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Cognitive load theory, the transient information effect and e-learning

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ABSTRACT

When using modern educational technology, some forms of instruction are inherently transient in that previous information usually disappears to be replaced by current information. Instructional animations and spoken text provide examples. The effects of transience due to the use of animation-based instructions (Experiment 1) and spoken information under audio-visual conditions (Experiment 2) were explored in a cognitive load theory framework. It was hypothesized that for transient information presented in short sections, animations would be superior to static graphics, due to our innate ability to learn by observing. For transient information in long sections, animations should lose their superiority over static graphics, due to working memory overload associated with large amounts of transient information. Similarly, the modality effect under which audio-visual information is superior to visual only information should be obtainable using short segments but disappear or reverse using longer segments due to the working memory consequences of long, transient, auditory information. Results supported the hypotheses. The use of educational technology that results in the transformation of permanent into transitory information needs to be carefully assessed.

1. Introduction

Instructional technology is becoming increasingly sophisticated and increasingly ubiquitous. While there can be little doubt that the introduction of technology allows novel and beneficial forms of teaching and learning, those novel forms sometimes have unintended, incidental, and negative consequences. In this paper, we are concerned with the transient information effect (Leahy & Sweller, 2011; Sweller, Ayres, & Kalyuga, 2011). It occurs when instructional procedures present information in a form that is transient and difficult to retrieve rapidly and when required. The use of both animations and spoken information provide examples. While technology permits the ready use of animations and spoken text, both incidentally transform the permanent information associated with hard copy into transient information that rapidly disappears to be replaced by new information. Transient information has negative cognitive load consequences that are explored in the two experiments of this paper. We will begin by outlining cognitive load theory.

Cognitive load theory is a framework of instructional design principles based on the characteristics and relations between the structures that constitute human cognitive architecture, particularly working memory and long-term memory. The theory assumes that human cognitive architecture is a natural information processing system, analogous to other systems such as evolution by natural selection (Sweller, 2011, 2012; Sweller et al., 2011; Sweller & Sweller, 2006). It can be specified by five principles:

1. *Long-term memory and the information store principle.* Most human cognition is driven by the contents of an enormous information store (De Groot, 1965). In human cognition, this structure is long-term memory.
2. *Schema theory and the borrowing and reorganizing principle.* This principle assumes we learn primarily through borrowing schemas from other people's long-term memories (e.g., through listening or reading what others have written). These schemas are constructively reorganized through the lens of our own long-term memory. This reorganization process is inexact, resulting in some random changes.
3. *Problem solving and the randomness as genesis principle.* The borrowing principle does not create new information except insofar as borrowing is inexact. If knowledge is unavailable either through our own or other people's long-term memories, we must problem solve by randomly generating moves and testing their effectiveness. This process generates new knowledge.

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4. *Working memory and the narrow limits of change principle.* Working memory processes must deal with the novel information generated by the randomness as genesis principle. The randomness inherent in reorganization and random problem solving generates extremely large problem-solving spaces. To reduce the problem-solving space, working memory is limited in both capacity (Miller, 1956) and duration (Peterson & Peterson, 1959).
5. *Long-term working memory and the environmental organizing and linking principle.* Working memory is only limited when processing novel information. It is able to deal with vast amounts of previously organized information brought in from long-term memory (Ericsson & Kintsch, 1995) reducing the burden on working memory and thus lowering cognitive load.

The structure and characteristics of this cognitive architecture indicate the primary purpose of instruction is to construct schemas in long-term memory. Instructional designs that do not aim to alter long-term memory and which ignore working memory limitations when processing novel information are unlikely to be effective. As well as human cognitive architecture, cognitive load theory includes a framework of instructional design principles and postulates the existence of two distinct types of cognitive load (Sweller, 2010):

Intrinsic cognitive load is the cognitive load inherent within the information to be learnt. Intrinsic cognitive load is dependent on the degree to which individual elements of information must be processed simultaneously in working memory to be understandable (see Marcus, Cooper, & Sweller, 1996; Sweller, 1994, for more information). Intrinsic cognitive load is akin to the intellectual complexity of the materials and cannot be modified.

The instructional content of Experiments 1 and 2 used technical material that was high in element interactivity (Sweller, 2010). Cognitive load effects will not apply to highly automated information, or information specified without learning as the main goal. For example, everyday conversation or film and television dialogue can include quite extended spoken text; however, it can be easily processed. This text is quite different from the unfamiliar, technical, higher element interactivity material used in our experiments. The hypothesised results should be assumed only to be applicable to material that entails a higher working memory load from higher element interactivity material. Cognitive load theory becomes less relevant as levels of intrinsic cognitive load are reduced.

Extraneous cognitive load is the cognitive load that arises from instructional design practice and is within the control of the instructional designer. It is caused by an unnecessary increase in the number of elements that must be processed simultaneously in working memory due to instructional design factors. The majority of research in cognitive load theory has traditionally concentrated on techniques to reduce extraneous cognitive load in instructional materials (for more information, see van Merriënboer & Ayres, 2005; Sweller, 2010; and Sweller et al., 2011).

All cognitive load associated with instruction can be divided into intrinsic and extraneous cognitive load. In addition, the term "*germane cognitive load*" is frequently used, often as an independent source of cognitive load. An alternative interpretation is that because germane cognitive load is closely related to and dependent on intrinsic cognitive load, it is appropriate to define it in terms of intrinsic cognitive load (Sweller, 2010). Accordingly, germane cognitive load refers to working memory resources required to deal with intrinsic cognitive load resulting in learning. Similarly, working memory resources are required to deal with extraneous cognitive load and are sometimes referred to as extraneous resources. Reducing extraneous cognitive load can increase germane cognitive load, by releasing working memory capacity for learning (Sweller, 2010).

1.1. The present study

Many instructional design guidelines have been generated from cognitive load theory (Sweller, 2011, 2012; Sweller et al., 2011). Effective instructional designs should aim to keep total levels of intrinsic and extraneous cognitive load to within the learner's working memory limits. Transient information is one of the factors that may cause cognitive load to exceed working memory limits. Information is transient when elements of information that must be processed by a learner disappear to be replaced by new elements. If the new and old elements interact then the old elements must be held in working memory while the new elements are processed. Modern educational technology frequently and incidentally transforms permanent information into transient information. The effect can result in an overwhelming working memory load.

As an example, when a series of static graphics used to depict motion is replaced by an animation depicting the same motion, not only is the visual information rendered more realistic as is the intention, but a permanent depiction is replaced by a transient depiction. The consequence may be a considerable increase in working memory load. Static graphics allow learners to rapidly and easily refer back to previous information as needed. Depending on the technology, it may be difficult or impossible to switch rapidly and easily between various aspects of an animated depiction. The natural way to view an animation is serially. Exactly the same argument applies when written text is replaced by spoken text. Permanent, written text allows us to easily and rapidly refer back to text previously read. It can be much more difficult to refer back to transient, spoken text and that difficulty may negate any advantages associated with a more natural mode of presentation.

One way in which the potential problems associated with transient information may be overcome is to present the potentially transient information in much shorter segments. A short segment of information should impose a reduced cognitive load compared with a longer segment. By reducing the cognitive load associated with long segments of information containing lots of interacting elements, the natural advantages of animations and speech may manifest themselves. For animations this means allowing us to tap into our innate ability to learn by observing (Ayres, Marcus, Chan, & Qian, 2009; Wong et al., 2009); and for speech this means harnessing the highly practiced skill of learning by listening within a dual modality context (Mousavi, Low, & Sweller, 1995).

Experiment 1 of this paper applied cognitive load theory to some of the consequences of presenting animations during instruction while Experiment 2 applied the theory to some of the consequences of using audio-visual instructions. In both cases it is suggested that as the length and complexity of transient instructional information associated with animations and audio-visual presentations increases, extraneous working memory load also increases resulting in the benefits of animations and audiovisual instructions decreasing or even reversing compared to alternatives.

1.2. Aim-Hypothesis

In the two experiments, transient vs. permanent information was compared using longer and shorter segments of information. In both experiments, we hypothesised a condition by segment length interaction. In Experiment 1, there should be a greater advantage for animations over static graphics using short segments of information compared to long segments of information (Hypothesis 1a), and in Experiment 2, there should be a greater advantage for audiovisual presentation over a visual only presentation using short segments of information compared to long segments of