules. According to Sweller (1999), this split-attention effect is modeled by what the eyes see and only some of that information can be processed to visual working memory.

Another effect similar to the split-attention effect is the redundancy effect. According to Asraj, Freeman, and Chandler (2011), the redundancy effect is the same unwanted information presented in various forms and it interferes with the learning process. If an instructor can present multiple sources of information in isolation it will decrease the cognitive load of the learner. "The goal of e-learning tools should be only to have redundancy when the information cannot be presented in isolation" (Asraj et al., 2011, p. 6). Again as an instructor, one would have to assess the learners and their familiarity with the content to determine whether or not items can be presented in isolation.

Prior Knowledge of Learners and Cognitive Load

It's important on an instructional stand point to assess your learners' prior knowledge especially when considering cognitive load. New information that a learner would have to infiltrate either as new information or as a new schema would impact working memory. If a learner already has prior knowledge and has interacted with the content or elements then working memory would be reduced. On the other hand, if the learner has not encountered the new content or elements previously, then the learner would have to process the new content and cognitive load would be increased. According to Sweller (1999), the impact of cognitive load depends on the number of elements that a learner has to process simultaneously and that also depends on the learner's interactivity between these elements. One way to look at this statement by Sweller and how it impact extraneous cognitive load is to consider in the state of Indiana the number of K-12 school administrators that have to learn the new teacher evaluation rubrics. And, if administrators also learn the new technology tool that would eventually help them streamline the evaluation process, it would increase their extraneous cognitive load in working memory. Administrators would be concentrating on more than two elements within their schema with some interaction. They would have knowledge on the evaluation rubric and no previous interaction with the technology involved such as data, reports, and tools that encompass the evaluation software. Administrators would lose information regarding the rubrics in their working memory due to the evaluation technology software taking up more space within their working memory thus increasing their extraneous cognitive load. However, if administrators already have prior knowledge regarding the evaluation rubrics and the evaluation technology tools and software, then this would not be a demand on the administrator's cognitive load in working memory. This same scenario can be applied to learners in an e-learning environment. Learners taking a graduate class, for the first time in an e-learning environment, would not only have to learn the new class content but also how to utilize the tools such as accessing the class, posting on discussion boards, and uploading assignments thus increasing their cognitive load. If instructors access learners' prior knowledge in regards to the e-learning tools, it could decrease cognitive load if the learners already have that knowledge on e-learning tools. Asraj et al. (2011) state that if designed materials are employed in the instructional techniques where the learner spends an abundant mental effort understanding the tool rather learning the concepts, then "extraneous cognitive load can interfere with schema acquisition and automation, and hence hinder the learning process" (p. 5).

Prior Knowledge: Sequencing or Concurrent Information

Clark, Ayres, and Sweller (2005) researched the impact of sequencing and prior knowledge on learning mathematics through spreadsheet applications. The outcomes of their research showed that learners with low level prior knowledge of spreadsheets had more effective learning outcomes if the spreadsheet knowledge was learned prior to the mathematical content (p. 22). And, learners with high-level prior knowledge of spreadsheets had more effective learning outcomes when the spreadsheet knowledge and mathematical content was presented concurrently. So for an instructor to know what method to utilize, sequencing or concurrent information, the instructor would have to know the learners' expertise of the content. The research by Ayres et al. reaffirmed that cognitive load is increased for the learners with low prior knowledge if information is presented concurrently instead of sequentially thus increasing working memory and preventing learning on the targeted content (2005, p. 22).

Managing Cognitive Load and its Application to Instructional Design

Cognitive load is a very important element to consider when designing instruction. As an instructor, the content of the information should be presented in an organized fashion in order to achieve learning outcomes. "There are many factors that an instructional designer must consider, but the cognitive load imposed by instructional designs should be the preeminent consideration when determining design structures" (van Merrienboer, Kirschner, & Kester, 2005, p. 12). In order for learners to learn the targeted content information, an instructor needs to consider how not to overload the working memory and interfere with learning, and move important information into long-term memory. Once this information is in a learner's long-term memory, then the learner can recall that information for future use. As an instructional designer, it's important to design instruction knowing what to include in the design such as sequencing information or presenting content concurrently. Also, a designer needs to know when to utilize text, video, audio and interactivity properly. Furthermore, designers need to know what problems to utilize for learners, such as worked problems in favor of conceptual for novice leaners because it helps reduce cognitive load.

It's important for designers to reduce extraneous cognitive load by using materials that relate directly to the content. Designers definitely don't want to use materials that are irrelevant to the instruction. A design may look nice with many pictures, sounds, and videos, but is it necessary? If it is not necessary to the learning outcomes, it would be best to remove them. Extraneous cognitive load is controllable by the designer, so use materials relevant to learning. Again intrinsic is not controllable by the designer but it can be aided when controlling extraneous cognitive load. It is of value to the designer to look at a learner's intrinsic loads. When learners' intrinsic is high, extraneous cognitive load has to be lowered. E-learning adds another dimension to instructional design, especially when considering static or animations. Animations are better for experienced learners, and static favors novice learners. However, shorter animations are superior to static graphics and static is superior over longer animations. When presenting information it's best to format it in isolation, unless it's impossible to do so, as not to induce redundancy or split-attention effect. Prior knowledge impacts instruction enormously. If a learner has prior knowledge of the content, cognitive load is lower compared to if prior knowledge does not exits and it's increased. When considering prior knowledge and e-learning tools, cognitive load is lower when the learner knows how to implement the tools, thus not interfering with learning. Furthermore, as instructors access prior knowledge, they would want to sequence content for novice learners and present content concurrently for expert learners.

Future Research

Many studies have been done on cognitive load theory in intrinsic, extraneous, and germane. Further studies can be conducted on how learners' motivation is involved and effects cognitive load. These studies should be conducted and compared in different subject matters and grade bands such as elementary, middle school, high school, and college levels. This would allow different views between the maturities of the learners. Cognitive load theory research should be compared in a face-to-face environment and e-learning environment. In addition, how does one best design instruction and research cognitive load with students in an e-learning environment that have high interaction with classmates with various prior knowledge and motivation.

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