

CHAPTER II

LITERATURE REVIEW

Introduction

This literature review focuses on five areas concerning interventions with novice learners of mathematics: working memory and cognitive load theory, the learning of mathematics, creating a connection between cognitive load theory and the learning of mathematics, reteaching strategies, and the use of computer or Web-based instructional tools.

Working Memory and Cognitive Load Theory

Cognitive load theory has received a considerable amount of attention over the past several decades, particularly in the areas of instructional technology and instructional design. Understandings of this theory require an understanding of memory. Strides memory research has made were highlighted recently when audio recordings of an individual studied five decades ago were broadcast to the public (Newhouse, 2007). The 1953 case involved "H.M." who suffered from extreme epileptic seizures. In an effort to provide some relief, he, his family, and his medical staff decided to remove parts of his hippocampus where the seizures appeared to originate. After the procedure, H.M. was left without the ability to recall recent events, indicating many complexities of the information processing system. The broadcast centered around many taped conversations with H.M. regarding his ability to recall events. The initial dialogue focused on his struggle to recall more recent information, such as "Who is the current president?" and "What did you eat for lunch?" Later in the interview, when asked about

information that had transpired prior to his operation, H.M. could quickly describe events leading to the Stock Market crash of the 1940s. H.M.'s surgery revealed the effect the hippocampus has on repositioning information into long-term memory.

Prior to this case, most scholars viewed memory as one large-scale storage unit that concentrates on the use of language as a marker of understanding, indicating an input comprehension process and a produced verbalized output as an indicator of one's knowledge (Newhouse, 2007; MacKay, Stewart, & Burke, 1998). Both Newhouse and MacKay et al. showcased H.M. and his capability to form long-term memories despite his handicap, creating an understanding of explicit and implicit memory (Bruning, Schraw, Norby, & Ronning, 2004). Explicit memory is declarative information that addresses facts (semantic memory) and experiences (episodic memory). Implicit memory, in turn, addresses information from a procedural context.

This body of research has further classified three main areas of an individual's memory: sensory, short-term, and long-term memory (Chandler & Sweller, 1995; Kalyuga, Chandler, & Sweller, 1999; Kalyuga, Ayres, Chandler, & Sweller, 2003; Mayer & Moreno, 2003; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Clarke, Ayres, & Sweller, 2005; Kalyuga & Sweller, 2005; Brooks & Shell, 2006). Sensory memory is defined as the information that is introduced into the conscious through the senses (Bruning, Horn, & PytlikZillig, 2003; Mayer & Moreno, 2003; Moreno, 2006). This includes information such as sights and sounds that can be influenced by a plethora of environmental factors, ones that can hinder or help move information into conscious processing.

Working memory is the area of information processing where conscious thought

transpires and is considered to be limited (Baddeley, 1992; Brooks & Shell, 2006; Paas, Renkl, & Sweller, 2003). Miller (1956) and Simon (1974) discussed this capacity in terms of "chunks" of information that can be strung together. Early workers (e.g., Miller, 1956) believed that an individual can process an upper limit of between seven and ten "chunks" in working memory at any given time.

Finally, long-term memory is where information eventually is stored. Most consider its capacity to be virtually limitless. It is where information can be organized together with existing knowledge, thereby creating a framework (or schemata) guiding the eventual recall of information (Bruning, Schraw, Norby, & Ronning, 2004). Working memory activates this portion of the memory system; it brings existing knowledge back, allowing instruction to utilize prior knowledge as a basis to build new knowledge.

This basic understanding of the information processing system has created a wealth of research in the areas of instruction and instructional design that has analyzed ways to reduce the impediments to learning. Gagné, Briggs, and Wager (1992), for example, built upon this cognitive framework by addressing topics around instructional outcomes, performance objectives, sequencing instruction, and assessment. This framework provided several educational considerations that designers should address when selecting multimedia, designing individualized instruction, and evaluating the selected materials.

Morrison, Ross, and Kemp (2004) suggested a non-prescriptive strategy of instructional design that focused instruction on the individual learner. Their suggestions centered around a holistic instructional design approach encompassing nine parts which

included defining the instructional problem, determining the learner characteristics, performing a task analysis, writing instructional objectives, sequencing the content, designing an instructional strategy, designing the message, developing the materials, and measuring and evaluating outcomes. These nine separate areas are then encapsulated by a continual cycle of revision, evaluation, planning and support. This cycle suggests that instructional design is a never-ending process.

This brief introduction to two instructional design strategies is far from exhaustive; others strategies could be described. However, the early work of Chandler and Sweller (1995) best exemplifies the connections to memory research. In one study, they discussed the negative impacts of using a traditional software manual for teaching computer software use (such as CAD/CAM, word processing and spreadsheets). When the text manual is separated from the computer interface, a split-attention effect impedes learning for a novice learner; the number of items the learner has to focus on is unnecessarily high. This high element interactivity taxes the overall working memory of the novice learner and impedes learning of the desired software skills.

Cognitive load theory focuses on the demand placed upon working memory and provides further guidance to strategies that address the three different types of "load" identified by Sweller and his colleagues (Ward & Sweller, 1990; Chandler & Sweller, 1991; Sweller & Chandler, 1991; Chandler & Sweller, 1995; Kalyuga, Chandler, & Sweller, 1999; van Merriënboer, Kirschner & Kester, 2003). These types include intrinsic, extraneous, and germane cognitive load.

According to van Merriënboer and Ayers (2005), intrinsic cognitive load is determined by the combination of the nature of the materials and the expertise of the

learner. The less experienced learner requires less interactivity with the materials within working memory in order to form meaning. Adding interactivity, something that might assist a more experienced learner, creates a greater possibility for overload and make it difficult for the novice to form meaning. From an instructional design perspective, this load is considered to be within the learner and can only be addressed from a prior knowledge perspective. The building of understanding in the subject matter can develop deeper schema in the area, thus decreasing the amount of interactivity within the materials (Ayres, 2006).

Extraneous cognitive load addresses the materials used in learning (Kester, Lehnen, Van Gerven, & Kirscher, 2006). There has been a considerable amount of documentation on various strategies designed to keep this load to a minimum (Moreno, 2006; Seufert & Brunken, 2006; Gerjets & Hesse, 2004; van Merriënboer & Sweller, 2005; Bruning, et al., 2003; Clark & Mayer, 2003). Examples include the placement of text in relation to corresponding images and the use of narration for certain enhancements, to cite just two (Mayer & Moreno, 2003).

Whereas intrinsic and extraneous cognitive loads are considered to have a negative impact on working memory, germane cognitive load may be positive and has been of interest in recent studies. Originally considered to be outside the control of an instructional designer (Sweller, van Merriënboer, & Paas, 1998), germane cognitive load is focused on self-regulation and addresses the processing, construction, and automation of schema (Paas, Renkl, & Sweller, 2003). Germane load is considered to be self-regulated by the individual (Schunk, 2005). Instructional design strategies addressing just-in-time learning, worked examples, feedback, and increasing student

motivation (van Merriënboer, et al., 2006; van Merriënboer, et al., 2005; Kester, et al., 2006; Olin, Reiser, Xiaoxia, Lim, & Park, 2006) have proven fruitful.

Intrinsic, extrinsic, and germane are considered to be additive in their overall impact on working memory, an entity whose capacity is limited. In learning situations where the sum of loads is less than the available working memory capacity, learning is likely to be successful. When the sum exceeds the learner's capacity, however, successful learning is far less likely.

The Learning of Mathematics

Most mathematics curriculum follows a prescriptive instructional model highlighted within the NCTM Principles and Standards (2000). This model suggests balancing a learner's experiences in the five areas of number sense, algebraic concepts, geometry, measurement, and data analysis and probability. As a student progresses through their P-12 education, specific instruction in each of these areas should be emphasized, with a heavier emphasis on number sense placed in the early grades, more emphasis on algebra in the secondary curriculum and a fairly consistent geometric and data analysis throughout. Figure 2.1 highlights these recommendations.

A Connection between CLT and the Learning of Mathematics

An early connection between the learning of mathematics and cognitive load theory can be found in the work of Baroody (1985) and Sweller and Chandler (1991). Baroody discussed the need for students to master basic number combinations by creating stronger connections to long-term memory. Thus, he advocated that supporting

instructional practices that promote schema development is a necessity before moving to more advanced topics. Sweller and Chandler, though, discussed the components of CLT while trying to learn mathematics simultaneously with spreadsheets. Sweller and Chandler's research found that working memory is limited and suggests that integrated math instruction with students who have no prior experience working with the spreadsheet software can be unfavorable. This connection to CLT further suggested that early instruction of the Web-based system should precede the delivery of content material since novel information presented with novel experiences tends to impede learning.

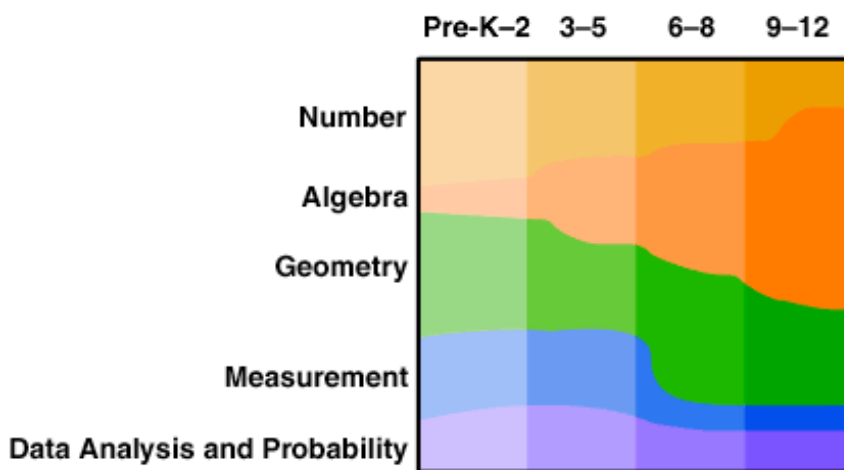


Figure 2.1: Emphasis of Mathematics Content Standards Across the Grades.
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As the CLT literature has expanded our understanding of working memory, additional research in the learning of mathematics has addressed other areas including the background behind and the development of math anxiety (Brady & Bowd, 2005;

Brown & Quinn, 2006; Cates & Rhymer, 2003; Furner, et al., 2005; Malinsky, et al., 2006; Micallef & Prior, 2004). Most of this research has focused on college students and their levels of anxiety regarding mathematics, but the literature has remained consistent; high math anxiety can be attributed to poor performance earlier in one's academic career (Margolis & McCabe, 2006). Thus, a high anxiety level is directly related to negative experiences found somewhere in the educational process.

Other research in this area has addressed the causation of math anxiety. Fiore (1999) described "math abuse" as the negative experiences from parents, teachers, or materials contributing to math anxiety. This creates a link between experience and performance, indicating a connection between the two in the development of one's mathematics efficacy.

This connection suggests designers of instruction should guide students at an earlier age to utilize more accelerated mathematics programs. In a longitudinal study, however, Ma (2003) found that both accelerated and non-accelerated students developed anxiety toward mathematics similar rates. In fact, Ma stated that increased math anxiety of secondary students as they neared graduation was attributable to factors pertaining more to the individual student than to those about materials.

Tollefson (2000) and Lee (2000) both discussed efficacy from Bandura's lens. Bandura (1993) defined self-efficacy from the basis that belief in one's abilities can influence how that individual "feels, thinks, motivates themselves, and behaves." He suggested that efficacy influences the four processes of selection, affection, motivation, and cognition. Tollefson (2000) elaborated on this view of efficacy by establishing efficacy's role in education, particularly in regards to student motivation. Once again,

Tollefson focused on Bandura's publications by framing learning around a social learning theory context.

Lee (2000) examined the use of Multi-User Dungeon (MUD) environments and used Bandura's social learning theory to identify MUDs as a rich and promising research environment to study an individual's self-efficacy. Lee addresses efficacy expectation and the predictability of human behavior. By creating online environments that address these areas, researchers could further study the three dimensions according to the generality of self-efficacy. According to Lee (2000), the first dimension refers to task specific self-efficacy (TSSE) and has been of great interest in many domains, including mathematics. Other fields have tried to study a more generalized self-efficacy (GSE), which appears to be a good indicator of success when a person encounters new situations. Finally, a middle-ranged self-efficacy is defined as those areas of efficacy not related to task or generality. This last topic of great interest to researchers considering issues involving career task self-efficacy (Lucas, Wanberg, & Zytowski, 1997), children's perceived self-efficacy (Bandura, 1997), and/or academic self-efficacy (Lent, Brown, & Larking, 1987).

Regarding the research centered on either TSSE or middle-ranged self-efficacy, a considerable effort addressed the increase of self-awareness in math and science, emphasizing guided instruction, engaging in real world applications, and conceptualizing subject material (Fouad, 1995; unknown, 2007; Cavanagh, 2006). This effort has fueled research in instructional strategies aimed at utilizing "learning styles" or "multiple intelligences" methods to ensure instruction meets the needs of the individual learner (Furner, et al., 2005; Rule & Lord, 2005; Bender, 2005). For example,

Furner et al. (2005) explored the use of such instructional methods within Exceptional Student Education and English Language Learners programs. These methods used strategies focused on the multimodal and linguistic, respectively, to a high degree of success. One limitation to this study, however, was that the research studied environments where the student population was not diverse in their preferred “style,” creating some concerns about the validity within the study.

Gomleksiz and Bulut (2007) provided mixed results in their study of a new primary mathematics curriculum in Turkey that addressed individual lessons from a multiple intelligences perspective. The data collected focused on many variables including class size, gender, and teaching experience. Though a statistical analysis suggested that varying instructional methods increased factors like student engagement and motivation, the overall effects on assessments were not significant.

As a noteworthy point, Gomleksiz and Bulut’s particular body of literature on assessment further supports the recent report published by the National Center on Education and the Economy (2007). In their ten step plan addressing necessary changes to the modern public educational system, step number four spoke about the need to develop "standards, assessments, and curriculum" that are reflective of the demands our children will face in their future. This report acknowledged the shortcomings of NCLB (Guisbond, 2007; Wolk, 2007) and suggested a renewed effort on improving the entire educational system from an administrative, instructional, and learner perspective. This report further acknowledged the many programs that have succeeded in finding educational solutions designed to meet the needs of the individual learner (Pogrow, 2006; Sanders, 2003), suggesting a positive aspect to a complex issue.

The emerging literature surrounding NCLB and its impacts upon children and schools suggests that the United States is at the threshold of educational change. This literature review could expand upon this by addressing several social, ethical, and governmental issues pertaining to poor student achievement. The need for this literature review, however, is simply to acknowledge that a learner's efficacy is a result of their experiences. Future researchers might consider addressing these experiences from the teacher-learner relationship, but it is the student's internal processing that is the target of this study. As his or her personal experiences increase, the learner forms a view regarding the material. From an instructional design perspective outlined by van Merriënboer and Ayres (2005), one should consider this innateness independent of the instructional designer.

Ayers (2006) recently refuted this claim in his study of thirteen-year-old students using a parts-task, a whole-task, or a mixed approach in learning a specific mathematics task. In this study, the conclusion was made that a parts-task approach was effective in lowering the cognitive load for the student, but only benefited learning for the novice learner. In contrast, those students with more prior knowledge scored higher when using the whole-task approach. This recent literature suggested that an emphasis be placed on prior knowledge in the instructional process, once again highlighting the critical components of memory within learning.

Another movement in the mathematics literature emphasizes the importance of improving students' self-regulatory strategies. Mooney, Ryan, Uhing, Reid and Epstein (2005) conducted a literature review and found that students with behavioral and emotional disorders were most successful when utilizing self-regulatory strategies. A

focus on strategy and motivation were suggestions to improving overall assessment performance.

Additional supporting evidence on promoting self-regulatory processes was highlighted by Schweinle, Meyer and Turner (2006). In their study, an examination of elementary students was structured using flow theory (Csikszentmihalyi, 1975) to describe the characteristics of highly motivated students. According to flow theory, the perception of an activity being rewarding to a learner relates to the attractiveness and challenge of that activity. A near optimal experience occurs when the learner feels challenged but also that his or her skills are both balanced and above average relative to the activity. To increase an individual's motivation toward a particular task, educators should provide challenging activities that engage the learner. Further indicators recommend that additional factors play a role in the student's motivation. Major findings in this study suggested that instruction should provide feedback and clarification of mathematics concepts, promote more autonomy within the activities, and emphasize metacognition.

Finally, a recent analysis of three case studies conducted by Butler, Beckingham, and Lauscher (2005) highlighted the self-regulation of below average eighth-grade students. This study discussed the implementation of a Strategic Content Learning (SCL) instructional model in order to meet the goals of building a conceptual understanding of the mathematics material in tandem with procedural skills in the same area. The success of this process relied heavily on the introduction and development of self-regulation strategies that expanded the metacognitive abilities of the learner.

Reteaching Strategies

"Reteaching" is a term with little supporting descriptive research. The connotation of the term suggests that the learner didn't adequately display a proficiency in the subject matter. Sullivan (1991) appeared to be the earliest researcher to use the term "reteaching" in a study of three college students who were struggling in understanding various literary works. A common theme within these three cases centered around the adaptations to outdated instructional procedures resulting in better comprehension of literary works such as *Pride and Prejudice*, *Wuthering Heights*, and the *Heart of Darkness* within a college classroom.

Haley (1996) resonated a similar theme in her reflections when teaching college students Huck Finn in an English class. In her opinion, activities that required students to make connections to more recent events worked best, allowing each student to place the readings into a more comfortable and familiar context. Thus, her assignments required students to make comparisons between the reading material and recent cultural events. Even though Haley's experiences depict the changes in instructional practice, they are not necessarily descriptive of those learners who simply did not understand the material.

This limited research on reteaching provided a basis to look more closely at the characteristics of those students who were struggling while learning mathematics. The National Council of Teachers of Mathematics (2007a, 2007b, 2007c, 2007d, 2007e) published several briefs identifying these characteristics, indicating a range of possibilities including student difficulties in accessing schema on specific arithmetic

facts, impulsivity, difficulties in forming mental representations of concepts, poor number sense, and holding information in working memory. Additional briefs by the NCTM (2007a) identified six different strategies with students in either special education programs or low-achieving groups. Table 2.1 shows that, for students participating in the special education program, the strategies of “think-aloud” and systematic, explicit instruction were found to be most effective (i.e., largest effect sizes). “Think-aloud” is a strategy where students are encouraged to verbalize their thought processes through writing, talking, or drawing each of the steps necessary to solve particular problem. Systematic and explicit instruction is where the teacher demonstrates a specific plan using a highly structured approach.

Table 2.1

Effect Sizes for Instructional Strategies Tested with Special Education and Low-Achieving Students

Instructional Strategy	Effect Size for Special Education Students	Effect Size for Low-Achieving Students
1. Visual and graphic depictions of problems	0.50	NA
2. Systematic and explicit instruction	1.19	0.58
3. Student think-alouds	0.98	NA
4. Use of structured peer-assisted learning activities involving heterogeneous ability groupings	0.42	0.62
5. Formative assessment data provided to teachers	0.32	0.51
6. Formative assessment data provided directly to students	0.33	0.57

Note: From "Effective Strategies for Teaching Students with Difficulties in Mathematics," 2007.

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The other four strategies tested within the special education student population included: visual and graphic depictions of problem; the use of structured peer- assisted learning activities involving similar ability groupings; formative assessment data provided to the teachers; and formative assessment data provided directly to students. Table 2.1 highlights the moderate to small gains in terms of the overall improvement of students' learning, suggesting that similar techniques might be effective with lower-ability learners and produce similar outcomes. This group implemented four of the six techniques finding similar moderate effect sizes with each. Furthermore, direct instruction and formative assessment data provided directly to students were very closely related, suggesting that combinations of these three might create a supportive environment focused on improving mathematical skills.

The Use of Computer/Web-Based Instructional Tools

There appears to be little research indicating the effect of EDU or other Web-based materials within an elementary educational setting. Healy (1998) professed with much skepticism that society should be cautious about setting children in front of computers under the guise that it will improve learning. Though the message of this text was intended to encourage parents and educators to consider student learning at face value and further motivate teacher preparation programs to address the needs of better technology integration, the intent was notably misinterpreted and resulted in the identification of fourth-grade as an appropriate age in which to introduce computers into the curriculum.

From an instructional perspective, results recently published by the National Center for Education Evaluation and Regional Assistance (Ferraro, D., Van de Kerckhove, W., 2007) further indicated that the use of reading and mathematics software with elementary students showed no significant improvement in assessment scores. As teachers and schools make strides towards improving performance through assessment, this data suggests only marginal improvements are to be found.

However, Trotter (2007) suggested one should use caution in the interpretation of this report. Class size, not technology, was one contributing factor related to performance that was not discussed in the report. The data actually showed first grade reading scores were statistically higher with smaller classes, whether or not technology was implemented. Fourth grade reading scores contradicted the report's conclusions and actually showed student improvement when using the technology. Trotter also highlighted another overlooked factor – the time students were actually working with the software. The information collected during teacher interviews indicated technology was used during the instructional time only ten percent of the time.

Additional efforts to counterbalance the negative messages regarding the use of technology in education have been underway for years. The National Educational Technology Standards, or NETS (Kelly, McAnear, & International Society for Technology in Education, 2002) is one such example. These widely adopted standards actually address Healy's (1998) intent of teacher preparation by outlining the technology skills necessary for each individual student, classroom educator, and administrator to support both "teaching and learning."

Tuttle (2007) did identify specific technologies being used at the elementary, middle, and high school levels to improve mathematics. The creation and use of online videos, interactive white boards (SMARTboards), and podcasts were just a few of the technologies mentioned, highlighting the impact that technology has had in learning communities where students and teachers have applied mathematical concepts to meaningful problems.

The utilization of EDU as a learning tool has received very little study, particularly in the areas of practice problems and feedback given to college students for preparation purposes. Narloch, Garbin, and Turnage (2006) did report positive assessment results along with student participation in lectures by those who had completed practice problems delivered through EDU prior to course lectures. Their findings suggested those students who utilized the EDU practice problems would frequently engage in critical discourse throughout the lecture suggesting the higher student participation was attributed to prior knowledge. This particular study was an extension of Garbin and Orr's (2002) earlier experiments where they explored Web-based tools utilizing three modified instructional strategies. Those included using EDU to provide additional supportive lecture materials, substituting lecture materials with online activities, and providing additional opportunities for remediation of incomplete learning. Though the first two experiments explored how a Web-based tool such as EDU can be used for direct instructor support, the third experiment supported a conclusion that Web-based practice materials can support struggling students.

With the exception of studies reported by software companies when promoting their products, refereed literature addressing the effect of computers and/or software on

K-12 student populations is rare. One example was a study conducted on a product called *Animation Tutor* (Reed, 2005). The study emphasized how teachers have supplemented their intermediate algebra instruction by utilizing this particular software. The documentation of teachers' experiences suggested that the use of the software improved students' learning. This conclusion, however, was extrapolated from perceived gains provided by the individual teachers and not through the direct results of student performance.