Managing Cognitive Load in e-Learning Paradigms using the Synchronous Cyber Classroom and Rigorous Instructional Design

Megan HASTIE [a*]
[a]*Education Queensland, Australia*
Nian-Shing CHEN[b]
[b]*National Sun Yat-Sen University, Taiwan*
Richard SMITH[c]
[c]*Southern Cross University, Australia*
*mhast5@eq.edu.au

Abstract: This paper is about the management of cognitive load in e-learning paradigms. We describe the use of the synchronous cyber classroom in managing learner cognitive load at an Australian school of distance education before examining specific technological and instructional design considerations required for visual, written, and auditory communication. The learner's intrinsic cognitive capacity in technology enhanced learning environments is linked to the role of the teacher in managing extraneous cognitive load. We also identify the need for accountability around professional skilling if teachers are to develop the comprehensive Web 2.0 repertoire, and definitive evidence gathering and reporting protocols, needed to demonstrate student achievement. We conclude that in order to maximise student achievement in e-learning settings, it is imperative for teachers to apply evidence-based research, specifically neuroscience-based approaches, and to use pedagogy based on high-level knowledge synthesis and systematic instructional design.

Keywords: cognitive load, e-learning instructional design, synchronous cyber classroom

Introduction

World-wide, teachers need to come to terms with the use of new digital technologies and must be prepared and trained to manage the competing and complex pedagogical demands of the 'digital age', including issues around cognitive load. In this paper we focus on the role of Web 2.0 tools and instructional design in the management of cognitive load, as part of our ongoing research and development in e-learning paradigms (Hastie, Chen, Smith et al, 2011, 2012). We define cognitive load as the load on working memory during instruction, with cognitive overload being the result of intended cognitive processing exceeding the learner's available cognitive capacity (Mayer & Moreno, 2003).

In addressing these challenges, we cite evidenced-based research where enhanced cognitive function in students has been reported by teachers who have applied 'best practice' in instructional design when working in e-learning settings (Hastie, Chen, & Kuo, 2007). In this paper we define e-learning as learning that results from experiences and interactions in an Internet environment, using e-learning pedagogy and facilitated by a skilled e-learning manager - a role we regard as pivotal in re-engineering educational paradigms (Hastie, Chen & Smith, 2011).

In this study the Blended Cyber (BC) mode of delivery is used as the preferred pedagogical approach at an Australian school of distance education. The BC mode combines different instructional methods, modalities and delivery 'media', including online and face-to-face instructional settings in which participants may be physically present and/or 'cyber'. The teacher in this study used the BC mode as a pedagogical framework to determine then match instruction to the situation-specific needs of students, using Web 2.0 cyber synchronous technologies. Previous research showed that participants can use these technologies to access each other across time-zones, continents and oceans, thereby negating the effect of 'distance' (Hastie, Chen, & Todd, 2008), and that the synchronous cyber classroom, in particular, provides a learning environment that can outperform both asynchronous online instruction and traditional face-to-face instruction (Chen et al, 2005). These findings were replicated in studies conducted with early childhood and primary school students in the Australian school of distance education (Hastie et al, 2003, 2008), as evidenced in enhanced learning outcomes attributed to students being actively engaged in visual, auditory and kinaesthetic interactions in synchronous cyber classroom sessions (Hastie, Chen et al, 2011, 2012).

We cite new findings that have enabled us to develop an approach to e-learning that can be adopted by teachers working in digital environments, to manage student cognitive load. We now examine the literature on cognitive load to investigate the implications for its management in e-learning paradigms.

1. Literature Review

At the crux of cognitive load theory is the interplay between working memory and long-term memory. The literature reveals a growing disquiet around cognitive load, particularly cognitive overload when 'multimedia' is incorporated in instruction. Given that early research on the cognitive capacity of humans indicated working memory can hold seven objects, plus or minus two (Miller, 1956), there are clear implications for technology enhanced learning and the use of multi-modal delivery media.

Cognitive load theory emerged from neuroscience research. Long-term memory was found to store knowledge and skills on a permanent basis while working memory was found to perform the intellectual tasks associated with consciousness (Sweller, 1988). Information is stored in long-term memory but only after first being attended to, and processed by, working memory (Mayer, 2008). Thus, working memory is said to enable us to think logically and creatively, allowing us to solve problems and to be expressive, to direct our attention so we can 'think about something', and to process information. However, working memory is limited in both capacity and duration and, under some conditions, these limitations will impede learning. The capacity of working memory may be expanded slightly through combining the senses that are used when presenting information. For instance, it is easier to attend to a body of information when some of the information is visual and the remainder of the information is auditory, as opposed to all the information being presented through a single sense, either fully visual or fully auditory. In research undertaken at the Hear and Say Centre, Brisbane, it has been demonstrated that the stimulation of neural pathways in the auditory areas of the brain results in accelerated speech, language and cognitive development in children with profound hearing loss (Hastie, Dornan, Chen, Smith, & Elston, 2011). Neuroscience then is providing fresh evidence on cognition and cognitive load. Mayer (2003) identified intrinsic and extraneous sources of cognitive load. Intrinsic load is a result of the complexity the learner experiences when interacting *with* new knowledge and skill and correlates directly with the intrinsic nature (difficulty) of the 'to-be-learned' content. Extraneous load is the result of decisions made *for* the learner through the design and delivery of instructional materials. A learner's intrinsic cognitive load cannot be modified by instructional design, but instructional materials can be changed so that the extraneous cognitive load is modified. If on-task mental ‘load’ or activity during learning can be modified, the implications for teachers are profound. Mayer (2008) applied this to instruction that included multimedia, developing The Cognitive Theory of Multimedia Learning, (CTML), based on the assumption that humans possess separate systems for processing pictorial and verbal material (dual-channel assumption). Each channel is limited in the amount of material that can be processed at one time (limited-capacity assumption), and meaningful learning involves cognitive processing including building connections between pictorial and verbal representations (active-processing assumption). Words and pictures are presented to the learner via a multimedia presentation, and then processed along two separate, non-conflicting channels. Words and pictures enter the sensory memory through the ears and eyes. The learner actively selects words and images from the sensory memory. These enter the working memory and are organized into a verbal model and a pictorial model. Mayer claims that each channel can process only a few ‘chunks’ of information in working memory at a given time. The verbal and pictorial models integrate with prior knowledge retrieved from long-term memory and then integrate within the working memory. However, cognitive overload occurs when the extraneous load exceeds the learner's available cognitive capacity.

The Web 2.0 tools and the social networking phenomenon has created an unprecedented input-output dynamic, loosely termed ‘the information age’, allowing for visual and verbal (dual-channel) processing, but also allowing for visual and verbal contributions. We decode, but now more than ever, we encode. Extrapolated to e-learning, learners join cyber synchronous environments together with multiple participants from multiple locations and across multiple time-zones (Hastie, Chen & Todd, 2008), using technology enhanced learning solutions to negotiate content (Hastie, Chen & Smith, 2010), working brain-to-brain in teacher-directed online lessons in ‘real’ time (Hastie & Palmer, 2006), and build bridges across the ‘digital divide’ to empower learners in developing nations (Hastie, Chen & Leeming, 2009). A range of instructional approaches can be adopted by teachers working in digital environments. This can be summarised in the Holistic Blended Cyber Model (Hastie, Hung, Chen, & Kinshuk, 2010). The model lists ten Modes or interpretations of the Blended Cyber mode of delivery that can be used by teachers to meet the situation-specific instructional needs of students, as listed in Table 1. Mode 10 is considered to be 'optimal' because it offers the richest ‘blend’ of instructional methods, modalities and delivery media, including online and face-to-face instruction, allowing participants to be physically present and/or ‘cyber’. Used in association with the Holistic Blended Cyber Model, Gagne’s instructional design model (2004), specifically the Nine Instructional Events, offers further pedagogical options including gaining attention (reception), informing learners of the objective (expectancy), stimulating recall of prior learning (retrieval), presenting the stimulus (selective perception), providing learning guidance (semantic encoding), eliciting performance (responding), providing feedback (reinforcement), assessing performance (retrieval) and enhancing retention and transfer (generalization).

Table 1: Holistic Blended Cyber Model (Hastie, Hung, Chen, & Kinshuk, 2010)

1	(PA + PS)	Physical Asynchronous + Physical Synchronous
2	(PA + CA)	Physical Asynchronous + Cyber Asynchronous
3	(PA + CS)	Physical Asynchronous + Cyber Synchronous
4	(PS + CA)	Physical Synchronous + Cyber Asynchronous
5	(PS + CS)	Physical Synchronous + Cyber Synchronous
6	(CA + CS)	Cyber Asynchronous + Cyber Synchronous

7	(PA + PS + CA)	Physical Asynchronous + Physical Synchronous + Cyber Asynchronous
8	(PA + CA + CS)	Physical Asynchronous + Cyber Asynchronous + Cyber Synchronous
9	(PS + CA + CS)	Physical Synchronous + Cyber Asynchronous + Cyber Synchronous
10	(PA + PS + CA + CS)	Physical Asynchronous + Physical Synchronous + Cyber Asynchronous + Cyber Synchronous

While Gagne's model was created for traditional Physical Face-to-Face (PF2F) classrooms, it has been adapted to Cyber Face-to-Face (CF2F) lessons in the synchronous cyber classroom (Hastie, Chen & Kuo, 2007), and applied in a variety of e-learning situations, including early childhood and primary education at the school of distance education (Hastie & Chen, 2010), and a tertiary program for Auditory-Verbal Therapists (Hastie, Dornan, Chen & Smith, 2011). Central to this debate is 'the teacher' and their instructional approaches (Marzano & Pickering, 1997; Hattie, 2003). Smith (2012) points to the current theoretical obsession with 'curriculum' over 'pedagogy' in Australian education, and says policy makers and managers need to re-determine the skill set of today's teacher trainees to avoid pedagogical skill deficits in teacher graduates. Teachers need the skills to draw on evidence-based research and need to use a neuroscience-based approach to learning that includes a comprehensive Web 2.0 repertoire to help them identify definite evidence gathering and reporting protocols that demonstrate student achievement (Top of the Class Report, 2007). We now describe a case study in which these instructional procedures and technologies have been applied.

2. Research Methodology

2.1 Using the Holistic Blended Cyber Model as a Pedagogical framework

During 2010-2012, the Holistic Blended Cyber Model was adopted as a pedagogical framework for e-learning in the development of an Australian e-learning program for Auditory-Verbal Therapists (Hastie, Dornan, Chen, Smith, & Elston, 2012) and at an Australian school of distance education. This paper reports on how the Model was used during 2012 to identify the situation-specific demands of distance education students, ranging from Traditional Face-to-Face (PF2F) to fully Blended Cyber (BC) modes of delivery, including Physical Asynchronous (PA), Physical Synchronous (PS), Cyber Asynchronous (CA) and Cyber Synchronous (CS). Students enrolled at the school were encouraged to participate in the school's e-learning program using a Learning Management System (BlackBoard) and Cyber Synchronous (CS) tools (Elluminate), and other technologies (email, Skype and telephone). Student participation in the e-learning program was situation-specific, depending on Internet access and time-zones.

In this case study the majority of students (93%) had high-level Internet connectivity and high-level access. For students with high-level access, most (71.5%) participated in Cyber Synchronous (CS) sessions. Limited access to the Internet and significant time-zone difference accounted for those students (28.5%) who did not participate in CS sessions, with one student (7%) living on a yacht at sea with sporadic Internet access. For students with limited Internet access, course materials were provided on a USB and in hard copy. Thus, the level and mode of participation in the e-learning program by individual students was determined by their access to the Internet, as described in Table 2.

Table 2: The Holistic Blended Cyber Model - Applied to Instruction

Mode	Formula	The Participant Experience
1	PA + PS	• Access print and/or multi-media resources and • Attend a physical lecture or discussion
2	PA + CA	• Access print/multi-media resources and • Use discussion forum or social media
3	PA + CS	• Access print and/or multi-media resources and • Participate in a cyber synchronous session
4	PS + CA	• Attend a physical lecture/discussion and • Access web-based digital resources
5	PS + CS	• Attend a physical lecture or discussion and • Participate in a cyber synchronous session
6	CA + CS	• Access web-hosted digital resources and • Participate in a cyber synchronous session
7	PA + PS + CA	• Access print and/or multi-media resources and • Attend a physical lecture or discussion and • Access web-based digital resources
8	PA + CA + CS	• Access print and/or multi-media resources and • Use discussion forum or social media and • Participate in a cyber synchronous session
9	PS + CA + CS	• Attend a physical lecture and • Access web-based digital resources and • Participate in a cyber synchronous session
10	PA + PS + CA + CS	• Access print and/or multi-media resources and • Attend a physical lecture or discussion and • Access web-based digital resources and • Participate in a cyber synchronous session

2.2 Managing cognitive load in the synchronous cyber classroom

In this study, the focus is on the student cohort (71.5%) who operated in Mode 10: that is, those who accessed Physical Asynchronous, Physical Synchronous, Cyber Asynchronous and Cyber Synchronous (PS + PS + CA + CS) instructional methods, modalities and delivery media. These students accessed digital resources via the LMS, attended physical lectures on-campus during the Term, used social media (in teacher supervised chat-rooms) and participated in cyber synchronous sessions (CS). In particular, tri-weekly synchronous cyber classroom lessons enabled the teacher to provide direct instruction. These included group sessions of forty-five minute duration in English, Mathematics, and other curriculum areas. Individualised sessions were conducted for students requiring extra support. Content was prepared by the teacher prior to the lesson and uploaded on the interactive synchronous whiteboard. Students logged-into the session and used a computer headset with built-in microphone to listen and speak, enabling auditory-verbal and visual-pictorial processing. Students were encouraged to write and draw on the whiteboard and to use the chat-room using visual, verbal and kinaesthetic processing (Hastie & Chen, 2010). In this way, students were actively engaged in information decoding (dual-channel processing) and encoding in a teacher-directed e-learning program where optimal cognitive function was prioritised.

3. Using instructional design to manage cognitive load in synchronous cyber classrooms

To optimize cognitive function, the teacher developed a lesson template for the synchronous cyber classroom based on Gagne's Nine Instructional Events, as illustrated in Table 3.

Table 3: Instructional Design for the Synchronous Cyber Classroom

Gagne's Instructional Events	Applied to Cyber Synchronous lessons	Examples
1. Gain attention	Welcome student/s to lesson State the Curriculum Key Learning Area	▪ Good afternoon student/s. ▪ Welcome to our English session.
2. Inform learners of objectives	Show the lesson plan Highlight main topic/s	▪ This Unit is about … ▪ In this lesson we will work on …. ▪ Today's we'll practice ….
3. Stimulate recall of prior learning	Ask students to reflect on their prior knowledge and understandings of the lesson topic/s	▪ What do you already know about ...? ▪ This lesson follows-on from ... ▪ Do you remember ...?
4. Present the content	Sequence lesson content using - verbal representations (VoIP) - visual representations (whiteboard)	▪ Let's talk about ... ▪ Here's an example of ... ▪ This website has information on ...
5. Provide 'learning guidance'	Build connections between visual and verbal representations	▪ This picture shows ... ▪ In this diagram we see … ▪ This animation explains ...
6. Elicit performance (practice)	Provide activities for student/s to practice skills and demonstrate understandings - Individual and group discussion - Verbal responses and discussion - Written responses on whiteboard/ in chat-room	▪ Read the problem and write your answer. ▪ Explain how you … ▪ What strategy did you use to …? ▪ Describe …
7. Provide feedback	Provide verbal and written feedback on whiteboard/ in chat-room to: - Individual student/s - Whole Group - Parents/Home Teacher/s	▪ That's correct. Well done! ▪ Great answer, (student name). ▪ Do you need help with this question? ▪ Please check your answer again …
8. Assess performance	Provide opportunities for student/s to demonstrate mastery of skill/s and concept development using shared/individual whiteboard screens/chat-room Observe and record student/s skill and concept development - Anecdotal notes and checklists - Whiteboard screen-captures Review session recording	▪ Draw a diagram to show … ▪ Explain how you solved this problem. ▪ Record your responses in the chat-room please. ▪ Do you feel confident with this work?

9. Enhance retention	Link the lesson content to situations relevant to the student/s Link to learning outcomes and assessment Provide a Summary of the lesson content	▪ This formula/skill can be used to … ▪ The next task to be completed is … ▪ Today we worked on … ▪ In the next lesson we will …

This template highlights elements fundamental to cognitive load management and was used to give students the best chance during teacher-directed lessons to achieve 'germane' cognitive load, that is, cognitive load devoted to the processing, construction and automation of schemas. Key learning objectives identified in the curriculum materials and sequenced to match student cognitive function, determined by age-and-stage of development. Instructional design 'best practice' principles for the synchronous cyber classroom were applied (Hastie, Chen, & Kuo, 2007), along with strategies devised to manage cognitive load in multimedia. These included pre-training, segmenting, signalling, spatial contiguity, multimedia and personalisation principles (Mayer, 2008).

Specific teaching strategies were used to ensure that the pace of instruction matched student cognitive load, that is, working memory. The teacher presented content in segments that were sequenced to provide guided practice of concepts. Students responded in verbal and written forms using the Web 2.0 tools, with responses monitored to determine concept mastery before proceeding. Hence extraneous load was modified and instrinsic limitations of working memory (capacity and duration) accommodated by the e-learning manager to achieve 'germane' cognitive load and optimal cognitive processing.

4. Findings and Implications

The main finding in this paper is that teachers have a core responsibility to manage student cognitive load through the application of sophisticated pedagogical practices using evidence-based research for decision-making around instruction. Teachers need to use a neuroscience-based approach to learning that includes a comprehensive Web 2.0 repertoire, and the identification of definite evidence gathering and reporting protocols to demonstrate student achievement.

Our second finding is that teachers need to be coached in the use of rigorous instructional design principles to develop the 'skill set' necessary when working with digital learners. Failure to address this issue may result in teachers being a causative factor of cognitive overload for e-learners, rather than the facilitators of 'germane' cognitive load.

Finally, this has implications for teacher pre-service level and on-going professional development in instructional design and technological development. It also has implications for school management. The professional development and performance outcomes of teachers and staff must become a core responsibility and accountability for school managers if we are to optimise instruction, including optimal cognitive function, for twenty-first century learners.

Conclusions

In this paper we have described ways to manage cognitive load through high-level knowledge synthesis and systematic instructional design. Teachers need to draw on evidence-based research and a neuroscience-based approach to pedagogy. They must lift their skill level by developing a comprehensive Web 2.0 repertoire to identify definitive evidence gathering and reporting protocols to demonstrate student achievement.

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