DYNAMICALLY ANNOTATED INSTRUCTIONAL DESIGNS: EFFECTS ON

UNDERPREPARED MATHEMATICS LEARNERS

by

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Abstract

The *mathematics problem* (Hourigan & O'Donoghue, 2007)—mathematical underpreparedness of nearly a third of first year students—affects many colleges in North America, Great Britain and Ireland. This quantitative study sought to determine whether dynamic or static annotations used in online mathematics instruction resulted in better learning outcomes. An adaptation of the NASA-TLX instrument was used to capture workload and performance data before and after an online mathematics learning activity. These data determined each learner's degree of mathematical preparedness and post learning performance, respectively. Workload and performance data were combined to calculate (a) instructional efficiency, (b) performance efficiency (van Gog & Paas, 2008) and (c) instructional conditions efficiency (Tuovinen & Paas, 2004). Analyses revealed strong evidence that static annotations (presented in a formal way and all-at-once), resulted in greater instructional efficiency and instructional conditions efficiency than dynamic annotations (presented informally and little-by-little). A pattern analysis of annotation use versus mathematical preparedness suggested that using static annotation use resulted chiefly in instrumental (rules without reason) understanding. This may have been facilitated by a *channelling effect*; procedural information provided visually in static annotations, supporting (problem solving) information via audio narration. Greater germane cognitive load was expended when dynamic annotations were used, suggesting opportunity for greater relational (deep) understanding. Poorer observed overall performance by dynamic annotation users may have been a consequence of the immediacy of performance testing after learning; reflection and other metacognitive processes take time and are essential to developing *relational* (deep) understanding

(Reason, 2003). Further research is needed to confirm the conjecture that dynamic

annotations result in greater relational understanding.

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CHAPTER 1. INTRODUCTION

For many vocations, acquiring competency in mathematics is an important part of workplace preparation (Clark, Nguyen, & Sweller, 2006; Watson, 2003). There is evidence that a large number of learners are underprepared in mathematical skills. Half of California's grade 11 students (15% sampling rate) scored below proficient (California Department of Education, 2008). In Arizona, results on a state-wide mathematics test, now a high school graduation requirement, are discouraging and reflect a (US) nation-wide pattern of mathematical underpreparedness (George, 2006). Such observations are not, however, constrained to North America. In the United Kingdom and Ireland, this has come to be known as the mathematics problem (Hourigan & O'Donoghue, 2007).

In Canada, many students attend community colleges to acquire vocational competencies while the more academically-inclined attend universities. A recent study confirmed that about a third of those enrolled in community college technology programs exhibit underpreparedness in mathematics (Schollen, et al., 2008). This put these learners at risk of not successfully completing their programs. McCabe (2003) observed that ―most academically deficient students do not lack talent. They lack preparation. Community colleges have the capability to develop these talents for the benefit of the students and our nation. We have no more important mission" (p. 7).

Background of the Study

Relational learning of mathematics requires students to think holistically and to solve authentic, non-routine workplace problems (Reason, 2003). Mitchell (2007), a community college mathematics teacher, uses a tablet computer connected to a projector in a technology-rich face-to-face classroom. He justifies using such technology, asserting that mathematics ―cannot be taught effectively in a static environment" (p. 2). PowerPoint presentations, pre-edited documents or static web pages, are largely inert. To demonstrate processes, themselves inherently dynamic, he annotates the subject matter, elaborating key teaching points in response to actual or anticipated learner questions (R. Mitchell, personal communication, January 26, 2009). Mitchell used tablet and stylus to overlay prepared notes with value-added annotations and elaborations. He then published the resulting annotated notes in Blackboard, sharing these static artifacts of lessons taught with his students. This approach resulted in greater learner success (Mitchell, 2007).

It is unclear, however, whether the improved learning Mitchell observed is attributable to factors other than his novel use of annotations and technology during mathematics instruction. For example, improved performance could be due to increased in-class learner engagement and listening because students no longer split attention between listening and note-taking. They, or other students lacking the willingness or ability to write meaningful, usable notes of their own, rely on teacher-provided notes as a proxy for their own. Alternatively, annotations may have served as mental cues, reminders of what transpired during the classroom lesson, aiding in learner recall. The observed improved learning may simply be attributable to the signaling effect; learning

outcomes improve when learners are given cues and other signals to help them focus on important aspects of the problem being solved (Mayer & Moreno, 2003).

Statement of the Problem

In a classroom filled with diverse learners, a broad range of skills and abilities is exhibited. Teachers struggling to cover the intended curriculum to meet workplace expectations divert scarce instructional time and resources to prerequisite skills. This is not a trivial concern; many teachers lament that the pressure on getting through subject-matter content is extreme. "They may teach for exposure – that is, students learn a little about many things … [rather than] emphasizing big ideas [which] helps students understand the discipline, develop higher-level thinking skills, and make connections among and between concepts" (Conderman & Bresnahan, 2008, p. 176).

Annotations added to learning materials may be used to directly support face-to-face instruction (Mitchell, 2007). Today's technologies may also be used to augment face-to-face instruction with online media-rich adjuncts. Multimedia annotations serve to help learners sense and select content, to focus attention on then-important teaching points (Ozcelik & Yildirim, 2005); organize their work; make sense of what they see and what they hear by collating and integrating new learning with prior knowledge, all essential to active learning (Mayer & Moreno, 2001); and learn with understanding (Bransford, Brown, & Cocking, 2000; Reason, 2003). What is unclear is whether annotations used to elaborate upon an important teaching point on solving a complex, real-world mathematical problem are more efficient (in terms of learning or performance) when applied all at once (as a static annotation) or little by little (as a dynamic annotation).

Theoretical Framework

Developing mathematical proficiency is about mastering non-routine processes and principles (far-transfer learning), not just about committing facts, concepts or routine procedures (near-transfer learning) to memory (Clark, 2008). Situated in a real-world context, perhaps a simulated workplace, the four-component instructional design (4C/ID) model, is intended to facilitate the learning of complex, workplace whole-tasks and is well-suited to vocational training (Bastiaens, van Merriënboer, & Hoogveld, 2002; van Merriënboer & Kirschner, 2007; van Merriënboer, Kirschner, & Kester, 2003), the forté of many community colleges. The 4C/ID model, underpinned by cognitive load theory, organizes whole-tasks into simple-to-complex sequences based on elaboration theory (Reigeluth, 1999); supported by just-in-time procedural information, faded as learners master procedural skills; part-task practice aimed at automating constituent skills; and, omnipresent supporting information (van Merriënboer & Kirschner, 2007).

Like the 4C/ID model, the cognitive theory of multimedia learning (Mayer, 2001) is also underpinned by the cognitive load theory. Built on previous work by Paivio (1986) and Baddeley (1992), Mayer's theory assumes that: (a) Learning occurs when learners actively process information; (b) learners simultaneously process visual and auditory inputs (dual channel learning); and, (c) working memory capacity is limited (Höffler & Leutner, 2007). When a learner's working memory capacity is overloaded, learning is impaired (Sweller, 1994).

Essentially a model of problem solving, the structured design for attitudinal instruction (Kamradt & Kamradt, 1999) integrates cognitive, affective and psycho-motor elements. Introducing affective concerns aligns with: (a) this study's definition of a

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competency; the knowledge, skills and attitudes required to successfully complete workplace tasks; and, (b) the stated intentions of the 4C/ID: to improve knowledge, skills and attitudes through whole-task authentic learning activities (van Merriënboer & Kirschner, 2007).

The body of literature on the cognitive load theory is growing and many effects, such as the signaling effect briefly mentioned earlier, have been demonstrated using experimental designs with random assignment. As analytical methods mature, there is a shift from performance testing and analyzing chiefly learning outcomes among alternative treatments, towards richer multi-dimensional analyses combining learning outcomes (test performance) and cognitive load (alternatively called workload or mental effort) in 2-dimensional and 3-dimensional ways, as summarized in Table 1.Tuovinen and Paas (2004) hint at future four (or higher) dimensional models.

Table 1. Analysis methods associated with cognitive load theory

Analysis Method	Independent Variables	Dependent Variables	Associated Metastudies
Cohen's d	presence of one or more instructional design features	test performance	Hoffler and Leutner (2007)
2-dimensional performance efficiency	presence of one or more instructional design features	1. mental effort during testing 2. test performance	Paas and van Merriënboer (1993)
2-dimensional instructional efficiency	presence of one or more instructional design features	1. mental effort during learning 2. test performance	van Gog and Paas (2008)
3-dimensional instructional conditions efficiency	presence of one or more instructional design features	1. mental effort during learning 2. mental effort during testing 3. test performance	Tuovinen and Paas (2004)

Building on prior studies investigating effects associated with the cognitive load theory, this study also investigated various cognitive load effects on underprepared learners. The focus of this study was not remedial instruction for the underprepared, rather investigating cognitive load effects on the underprepared in the context of a diverse group of learners, a mix of underprepared, novice, competent and expert learners. Many instructional designs targeted novice learners. It is important that both underprepared and expert learners have the opportunity to achieve according to their potential, consistent with the objectives of no child left behind.

Purpose of the Study

The purpose of this quantitative research was to determine the extent to which instructional and performance efficiencies improve when a diverse group of learners, including the underprepared, access dynamic multimedia annotations embedded in online materials to learn complex, real-world mathematical problem solving. This study tested the conjecture that instructional materials with embedded dynamic annotations result in greater instructional and performance efficiencies than instructional materials containing static annotations. Aimed at the mathematics problem, the target population comprised community college students enrolled in technology programs.

Well designed online learning materials may be used by distance learners or in a hybrid mode of delivery as supplements to face-to-face classroom learning. There may be a useful role for such online adjuncts to face-to-face learning targeted at a diverse group of learners, including the underprepared. Required is a balanced instructional design for online learning that aligns with a meaningful theoretical framework to (a) make the intended curriculum accessible to all learners, whether underprepared or not; (b) make

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selectable learning materials associated with prerequisite competencies available to learners who need or want them; and (c) publish online learning materials in a form optimizing the use of visual and auditory sensory pathways and learners' cognitive capabilities. This instructional design should support the sensing, selecting, organizing, collating and integrating elements of active learning.

Research Questions and Hypotheses

Efficiency constructs emerge from system theory and relate the outputs resulting from a value-added process to its inputs. Instructional efficiency incorporates mental effort measured during learning (instruction) to performance measured on a post-learning performance test. A similar construct, performance efficiency, relates the mental effort and performance, both measured during a post-learning performance test. A third construct, instructional conditions efficiency, combines instructional and performance efficiencies into a new construct, yet unproven, believed to be more conservative. In this study, instructional and performance efficiencies, and their aggregate, instructional conditions efficiency, were used to explore potential benefits of using dynamic multimedia annotations.

For a diverse group of learners, including the mathematically prepared and underprepared, the following research questions were investigated:

1. To what extent does 2-dimensional performance efficiency of the treatment group improve when using dynamic multimedia annotations, compared to using static multimedia annotations?

   Null Hypothesis: There is no statistically significant difference in 2-dimensional performance efficiency of the treatment group compared to the control group.

2. To what extent does 2-dimensional instructional efficiency of the treatment group improve when using dynamic multimedia annotations, compared to using static multimedia annotations?

   Null Hypothesis: There is no statistically significant difference in 2-dimensional instructional efficiency of the treatment group compared to the control group.

3. To what extent does 3-dimensional instructional condition efficiency of the treatment group improve when using dynamic multimedia annotations, compared to using static multimedia annotations?

   Null Hypothesis: There is no statistically significant difference in 3-dimensional instructional condition efficiency of the treatment group compared to the control group.

Significance of the Study

Heretofore, many cognitive load theory studies focused on instructional interventions resulting in observable effects with whole groups of learners without investigating effects on constituent sub-groups such as underprepared learners. In contrast, this study differentiated on the basis of underpreparedness in mathematics, within a diverse group of learners in a classroom environment. The degree of underpreparedness is indicated by the learner's performance on a mathematical preparedness test providing a post hoc basis for assigning participants into groups depending on degree of underpreparedness. The resulting two factor analysis of variance with replication—treatment vs. mathematical preparedness—may surface new effects somewhat akin to the expertise-reversal effect.

Many teachers use learning styles theories to inform teaching practices but are unaware of recent criticisms that ‒despite the popularity of the learning styles inventory, the design strategy, reliability and validity … were largely unsupported by the research evidence" (Alton-Lee, 2008, p. 256). This echoes British findings that ‒evidence for [learning] styles is highly variable, and for many the scientific evidence base is very slender … authors are not by any means always frank about the evidence for their work" (Hargrieves, et al., 2005, p. 11). Others are more direct and frank, stating that ‒learning styles are one type of unproductive instructional mythology pervasive in the training profession. At best, most learning style programs are a waste of resources, and at worst, they lead to instructional methods that actually retard learning" (Clark, et al., 2006, p. 248). Notwithstanding these assertions, it was not the intention of this study to disparage learning styles theories.

The effects emerging from the cognitive load theory are evidence-based and should, therefore, enjoy at least equal acceptance in the broader educational community. Most mathematics teachers easily recognize symptoms of cognitive overload: the blank stares, learners stuck and not knowing how to proceed. By viewing educational challenges like the mathematics problem through the lens of cognitive load theory it is hoped that useful new evidence-based best practices emerge, resulting in greater collaboration between communities of teachers (practitioners) and theorists (scholars). ―There is a substantial need for inquiry into the effectiveness and the efficiency of an instructional approach based on the 4C/ID-model (the whole-task approach), as opposed to a conventional instructional approach (the part-task approach), with learners' expertise level being considered" (Lim, 2006). A whole-task approach, however, fosters greater relational understanding necessary to learning with understanding vis-à-vis conventional practices leading, at best, to competent technicians (Reason, 2003).

In a recent meta-study, Tversky, Morrison and Bétrancourt (2002) reported that many instructional designers concluded that animations had no advantages over still pictures. Challenging this conclusion, Höffler and Leutner (2007) report that the ―effect of animations versus static pictures was not the main target of most studies" (p. 726). Their meta-study suggests a contrary view and offers evidence of at least a medium overall advantage (Cohen's d=0.37) of improved learning outcomes arising from the use of dynamic instructional materials vis-à-vis their static counterparts. This study provided further evidence regarding the use of dynamic versus static annotations.

There is strong evidence that 2-dimensional efficiency measures provide meaningful insights (van Gog & Paas, 2008). In contrast, the efficacy of a new, more conservative 3-dimensional efficiency measure (Tuovinen & Paas, 2004) has not been fully demonstrated. This study contributes to the literature in this area.

Many are familiar with the kind of visual annotations that an editor might use to mark-up a manuscript. Multimedia annotations may take on similar roles but need not be static or silent. Mitchell (2007) used annotations to highlight important aspects in the solution of mathematics problems. His annotations were informal and consisted, essentially, of electronic ink applied to an existing electronic presentation, with voice-over narration. The resulting marked-up documents were posted to the Blackboard learning management system for sharing with students after the lesson was concluded.

This study went beyond Mitchell's use of annotations in a face-to-face classroom, comparing similar static and dynamic annotations used in instructional designs for online learning. Finally, in contrast with many previous studies comparing learning outcomes resulting from static animations or dynamic animations, this study took care to overcome problems of comparability when investigating instructional and performance efficiencies associated with using static or dynamic annotations; ―In order to know if animation per se is facilitatory, animated graphics must be compared to informationally equivalent static graphics" (Tversky, et al., 2002, p. 251). This study compared results, expressed as efficiencies, arising from the use of informationally equivalent dynamic and static annotations. The study also investigated a second dimension, efficiencies of the mathematically underprepared vis-à-vis their more mathematically able peers.

Definition of Terms

2-dimensional efficiency. A statistic combining workload (cognitive load) and performance. See performance efficiency and instructional efficiency.

3-dimensional efficiency. A statistic combining workload (cognitive load) experienced during a learning episode; cognitive load experienced during performance testing; and, test performance.

4C/ID. Abbreviation of four-component instructional design; where the four components are: A simple-to-complex whole-task sequence; just-in-time procedural information; supporting information and part-task practice (van Merriënboer & Kirschner, 2007).

Affective dissonance. Affective dissonance is a ―a discrepancy between two beliefs, two actions, or between a belief and an action [and that] we will act to resolve [such] conflict and discrepancies" (Huitt, 2001, ¶ 12).

Apprehension Principle: ―The structure and content of the external representation should be readily and accurately perceived and comprehended. For example, since people represent angles and lengths in gross categories, finer distinctions in diagrams will not be accurately apprehended." (Tversky, et al., 2002, p. 258)

Competency. The knowledge, skills and attitudes required to ―solve daily problems; to keep learning throughout life; to be an ethically responsible person; and to respect and be able to work with others, as demanded by [a] globalized world" (Villanueva, 2008, pp. 1-2).

Complex performance task. A complex performance task organizes interactions among learning elements as a web or complex network and, therefore, may be quite difficult to decompose into smaller, largely independent sub-tasks.

Compound performance task. A compound performance task organizes interactions among learning elements hierarchically and, therefore, may be relatively straightforward to decompose into smaller, largely independent sub-tasks.

Congruence Principle. ―The structure and content of the external representation should correspond to the desired structure and content of the internal representation. …Routes are conceived of as a series of turns, an effective external visual representation of routes will be based on turns." (Tversky, et al., 2002, p. 257)

Efficiency. A construct relating output (performance) to input (cognitive load) (Tuovinen & Paas, 2004).

Element interactivity. An attribute of the learning materials, element interactivity is the extent to which learning elements are interrelated. Low element interactivity is exhibited by simple and compound problem spaces; both permit easy decomposition of learning tasks into subtask sequences or structured decision trees. High element interactivity is exhibited by complex learning whole-tasks where subordinate tasks are generally arranged into non-linear unstructured decision webs or networks.

Extraneous cognitive load. ―The load placed on working memory by the instructional design itself" (Ayres, 2006, p. 389).

Far-transfer learning. Far transfer learning is chiefly of non-routine processes and guiding principles (Clark, 2008).

Germane cognitive load. ―The load placed on working memory during schema formation and automation. It also varies but is considered a positive factor because working memory resources are directly involved in learning" (Ayres, 2006, p. 390).

Inductive learning. Beginning with a ―complex real-world problem to solve, … students attempt to … solve the problem, … [generating] a need for facts, rules, procedures, and guiding principles, … [which] are either presented with the needed information or helped to discover it for themselves" (Prince & Felder, 2006, pp. 123-124).

Instructional efficiency. Instructional efficiency is calculated using cognitive load experienced during a learning episode and test performance (van Gog & Paas, 2008) and is an example of a 2-dimensional efficiency statistic.

Instrumental learning. Instrumental learning results when learners apply ―rules without reasons" (Reason, 2003, p. 5).

Intrinsic cognitive load. ―The load placed on working memory by the intrinsic nature of the materials to be learnt" (Ayres, 2006, p. 389).

Learner usage. Is the learner a user, abuser or refuser (Wood, 2001) of the learning material provided?

Mal-rule. Short for malformed rule, a mal-rule is an incorrect or inappropriate rule ―systematically applied instead of the correct rule" (Self, 1990, p. 114) applied ―either intuitively or based upon their prior experiences" (van Merriënboer & Kirschner, 2007, p. 174). Examples are shown in Table 2.

Table 2. Examples and non-examples of mal-rules

Mal-rule	Rule
$x(4x+3) = 4x^2 + 3$	$x(4x+3) = x(4x) + x(3) = 4x^2 + 3x$
$2^8 = 16$	$2^8 = 256$
$\dfrac{1}{x} + \dfrac{1}{y} = \dfrac{1}{x+y}$	$\dfrac{1}{x} + \dfrac{1}{y} = \dfrac{y}{xy} + \dfrac{x}{xy} = \dfrac{x+y}{xy}$

Math anxiety. ―An irrational dread of mathematics that interferes with manipulating numbers and solving mathematical problems within a variety of everyday life and academic situations" (Furner & Berman, 2003, p. 170).

Metacognition. ―Thoughts about thoughts, knowledge about knowledge, or reflections about actions" (Weinert, 1987, p. 8). ―Metacognition is the awareness and understanding of one's own thought processes; in terms of mathematics education, the ability to apply, evaluate, justify, and adjust one's thinking strategies" (Ontario Ministry of Education, 2006a, p. 28)

Modality principle. ―Students learn better when the verbal information is presented auditorily as speech rather than visually as on-screen text both for concurrent and sequential presentations" (Moreno & Mayer, 1999, p. 6).

Near-transfer learning. Near transfer learning is chiefly of facts, concepts and routine procedures, mastered by some through rote learning (Clark, 2008).

Novice learner. (a) A learner who meets prerequisite conditions but is unfamiliar with the new learning. (b) Alternatively, novice learners may be ―satisfied with just scratching the surface, … don't attempt to examine a problem in depth, ... don't make connections or see the relevance of the material in their lives" (Halter, 2003, ¶ 4).

Online adjuncts. Learning materials delivered online as supplements to a face-to-face course. The result is a hybrid learning experience, a blend of face-to-face and online learning.

Performance efficiency. Performance efficiency is calculated using cognitive load experienced during performance testing and test performance (van Gog & Paas, 2008), an example of a 2-dimensional efficiency statistic.

Relational learning. Is ―knowing both what to do and why" (Reason, 2003, p. 5).

Satisfice. Satisfactory + suffice; from economics, a term used to describe a sufficient but suboptimal, or good enough outcome.

Simple performance task. A performance task comprising few interacting elements organized into simple sequences.

Underprepared learner. A learner that does not satisfy all pre-requisite knowledge, experience and metacognitive abilities; a learner considered pre-novice.

Assumptions and Limitations

⎯Neuroscience is *beginning* to provide evidence for many principles of learning that have emerged from laboratory research, and it is showing how learning changes the physical structure of the brain and, with it, the functional organization of the brain" (Bransford, et al., 2000, p. 4). Cognitive load theories (Mayer & Moreno, 2001; Sweller, 2004, 2010) are systems oriented, focus on input interventions and resulting outputs and do not directly investigate what goes on in the brain. It is assumed that (a) measuring task performance is a valid indicator of skill level and learning; and (b) that a learner's self-assessment of workload is a valid indicator of the cognitive load experienced by the learner. The target population for participants is community college students enrolled in technology programs. The subject matter of the online instructional materials for both the treatment and control groups is mathematics, specifically vector addition, a topic that is, for most participants, an unfamiliar, therefore, novel task. Though the results of this study have limited generalizability outside of community colleges and mathematics, nearly all participants are recent secondary school graduates and the results may be applicable to high school seniors as well.

Other assumptions relate to research participant abilities to use computers effectively; that they are able to: (a) access and use network-connected computer hardware; (b) effectively use conventional Windows-based desktop software; and, (c) access, navigate and effectively use the learning materials hosted on the Blackboard learning management system.

Nature of the Study

This study used a two-group experimental design with random assignment. A mathematical preparedness test provided data to calculate 2-dimensional performance efficiency scores for each participant. This construct was used to assign participants, post hoc, to groups based on mathematical preparedness for two-way analysis of variance with replication; treatment/control versus mathematical preparedness/unpreparedness. Both the treatment and control groups are provided learning activities with the same content and level of difficulty. Each complies with cognitive load theory and four-component instructional design principles (van Merriënboer & Kirschner, 2007). Only the annotations differ. The treatment group accesses learning materials with dynamic multimedia annotations, the control group static multimedia annotations.

Each participant reported on workload experienced during learning and again on a post-learning activity performance test contributing to 2-dimensional instructional efficiency and 2-dimensional performance efficiency, respectively. A newer (not yet proven) 3-dimensional efficiency construct, essentially combining these, was also calculated.

Independent variables were: (a) treatment, and (b) mathematical preparedness. Since preparedness in mathematics may be related to or interact with English language skill level, English language skill level was controlled. Potential moderating variables were: (a) participant level of competence in using the learning management system; and, (b) content of the treatment and control learning activities.

Analysis determined whether differences between treatment and control 2-dimensional instructional and performance efficiency, and 3-dimensional instructional

conditions efficiency, are statistically significant and whether greater benefits accrue to the mathematically underprepared than the prepared.

Organization of the Remainder of the Study

The literature review, Chapter 2 begins by exploring the problem domain before describing the interlocking theoretical frameworks underpinning this research: The cognitive theory of multimedia learning, cognitive load theory, and the 4-component instructional design model. The chapter concludes with a discussion of the nature and use of annotations particularly in relation to the problem domain.

Chapter 3 begins with a discussion of the conceptual framework of the study, and concludes with a description of the data collection instruments, a description of how the study was conducted, experimental design and analysis methods. Chapter 4 summarizes data collection and analysis outcomes; Chapter 5 the results, conclusions, and recommendations.

CHAPTER 2. LITERATURE REVIEW

This literature review explores the study's theoretical framework comprising the interlocking elements: (a) Mayer's cognitive theory of multimedia learning (Moreno & Mayer, 2002); (b) the 4C/ID model (Bastiaens, et al., 2002; van Merriënboer, et al., 2003) and associated ten steps design process (van Merriënboer & Kirschner, 2007); and, (c) Kamradt and Kamradt's structured design for attitudinal instruction though this is interpreted more as a problem solving model. Each supports holistic, relational learning (Reason, 2003) underpinned by the cognitive load theory (Brünken, Plass, & Leutner, 2003; Chipperfield, 2004; Cooper, 1998; Mayer & Moreno, 2003; Mousavi, Low, & Sweller, 1995; Paas, Renkl, & Sweller, 2003; Rikers, Gerven, & Schmidt, 2004; Sweller, 1994; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005).

Cognitive load theory is reviewed, including constituent intrinsic, extraneous and germane components of cognitive load; and some of the cognitive load effects observed in experimental studies. Complementary instructional design issues relate to teaching and learning mathematics; relational vs. instrumental learning (Reason, 2003); and TIPS principles and associated 3-part lesson plan promoted as current best practices (Ontario Ministry of Education, 2006a, 2006b). The chapter ends with a review of the nature and roles for annotations used in instructional designs.

Theoretical Framework

Underlying this study is the cognitive load theory. The theoretical framework incorporates: The 4C/ID model (Bastiaens, van Merriënboer, & Hoogveld, 2002), a modified form of Mayer's cognitive theory of multimedia learning (Moreno & Mayer,

2002) and the structured design for attitudinal instruction (viewed as a problem solving model) blending affective and psycho-motor concerns with the cognitive (Kamradt & Kamradt, 1999).

The Cognitive Load Theory

Cognitive load theory, supported by research, is founded on the assumption that working memory is limited to perhaps 7 ± 2 simultaneous elements (Mayer, 2001; Miller, 1956) and that ―working memory limitations profoundly influence the character of human information processing and, to a considerable extent, shape human cognitive architecture" (Kalyuga, Ayres, Chandler, & Sweller, 2003, p. 23). Total cognitive load (Figure 1) is the sum of germane, intrinsic and extraneous elements (Chipperfield, 2004).

$$CL_{total} = CL_{intrinsic} + CL_{germane} + CL_{extraneous}$$

Figure 1. Components of cognitive load.

―Mental effort is the aspect of cognitive load that refers to the cognitive capacity that is actually allocated to accommodate the demands imposed by the task; thus, it can be considered to reflect the actual cognitive load" (F. G. W. C. Paas, Tuovinen, Tabbers, & van Gerven, 2003, p. 64). For purposes of this study, the terms workload and mental effort both reflect the actual cognitive load.

―For learning to occur, there must be cognitive dissonance; it is alright for learners to struggle" (T. Brown, personal communication, March 24, 2009). This struggle takes place at the edge of what Vygotsky (as cited in Ogilvie, 2007) called the zone of proximal development; ―the distance between the actual development level as determined

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by independent problem solving and the level of potential development as determined through problem solving … in collaboration with more capable peers" (p. 162). Struggle is evidence that meaningful (germane) mental effort is expended. This cognitive dissonance, however, needs to occur in measured doses, so as not to incur an excessive mental load due to limited working memory (cognitive capacity).

Consider two learners who ―attain the same performance levels; one person needs to work laboriously through a very effortful process to arrive at the correct answers, whereas the other person reaches the same answers with a minimum of effort" (F. G. W. C. Paas, Tuovinen, et al., 2003, p. 65). The performance outcomes are the same, both get the correct result, but the first learner expends considerably more mental effort and, therefore, is less efficient than the second learner.

Stanford University's Edward Feigenbaum succinctly summarized the difference between novices and experts: What sets ―experts apart from beginners, are symbolic, inferential, and rooted in experiential knowledge. ... Experts build up a repertory of working rules of thumb, or ‗heuristics', that, combined with book knowledge, make them expert practitioners" (Dreyfus & Dreyfus, 2004, p. 4).

The progression from novice (via advanced beginner, competent, proficient) to expert is summarized in Table 3 (Dreyfus & Dreyfus, 2004; Kerber, 2004). Cardine (2008) provides a useful set of indicators at each level. Together with secondary mathematics achievement charts and exemplars (Ontario Ministry of Education, 2004, 2009), these are helpful when constructing rubrics used in the evaluation of mathematical performance.

Table 3. Novice to expert progression

Skill Level	Components	Perspective	Decision	Commitment
Novice	context-free	none	analytical	detached
				rule-based behaviour
Advanced Beginner	context-free and situational	none	analytical	detached
				incorporates some aspects of the problem
Competent	context-free and situational	chosen	analytical	detached understanding and deciding
				involved in outcome
Proficient	context-free and situational	experienced	analytical	involved understanding
		sees big picture		detached deciding
Expert	context-free and situational	experienced	intuitive	involved
				understands the situation and acts with conviction

A question arises whether the goal of instruction should be for all learners to achieve a target level of competency or whether a better goal might be to advance each learner in the intended direction (towards mastery) by a target amount. In the goal attainment model shown in Figure 2, the start line represents an expected set of prerequisite, entry-level expectations for a learning activity. The interval between the start- and the end-line represents the intended curriculum, ostensibly designed for novice learners.

Figure 2. Goal attainment.

The length (and direction) of each arrow represents the amount of learning. The tail and head of each arrow represent a learner's starting- and end-points, respectively. In the goal attainment model, each learner is expected to achieve the same level of learning. It is clear that many underprepared learners may not be able to achieve the learning goal without a supreme effort, extra time or other forms of accommodation. Competent

learners do not profit as much from the learning opportunity as novice learners while expert learners risk regressing to a standard below what they have already achieved.

The current educational paradigm is based on courses nearly always organized into academic years, semesters, quarters or courses of fixed duration. Consequently, much academic learning is constrained to goal attainment within a time box. This has implications for the underprepared and those with learning disabilities. Though they are often afforded accommodations such as extra time to write tests or to prepare assignments, this usually does not extend beyond the time-box, with the rare exception that a grade of incomplete may be awarded on a very short-term, temporary basis while missing requirements are fulfilled. The time box also disadvantages able learners who are at-risk due to factors such as employment responsibilities, health issues, family obligations, military or public service. Academic institutions generally do not embrace the full potential afforded by the anything, anywhere, anytime attributes of online learning. This reluctance, justified or not, has the unintended effect of filtering out members of the able but at-risk and the underprepared communities, discouraging them from even applying for admission to rigidly time-boxed courses or programs on offer.

In a performance improvement model (Figure 3), each learner advances by a comparable amount in the direction of greater ability in the subject matter. In effect, each learner has a personal learning goal, to advance in the desired direction by equivalent amounts. Neither competent nor expert learners are held back; all learners benefit from the learning in an equitable way.

Figure 3. Performance improvement.

Though not evident in face-to-face classrooms, the performance improvement approach is apparent in co-operative learning such as work placements or internships. Training employees in the workplace, whether via face-to-face, online or hybrid instructional modes, generally aims to improve performance rather than to seek certification or to achieve a particular exit standard.

Opportunities emerge for educational institutes to consider flexibly packaged instruction, with learners working at their own pace depending on abilities and circumstances:

> Students learn at different rates, yet the current industrial-age paradigm of education requires all students to learn the same thing at the same time and rate. This means that slow learners are forced on before mastering the content, and they accumulate learning deficits that make future learning more difficult, while fast learners are forced to wait and lose both motivation and the opportunity to learn more (Reigeluth & Carr-Chellman, 2009, p. 14).

Such a delivery model is, however, difficult to support as any professor supervising a protégé's dissertation or a teacher of learners with disabilities would attest. A broad implementation of such a model may be very expensive and less efficient than the factory model of education based on large groups of learners in classrooms organized into time box schedules.

The notion of teaching a course is turned upside-down, when learners take anything, anywhere, anytime—the hallmarks of online learning—requiring teachers to take on more flexible facilitator, advisor and mentor roles. When learners have the personal organizational and metacognitive abilities to succeed in online learning, the time box may be an unreasonable constraint; however, for the underprepared, those with cognitive or other impairments, or learners with limited time, resources or other obligations, continue to be disadvantaged.

Intrinsic Cognitive Load

Sweller initially regarded intrinsic cognitive load as a static attribute of the material to be learned (Clark, et al., 2006); the harder the material, the greater the intrinsic cognitive load. What makes learning material difficult is the requirement to process many elements in working storage simultaneously (F. G. W. C. Paas, Renkl, & Sweller, 2003), When interactivity among elements consists of straightforward and short linear sequences, the material is easily decomposed into smaller, easily-learned groups of elements that do not exceed the learner's cognitive capacity. Learning difficult materials with understanding requires simultaneous processing of many elements possibly organized into complex, changing webs or networks, thereby imposing a high intrinsic cognitive load. Sweller's early concept of intrinsic cognitive load did not depend on characteristics of the learner such as prior learning. This is problematic since learners with different prior learning experiences, given the same learning materials, would not assign the same level of difficulty to that subject-matter.

A consequence of learning is a transition from novice towards expert as new knowledge, skills and attitudes are integrated with existing schemas. Novices are at ―the initial stages of skill acquisition [whereas] high prior knowledge [is] evidenced by moderate-to-high domain expertise" (Reisslein, Atkinson, Seeling, & Reisslein, 2006, p. 93). During learning, students develop cognitive schemas encapsulating multiple interacting elements. The resulting cognitive schemas are themselves more powerful elements, each imparting less cognitive load than the sum of their parts; ―short-term memory is enhanced when people are able to chunk information into familiar patterns" (Bransford, et al., 2000, p. 33).

Consequently, van Merriënboer and Ayres (2005) redefine intrinsic cognitive load, making it dynamic and dependent also on the learner's level of expertise. A novice, working on a complex learning or performance task, struggles with many interacting elements. ―It follows that a large number of interacting elements for one person may be a single element for another more experienced person, who already has a schema that incorporates [these] elements" (p. 6). The intrinsic cognitive load, however, is reduced as a learner transitions from novice towards expert. This presents problems when designing learning materials for diverse groups of learners, with broad ranges of skills and experience, certainly exacerbated by large numbers of underprepared learners as described in the context of this study. This suggests that differentiated instruction or adaptive learning would be a better solution than a one-size-fits-all approach.

The segmentation effect advocates a strategy to manage intrinsic cognitive load by dividing learning experiences into what Mayer and Moreno (2003) call bite-size segments. This allows time between successive segments for learners to dwell on particularly challenging tasks, to build schemas, reflect, collate and integrate new learning with prior knowledge. According to Mayer and Moreno (2003), better learning transfer occurs with instruction partitioned into ―learner-controlled segments rather than as continuous unit" (p. 46); learner control of pacing of instructor-defined instructional segments.

However, van Merriënboer and Sweller (2005) warn that, for complex subject-matter, an instructional intervention that reduces the intrinsic cognitive load by segmenting the subject-matter into smaller chunks also reduces whole-task understanding and ―for learners to fully understand the material [associated with complex subject-

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matter] they must ultimately be presented with the materials in their full complexity, with all element interactivity that is typical of the domain" (p. 157). This suggests that necessary segmentation be undertaken on the basis of elaboration. A simple version of a whole-task problem may be considered initially. As the learner demonstrates mastery of the original abstracted whole-task problem, details of the full whole-task problem may be re-introduced gradually resulting in a simple-to-complex whole-task sequence (van Merriënboer & Kirschner, 2007).

Extraneous Cognitive Load

According to van Merriënboer and Ayres (2005), extraneous cognitive load is associated with processes that are not directly necessary for learning and can be altered by instructional interventions" (p. 6). Much of the literature on cognitive load theory is concerned with minimizing extraneous cognitive load and developing plausible explanations of the many observed effects. It may be hasty, however, to strip out all sources of extraneous cognitive load.

Learners may not be motivated to use learning materials perceived as bland, unappealing or uninteresting, nor would such learning materials foster persistent learner engagement. Astleitner and Wiesner (2004) identify a weakness in cognitive load theory, suggesting a role for extraneous motivational content. If greater engagement in learning results, then the introduction of extraneous motivational content or attention-grabbing presentation techniques is justified—subject to the constraint that the learner's limited cognitive capacity is not exceeded. Intrinsically interesting real-world whole-tasks or learning situated in the context of a modern workplace may, for example, be very motivating for learners engaged in vocational studies. In a sense, extraneous cognitive

load of a motivational nature could act as catalyst by fostering engagement and active involvement of the learner in the learning process.

Germane Cognitive Load

Germane cognitive load is ―associated with the processes that are directly relevant to learning, such as schema construction and automation" (van Merriënboer & Ayres, 2005, p. 7), in other words, the learning process itself. Instructional designs ought to challenge and motivate learners to expend germane cognitive load (Clark, et al., 2006), otherwise cognitive capacity created by a general strategy to decrease unnecessary extraneous cognitive load is not meaningfully exploited. An increase in germane cognitive load, evidenced by purposeful struggle, is essential for learning and may be used as an indicator of learning.

Cognitive Effects

Many of the effects associated with cognitive load theory are ―used to recommend instructional designs only applicable to novices" (F. G. W. C. Paas, Renkl, et al., 2003, p. 3). A consequence of this observation is the expertise reversal effect, occurring when a successful instructional design for novices increasingly becomes dysfunctional as learners acquire knowledge and experience during the novice to expert transition (Kalyuga, et al., 2003; van Merriënboer & Sweller, 2005). For example, van Merriënboer and Kirschner (2007) describe a strategy where learners begin by studying worked-out problems which are quickly faded to completion problems, then to full problem solving.

This strategy works well for a novice learner but is ineffective for expert learners who learn more through full problem solving eschewing the scaffolding provided for

novices. It is unclear, however, whether an instructional design targeting novices (having met prerequisite competencies) would benefit or hinder pre-novices (underprepared learners who have not met prerequisite expectations.) Some among the underprepared may find learning materials targeting the novice far too hard, eschewing their use, effectively giving up or quitting, thereby putting themselves at risk of not completing their studies successfully.

Other learners may refuse to use learning materials perceived redundant or already learned (Wood, 2001). This is a problem particularly for underprepared learners who, through flawed prior learning, integrated mal-rules into their networks of schemas, then falsely but confidently continue to apply their mal-rules resulting in faulty outcomes (Self, 1990; van Merriënboer & Kirschner, 2007). To defeat this faux expertise reversal effect, attitudinal barriers must be overcome to motivate such learners to use the learning materials and, through engagement, to identify and correct mal-rules. This further supports the assertion that cognitive load models be extended to include affective considerations like motivation and perseverence (Astleitner & Wiesner, 2004).

Learners may flit from one page-view of an online learning management system to another, expending minimal germane cognitive load at each stop. Nicknamed the butterfly defect, this behavior distorts the learner's perception of what knowledge consists of; coming to believe that ‒knowledge is a hypermedia-like structure … [preferring] to learn from sources that present fields of knowledge in a hypermedia structure, … sidestepping the acquisition of the logical, hierarchically structured connections and links that constitute science, as we know it" (Okan, 2003, p. 261). Such a view promotes a more atomistic view of the structure of knowledge, distorting or

obfuscating the big picture perspective so critical to solving the complex, real-world whole-task problems at the heart of vocational learning.

The coherence principle is demonstrated when learning outcomes are improved (effect sizes 0.59 to 1.17) when focusing instruction on essentials; excluding the words, sounds and video clips that are perceived as extraneous (Mayer, 2003; Mayer & Moreno, 2002). This speaks to what Astleitner and Wiesner (2004) call ―interference coming from one source [which disturbs] the semantic processing of information from other sources" (p. 9). Contrary to iPod users who, under the guise of multitasking, claim to work better listening to music, Moreno and Mayer (2000) found that extraneous background music or sounds, when added to instructional materials, increased extraneous cognitive load. Such ―auditory adjuncts can overload the learner's auditory working memory, as predicted by a cognitive theory of multimedia learning" (p. 117). Okan (2003) cautions that instructional designs should ―be well grounded in constructivist learning theory.… [Online instruction should act] as cognitive tools to engage students in learning, rather than to play with the software" (p. 261). A consequence of seductive multimedia used to foster learner engagement is diversion of limited cognitive resources from the germane towards the extraneous, crossing the line from education to edutainment.

Where the coherence principle focuses on restricting content of online learning materials to essential content, the personalization effect focuses on delivery; a more conversational, less formal, instructional style results in better learning outcomes and more creative solutions (effect sizes 0.96 to 1.60) (Mayer, 2003). This could be explained by a reduction in power distance between instructor and learner (Hofstede, 1980, 2004), a concept described later in this literature review.

The spatial contiguity effect suggests placing printed words nearby the graphics they are intended to describe. This reduces the ―need for visual scanning. … When printed words are placed near corresponding parts of graphics [more effective learning transfer results]" (Mayer & Moreno, 2003, p. 46). Notwithstanding the spatial contiguity effect, an instructional design using textual descriptions and elaborations alongside a diagram may still incur a very high cognitive load. The split-attention effect occurs when a learner's attention is divided between diagram and text overloading the brain's visual processor (van Merriënboer & Sweller, 2005).

The modality effect (Moreno & Mayer, 1999) addresses this issue, replacing text with audio narration thereby simultaneously sharing the workload between the visual and auditory sensory pathways. Properly balanced across dual channels, neither the sensory pathways nor the visual or auditory processors are overloaded; a fundamental thesis underpinning Mayer's cognitive theory of multimedia learning. The temporal contiguity effect is a reminder to synchronize the auditory and visual parts of a presentation ―to minimize [the] need to hold representations in memory. … Better [learning] transfer [results] when corresponding animation and narration are presented simultaneously rather than successively" (Mayer & Moreno, 2003, p. 46).

Aiming to accommodate different learning styles, instructional designs presenting essentially the same message using animation, audio narration and on-screen text result in a ―psychological redundancy that overloads working memory and depresses learning" (Clark, et al., 2006, p. 248). A corollary of the redundancy effect is that the each message, whether auditory or visual, should itself add value thereby avoiding unnecessary redundancy.

Reason's assertion of ―language as a pathway [to learning]" (2003, p. 5) is

consistent with the pre-training effect where, with ―pretraining in names and

characteristics of components, … better transfer [results] when students know names and

behaviors of system components" (Mayer & Moreno, 2003, p. 46). This also justifies

part-task practice, an element of the four component instructional design model (van

Merriënboer & Kirschner, 2007), focused on mastering constituent skills of whole-task

learning targets. Pretraining is also applicable not only to the subject-matter but also to

the deployment tools. For example, a learner must know the names and behaviors of the

components of the learning management system and how to operate and navigate within

the learning management system. Otherwise, a learner may incur a high level of cognitive

load imposed, not by the subject-matter but by the technologies used to impart the

learning materials. To reduce this extraneous cognitive load, learners should be oriented

to practices fostering effective use of the learning management system, its chief

components, structure, navigation and common learner work practices. This focuses

learners on content rather than on the nuances of the learning management system.

According to the signaling effect, extraneous cognitive load is reduced and

learning outcomes are improved when cues or annotations are used to focus a learner's

attention on what is currently important (Mayer & Moreno, 2003, p. 46). This is a rather

micro-level view and it is reasonable to consider the macro-level as well. For example, a

domain map, mind map, or other similar structure or tool may serve as a roadmap

signaling where the learner is currently situated within an overall schema representing a

whole-task problem or subject-matter domain. Network diagrams or graphs signal

connections among interacting elements or the degree to which the learner has completed

the whole-task problem, adding value as a knowledge construction tool as learners gleam the structure of the domain and how new learning fits into the schema. Much can be learned from object-oriented analysis and design and the features of unified modeling language (UML) which easily models many knowledge constructs and the relationships among them in consistent sets of class, class hierarchy, object, use case, sequence, collaboration, state, activity, component, and deployment charts (Hadjerrouit, 2007; Object Management Group, 2009).

According to the goal-free effect, a learner experiences a lower level of cognitive load when goal-free problems are posed vis-à-vis their goal-specific counterparts (van Merriënboer & Sweller, 2005). In the example shown in Table 4, greater goal specificity results in a higher level of cognitive load because multiple goals are specified in an order different from the required problem solving sequence.

Table 4. Comparison of goal specific and goal-free problems

High goal specificity	Low goal specificity
If a = b + 17 and b = 4c and c = 5×3-11, then what are the values of a, b and c?	If a = b + 17 and b = 4c and c = 5×3-11, then solve what you can.

Though it requires the same problem solving approach, the goal-free example does not overwhelm the learner with three goals and an implied problem-solving sequence. Instead, the learner focuses on identifying and solving whatever is initially possible, finding the value of c. Once c is found, b can be solved, and so on. The goal-free problem results in a higher level of learning with understanding; as learners

themselves prioritize and identify sub-goals and problem-solving strategies germane to the process.

The worked example effect and completion problem effect (van Merriënboer & Sweller, 2005) are related concepts. A worked-out example, as the name implies, is a problem shown with its detailed solution and serves as an exemplar for unsolved problems that may be presented alongside. According to the worked example effect, learners who study worked-out examples improve their understanding of such problems. During a learning sequence, whole-task study scaffolding should be faded to partly-solved problems requiring completion of remaining steps. In turn, these completion problems are gradually faded to full problem solving tasks as the learner develops the skills and confidence to work with greater independence.

The Cognitive Theory of Multimedia Learning

Building on the work of Paivio (1986) and Baddeley (1992), Mayer's cognitive theory of multimedia learning assumes that: (a) learners simultaneously process visual and auditory inputs (dual channel learning); (b) working memory capacity is limited (Sweller, 1994); and (c) visual and auditory inputs may be processed simultaneously (Mayer & Moreno, 2003). An adaptation of Mayer's model discriminates between collating the verbal and pictorial models in working memory, essentially a sense-making process, from subsequent integration of new knowledge with prior knowledge. The distinction is akin to the information technology the difference between unit testing (of a single process or component) and regression testing (confirming whether a new process or component fits in and does not have adverse effects on existing processes).

According to Mayer (2001), ―humans engage in active learning by attending to [sensing and selecting] relevant incoming information, organizing selected information into coherent models and integrating mental representations with other knowledge" (p. 44) resulting in the sequence: Sensing, selecting, organizing, then integrating. Referring to the auditory and visual sensory models, Sweller (Wallen, Plass, & Brünken, 2005) describes a need for sense-making, collating the ―visual and verbal mental representations by establishing connections between the two systems" (p. 61). Though not explicitly incorporated into Mayer's original model, Mayer and Moreno agree, confirming that collating (which they call integrating) ―occurs when the learner builds connections between corresponding events (or states or parts) in the verbally-based model and the visually-based model" (Mayer & Moreno, 2001, p. 2). In short, there appear to be two levels of integration: (a) collating of visual and auditory inputs into coherent representations in short-term memory and (b) integrating these mental models with prior knowledge. The consequence of making these distinctions explicit is an added step in the model of active learning: sense, select, organize, *collate*, and integrate. Summarizing, collating is associated with construction of new knowledge, integrating with connecting new to existing knowledge.

Motivation

Astleitner and Wiesner (2004) criticize Mayer's model: ―This multimedia learning theory does not consider motivational aspects … a non-cognitive quality" (p. 11), a criticism that applies to the cognitive load theory as well. They consider motivational elements ―important, because (a) motivation is influencing learning significantly; (b) motivational processes need memory resources and therefore increase or

decrease cognitive load; and (c) there is a more or less direct connection between cognitive and motivational variables, especially attention" (p. 11). Astleitner and Wiesner conclude that an instructional intervention ―which integrates cognitive and motivational aspects of memory usage and learning" (p. 11) leads to improved learning outcomes. Instructional interventions, however, ―will only be effective if people are motivated and actually invest mental effort in them" (F. G. W. C. Paas, Tuovinen, et al., 2003, p. 65). Ogilvie (2007) elaborates: ―People who relish new challenges that broaden their knowledge become ‗experts,‘ to be contrasted with others who become experienced non-experts" (p. 163).

One approach to managing motivation and extraneous cognitive load is to prefix instruction with motivational *minds-on* content (Ontario Ministry of Education, 2006a). Unlike seductive text or images that invoke emotional interest (Mayer, 2001), minds-on activities are cognitively interesting, serving to stimulate recollection of related prior knowledge. Merrill (2009) writes: ―Learning is promoted when learners activate relevant cognitive structures by … [recalling] prior knowledge or experience…. Learning from activation is enhanced when learners share previous experiences ... [and] recall or acquire a structure for organizing the new knowledge" (p. 51). Learners are (a) conditioned to be receptive to upcoming instructional activity by activating prior learning and (b) more persistent, motivated to successfully complete mathematics learning requirements while (c) minimizing extraneous cognitive load within actual *action!* instructional tasks. Following instruction, *consolidate/debrief* focuses on collating and integrating what was learned (Ontario Ministry of Education, 2006a), consistent with the tenets of constructivism.

Integrating Affective and Psychomotor with Cognitive Perspectives

The structured design for attitudinal instruction (Kamradt & Kamradt, 1999; Romiszowski, 1999) was adapted and repurposed as a problem solving model to enrich this study's theoretical framework with affective and psychomotor perspectives. The entry point to this model is recognizing that an unresolved need state exists; a problem that requires a solution. If motivated to do so, and if the learner-as-problem-solver perceives that a problem exists, relevant facts, concepts, (routine) procedures, (non-routine) processes and principles relevant to the problem are recalled. Problem solving strategies are identified and prioritized, and a plan of action is formulated. Action is taken to solve the problem. Informed by the values and beliefs of the problem-solver, an assessment is made about whether and to what extent the problem is solved; some aspire to excellence whilst others use a *satisficing* strategy—accepting a suboptimal but good enough outcome. If the problem is solved, a resolved need state results; otherwise the cycle may be repeated (if the problem-solver is motivated and perseveres), recalling other combinations of facts, concepts, procedures, processes and principles leading, in turn, to alternate problem solving strategies and subsequent attempts at solving the problem. Iterations continue until either the learner solves the problem to their satisfaction or gives up.

This short summary surfaces the importance of: (a) the learner's (problem solver's) motivation or predisposition toward action—the learner must want to solve the problem; (b) learner beliefs and values as a determinant of behaviors that are reward-seeking or escaping unpleasant consequences aligned with teacher-set standards (as proxy for societal expectations); (c) learner perseverance, strongly linked to maintaining a high

level of optimism and continued enthusiasm, evidenced by a learner taking ownership of the problem, persisting in solution efforts until a satisfactory solution is found (Huitt, 2001); and (d) whether the learner is predisposed (genuinely motivated) to become expert or is content to be an experienced non-expert—in a college classroom, those who strive for A grades versus those who are satisfied with a minimum passing grade, respectively.

The Four-Component Instructional Design

Learning of complex subject matter involves many interacting elements that must be processed simultaneously for full, rich learning to take place. Due to the constraints imposed by limited working storage capacity, a very high intrinsic cognitive load attaches to learning of complex subject-matter. To manage intrinsic cognitive load, a holistic analysis of the complex subject matter may be undertaken to classify which of the constituent elements are core and which might be deferred. Through prioritization and abstraction, elements essential to understanding the whole-task are identified yielding an initial simplified version of the whole-task. Consistent with elaboration theory (Reigeluth, 1999), the initial representation of the whole-task is elaborated as heretofore deferred elements are re-introduced at a pace matching the rate of learning. The resulting sequence of simple-to-complex whole-tasks scaffolds learning of complex tasks: ―Novice learners start to practice on the simplest version of the whole task encountered by experts in the real world and progress toward increasingly more complex versions" (van Merriënboer, Kirschner, & Kester, 2003, p. 6). This process is an example of inductive learning which ―helps students see the connections among pieces of critical information and to conceptualize, on their own terms, the broader perspective into which these pieces fit" (Silver Strong and Associates, 2005, ¶ 1).

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The 4C/ID model (van Merriënboer & Kirschner, 2007) supports complex learning; described as ─the integration of knowledge, skills, and attitudes; the coordination of qualitatively different constituent skills; and the transfer of what is learned to daily life or work settings" (van Merriënboer, et al., 2003, p. 5). Various forms of scaffolding are integrated into this model which is supported by a ten-step instructional design process (van Merriënboer & Kirschner, 2007). The 4C/ID model is especially well suited to vocational training (van Merriënboer & Kirschner, 2007), including the kinds of instructions that are the forté of many community colleges.

A chief construct of the 4C/ID model is the task. Task variability assures that each task contributes something new to the understanding of the big picture enabling the learner to solve different variants of a whole-task, rather than, in mathematics, solving the same problem type over and over again with different numbers, thereby fatiguing the learner.

─Integrated into pedagogical practice, scaffolding is intended to motivate the learner, reduce task complexity, provide structure and reduce learner frustration. … [Scaffolding] engages the learner actively at his/her current level of understanding until … support is no longer required" (McLoughlin & Marshall, 2000, ¶ 8). A key feature of scaffolding is that it is temporary. As learning occurs, scaffolding is withdrawn; fading at an optimal rate to enable learners to apply what is learned with greater autonomy.

Learner progress through a simple-to-complex task sequence is accompanied by a simultaneous reduction in scaffolding. According to van Merriënboer and Kirschner (2007) a useful form of scaffolding within a task class is the completion strategy which ─has been found to have positive effects on inductive learning and transfer" (p. 280) by

decreasing ̶extraneous cognitive load for novice learners … [who] start to work on worked-out examples, then complete increasingly larger parts of incomplete [problems], and finally work on conventional tasks" (van Merriënboer, et al., 2003, p. 6).

The 4C/ID model supports learning by providing supporting information, procedural information, and part-task practice. Supporting information is always available and assists the learner on (a) problem solving strategies such as identifying the initial state (starting point and important givens) and the goal state (including expectations vis-à-vis standards); (b) strategies on how to proceed from the initial to the goal state; and (c) other subject-matter-related knowledge common to all members of the task class. Procedural information is available on a just-in-time basis and focuses on the recurring, routine procedures and algorithms associated with the whole-task. Part-task practice is aimed at constituent tasks that are best automated; specific repetitive, routine skills and knowledge that the learner should be able to easily perform automatically, with a very small cognitive load.

Efficiency

In the context of cognitive load theory, higher efficiency is exhibited when ̶performance [output] is higher than might be expected on the basis of their invested mental effort [input]" (F. G. W. C. Paas & van Merriënboer, 1993, p. 238). In the sciences, efficiency is usually expressed as a ratio of output to input.

One such ratio, cognitive efficiency, Figure 4 was used in a recent study to measure the level of expertise of a learner (van Merriënboer & Sweller, 2005). When $E > E_{cr}$, where E_{cr} is a chosen critical level, cognitive efficiency is high, thereby demonstrating expertise.

$$E = \frac{P}{R}$$

Figure 4. Cognitive efficiency (E) as a function of mental effort rating (R) and performance (P).

Ratios are problematic when zeros or near-zeros occur, particularly in the denominator resulting in undefined or exaggerated outcomes. Pass and van Merriënboer derived and calculated an alternative statistic, the efficiency of instructional conditions; —an indication of the quality of learning outcomes" (van Gog & Paas, 2008, p. 16). The relationship between mental effort experienced during testing (E_T) and test performance (P), both expressed as standardized z statistics.

In a Cartesian coordinate system, 2D efficiency is the distance from the point (E_T, P) to the line $P = E$ as shown in Figure 5. Clearly, outcomes in quadrants III and IV are undesirable, both indicating low performance. Outcomes in quadrants I and II indicate high performance. Above the $P = E$ line, efficiency is reported as a positive value since performance exceeds cognitive load; below the line it has a negative value. This construct indicates the amount by which standardized performance exceeds cognitive load.

Figure 5. Test performance vs. mental effort.

In Figure 6, this construct is named 2D Performance Efficiency since it could be used to summarize performance and its associated mental effort.

$$2D\ Performance\ Efficiency = \frac{P - E_T}{\sqrt{2}}$$

where:

E_T = Test Effort
P = Performance

Figure 6. 3D performance efficiency.

In contrast, instructional efficiency (Figure 7), specifically incorporates "mental effort invested in the learning [instructional] phase instead of the [performance] test phase" (van Gog & Paas, 2008, p. 16) though performance continues to be measured on a post-learning test.

$$2D\ Instructional\ Efficiency = \frac{P - E_L}{\sqrt{2}}$$

where:

E_L = Learning Effort
P = Performance

Figure 7. 2D instructional efficiency.

Many cognitive load studies used 2-dimensional efficiency, twenty of which are summarized by van Gog and Paas (2008). Tuovinen and Paas integrate instructional and performance efficiencies into 3-dimensional efficiency shown in Figure 8. The derivation of this construct (Tuovinen & Paas, 2004) is the 3-dimensional equivalent of 2-dimensional efficiency developed by Paas and van Merriënboer (1993).

$$3D\ Efficiency = \frac{P - E_L - E_T}{\sqrt{3}}$$

where:
E_L = Learning Effort
E_T = Test Effort
P = Performance

Figure 8. 3D efficiency.

In a graphical representation of 3D efficiency, the octant where performance is high, and both test and learning effort are low, represents high efficiency. In contrast, the octant where performance is low and test and learning effort are high represents low efficiency. Early indications are that this statistic is more conservative than either of the 2-dimensional statistics alone. The efficacy of this statistic has yet to be fully demonstrated, however, "the 3-D approach … holds the promise of supplying more useful information about the value of instructional conditions than either of the previous [2-dimensional] measures alone" (Tuovinen & Paas, 2004, p. 149).

Annotations

The cognitive load theory and the cognitive theory of multimedia learning both remind instructional designers that working storage is limited, so the use of annotations must (a) not result in cognitive overload and (b) add value. Though the former seems obvious, the latter invites instructional designers to consider value-added roles for annotations applied to a multimedia-based learning experience.

When designing multimedia instructional materials, visual inputs may be textual, static imagery or dynamic imagery. Auditory inputs may be in the form of narration or non-verbal sounds. According to Weiss, Knowlton and Morrison (2002), Pavio's dual coding theory, ―text and graphics are encoded in two different cognitive subsystems, [which] seems to suggest that whether the graphics are static or animated is irrelevant. Thus, to some extent, theories of using graphics will apply to both animated and static graphics" (p. 466) including multimedia static or dynamic annotations. Notwithstanding a meta-analysis by Höffler and Leutner (2007) revealing a ―medium-sized overall advantage of dynamic over static visualizations" (Plass, Homer, & Hayward, 2009, p. 23), Tversky, Morrison and Bétrancourt (2002) caution that many studies claiming to investigate whether animations facilitate learning are inconclusive because ―animated graphics must be compared to informationally equivalent static graphics. … Lack of comparability of static and animated diagrams obviates conclusions about the benefits of animations in other studies" (pp. 251-252). In many such studies it is not clear whether animation or interactivity results in improved learning and performance.

Weiss et al. (2002) suggest how animations (including dynamic annotations) may be classified by: (a) purpose, is the role of the animation cosmetic, attention-getting,

motivation, presentation, or clarification? (b) physical attributes, surface structure, color and physical fidelity of animation, ―how closely the animation resembles the real world" (p. 469).; (c) functional fidelity reflecting ―how closely the animation behaves like the real world object" (p. 469); and, (d) nature of the subject matter, specifically, ―facts, concepts, principles or rules, procedures, interpersonal skills, and attitudes" (p. 742), similar to the classification scheme used by Clark (2008), facts, concepts, procedures, processes, and principles. Finally, ―for animation to be useful in the teaching of a concept, the concept should be relatively complex. That is, it should involve systems impacted by simultaneous influences, changes over time, or systems not visible to the naked eye" (Weiss, et al., 2002, p. 473).

Cosmetic annotations may play a motivational role, adding extraneous cognitive load to actual learning activities. Attention-getting annotations direct learner focus to what is currently important thereby aiding in clarifying procedures, adding an important time dimension to complex problem solving processes (Weiss, et al., 2002). Simple stylus and tablet annotations, accompanied by audio cues, are examples of low physical fidelity animations and may be used to guiding a learner's problem solving process, defining a path from problem to solution (trajectory). Whether the demonstrated problem solving process should be high or low functional fidelity depends on learners' prior learning and familiarity with the subject matter. There are clarification and presentation roles for annotations to facilitate learning of procedures (routine, repetitive, standardized and non-contextualized) and for enhancing learners' problem solving processes (non-routine, novel, highly variable and contextualized). Learning goals may be oriented towards automating the learning of near-transfer procedures whist applying sensible problem

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solving far-transfer processes in new an unfamiliar contexts. ―The more complex a concept, the greater is the potential for animation to function in a clarification role … if the content is too difficult to describe verbally, then animation can sometimes be used effectively" (Weiss, et al., 2002, p. 472).

Annotations may grab attention, helping learners sense what is currently important. Static annotations; such as bold face, italic, larger, colored or different fonts, underlining or encircling (Clark, et al., 2006) or white space surrounding an object; all passively catch a learner's attention. When many static annotations are present, they compete with each other for attention, increasing the extraneous cognitive load and defeating their intended purpose.

Presented dynamically, annotations may be applied (or removed) in real time using electronic ink (and electronic erasers) to encircle, underline or highlight. As learning focus shifts from one to another, annotations are added, deleted or modified. Gestures, like moving a mouse pointer, clicking buttons on virtual calculators or keyboards, help learners sense and select learning elements as the focus shifts from one teaching point to another. Sensing and selection annotations facilitate identifying and extracting salient information from what is given, parsing a problem statement, identifying and understanding the context or (mathematical) frames of reference applicable to far-transfer tasks.

Annotations may help learners organize their thoughts, helping them organize, strategize and plan using the Frayer model for concept development (Conderman & Bresnahan, 2008; Nessel & Graham, 2007a; Ontario Association for Mathematics Education, 2004), mind-maps (concept maps); pro-con T-charts, Venn diagrams (Nessel

& Graham, 2007b); cause and effect diagrams, or timelines. Furthermore, annotations may play an important part in learner persistence, providing supporting or procedural information when and as learners need them, thereby maintaining momentum. As an alternative to static presentations of worked-out problems, solutions to problems may be demonstrated dynamically and may be replayed for the benefit of struggling or ESL (English as a second language) learners. According to Moreno (2007), when learners observe the practices of experts, they are more likely to construct knowledge (bridging theory and practice) and to transfer what was learned to their own practice. Paradoxically, Moreno's study indicated that learners using animations that portray the practices of experts in online learning materials performed better in practice but retained less of the theory underlying that practice. Finally, Moreno concluded that signaling (combined with segmenting complex processes into smaller chunks) is a useful method to inform learners of context; to ―create a frame of reference in memory for identifying and evaluating future … scenarios" (Moreno, 2007, p. 778).

The conjecture that multimedia annotations are more effective than their static counterparts is not cost-free; a greater cognitive load is likely. This is not inherently bad. Within constraints imposed by limited working memory capacity, germane cognitive load increases give rise to opportunities for deep, relational learning. But, if germane or extraneous cognitive loads increase to the point where working memory capacity constraints are violated, then learning is impaired; either the learning material is too difficult or multimedia features impose too great an extraneous cognitive load.

The Wallen, Plass and Brünken Study

The Wallen, Plass and Brünken (2005) study provides a helpful theoretical foundation and useful models for data analysis and summarized research by Levin et al. (Carney & Levin, 2002; Levin, Anglin, & Carney, 1987) that categorized the way that pictures were used as supplements to text. Wallen et al. adapted the notion of annotations as pictorial supplements to text, studying chiefly hypertext-accessible textual annotations of text applied to the select, organize and integrate processes of Mayer's cognitive model of multimedia learning. Wallen et al. (2005) discouraged embedding decorative (motivational) annotations within online learning materials because of their contribution to extraneous cognitive load while adding little or nothing to the subject-matter content of the intended learning. Mayer agrees, adding the caveat that ―seductive text and seductive illustrations" (Mayer, p. 117), create emotional interest which, in turn, begets greater attention but that the resulting learning is characterized more by information acquisition rather than knowledge construction. Knowledge construction requires ―cognitive interest … the idea that students enjoy lessons that they can understand … [and that] cognition affects emotion" (p. 119). That, in turn, results in higher motivation and greater persistence. When seductive details are used in learning materials, learners may be led astray by assuming ―that the theme of the passage comes from the seductive details" (p. 119), sacrificing coherence. This suggests a useful role for low physical fidelity animations which by their nature are not so elaborate as to be considered seductive.

Though multimedia annotations are possible, Wallen at al. (2005) used only textual annotations presented alongside the hyperlinked word, phrase, sentence or paragraph each is anchored to. Commenting on his own research outcomes, Mayer (2001)

states: Students using text-only presentations ―do not perform well on tests of retention or transfer, even when we give the tests immediately after students finish reading the passage" (p. 23), an observation certainly applicable in all of the STEM (science, technology, engineering and mathematics) subjects.

In the context of instructional designs for teaching mathematics, Sweller (Clark, et al., 2006) challenged this media choice, describing a scenario where a geometric shape is to be described. A textual (or auditory) description imparts a high cognitive load as the reader (listener) attempts to balance many elements (side lengths, diagonals, angles, orientations) trying to visualize the relationships among them. In contrast, the corresponding visual portrayal of the same geometric shape embeds many constituent elements into a single coherent but rich element resulting in lower cognitive load and deeper understanding. This parable surfaces the importance of media selection; some content is better displayed visually than described aurally (or textually). The reverse may also hold true. It does not make sense to depict mechanical pinging noises that signal impending machine failure visually (or textually) when the auditory channel is available.

In the Wallen et al. (2005) study, ―participants were asked to access all available annotations" (p. 63) but no mechanism assured this, challenging whether this actually occurred; learners are more likely to select only the annotations or other scaffolds actually needed. According to Wallen et al. (2005), learners who received more than one type of annotation ―performed significantly worse" during testing (p. 66). It is unclear, however, whether their attribution is correct, whether their observation is as a result of the expertise reversal or some other effect. Positing that active learning comprises

sensing, selecting, organizing, collating, and integrating, roles for multimedia annotations may be expanded to support each of these five active learning steps.

Wallen et al. (2005) defined select-level annotations as definitions of ―individual words or concepts‖ (p. 62); inconsistent with the usual concept of selection involving choice and decision-making, for example, when parsing a mathematics problem statement by identifying and extracting salient information from what is given. They described the role of organization-level annotations as facilitating ―connection of words into ideas [or concepts]… a brief explanation of the idea in the specific context‖ (p. 62). Parsing language facilitates understanding; however, the latter part of their description was once more definitional, though now context-specific. Organizing annotations should go beyond definitional content, to help learners take on sense-making activities rather than short-circuit the process by presenting ready-made solutions or definitions. Wallen at al. (2005) described integration-level annotations as scaffolds to ―support the construction of connections between the different ideas and prior knowledge … [or show] links of the ideas in the paragraph‖ (p. 62). This objective was well intended but their examples of integration-level annotations are prose-dense, lengthy, and chiefly definitional passages that are sure to fatigue some learners.

Several of the Wallen et al. (2005) results were expressed in terms of ―recalled more ideas‖ (p. 65) or ―recognized more words‖ (p. 65) hallmarks of rather low levels of achievement associated more with vocabulary building or rote learning; more closely linked to near-transfer learning of facts, simple concepts and procedures. For mathematics learners, developing a foundation and vocabulary facilitates, but does not achieve, far-transfer learning of non-routine processes and the associated guiding

principles necessary to solving complex workplace problems. Learning of complex whole-tasks and learning for understanding both demand deeper, more significant far-transfer roles for annotations in mathematics instruction.

As technology advances, barriers to innovation evaporate. It is now relatively straightforward to create multimedia annotations using tools like Camtasia Studio (Techsmith.com, 2009) to substitute for the textual annotations used in the Wallen et al. study, returning to the fundamentals of earlier researchers promoting multimedia (see Carney & Levin, 2002; Levin, et al., 1987).

The Mathematics Problem

Underpreparedness in mathematics affects many secondary and post-secondary students. This has come to be known as the mathematics problem. Reason (2003) describes learning of mathematics as akin to walking a maze; without a map, a daunting prospect. She describes the learning process in constructivist terms as the integration of new mental models (schemas) into prior learning relying on acquiring and using ―language as a pathway‖ (p. 5), often expressed as rules, to communicate mathematical concepts both intra- (within the learner's own mind) and inter-personally (among others with a shared interest). Reason contrasts instrumental understanding or ―rules without reason‖ (p. 6) and relational understanding described as ―knowing what to do and why‖ (p. 5).

Key attributes of relational understanding include: a big picture perspective; constructivist extension of prior learning; tolerance and acceptance of risk, recognizing that it is okay to make mistakes; taking initiative to try (often multiple) new ways of tackling authentic, complex, workplace problems; and that engaging in mathematical

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activity is intrinsically interesting and satisfying. A consequence of learning task authenticity is higher ‑motivation to learn [which] affects the amount of time students are willing to devote to learning. Learners are more motivated when they can see the usefulness of what they are learning" (Bransford, et al., 2000, p. 61). Instrumental understanding results in weak connections with prior learning and no big picture perspective is evident. Under these circumstances, learning goals are reduced to atomistic, mechanical tasks getting answers, shunning requirements to show work that would demonstrate understanding beyond the superficial.

Extending Reason's analysis, relational learning is far-transfer learning of non-routine processes guided by high-level principles. Those mastering processes and principles readily see patterns, symmetry and beauty found in mathematics and are able to apply their knowledge to authentic, unfamiliar problems; exhibiting the characteristics of an expert. In contrast, instrumental learning is near-transfer learning of facts, concepts and (standardized, repetitive) procedures producing, at best, competent technicians; those who apply rules without reason (T. Brown, personal communication, March 24, 2009). Consistent with this study's theoretical framework, Prince and Felder (2006) describe inductive learning as ‑learner-centered … [imposing] more responsibility on students for their own learning … [where] students learn by fitting new information into existing cognitive structures" (p. 124).

A novice learner has little or no knowledge or experience with the target learning materials and may not have the necessary metacognitive skills to achieve beyond instrumental learning:

> Novice learners don't stop to evaluate their comprehension of the material. They generally don't examine the quality of their work or stop to make revisions as they go along. Satisfied with just scratching the surface, novice learners don't attempt to examine a problem in depth. They don't make connections or see the relevance of the material in their lives. (Halter, 2003, para 4)

This brief analysis of the mathematics problem confirms the importance of underpreparedness in mathematics as (a) an economic issue; an obstacle to developing strategic scientific, technological, engineering and mathematical skills needed in the future, and (b) the applicability of constructivist approaches to the design of mathematics instruction. The challenge for underprepared learners, essentially pre-novices, may be more acute; they may not be sufficiently well organized or may not be willing to accept responsibility for their own learning. This is further exacerbated by instructional designs focused on near-transfer learning of facts, concepts, and standardized, repetitive procedures oriented to solving small-scale problems limited to familiar contexts (Hourigan & O'Donoghue, 2007).

According to Catania, Dallrymple and Gadanidis (2003), ―lots of practice with the facts and procedures make [mathematics learners] good at memorizing and following instructions … until [they tire] of doing things they do not understand" (p. 19). Instruction must be purposeful and meaningful to learners who ―are most strongly motivated to learn things they clearly perceive a need to know. Simply telling students that they will need certain knowledge and skills some day is not a particularly effective motivator" (Prince & Felder, 2006, p. 123). Instead, ―effective instruction must set up

experiences that induce students to construct knowledge for themselves, when necessary adjusting or rejecting their prior beliefs and misconceptions in light of the evidence provided by the experiences" (p. 124); sense-making based on self- and peer-assessment, reflecting on alternative problem-solving approaches, what was done well and what could be done differently in future (Bransford, et al., 2000).

Inductive instructional designs using authentic, rich whole-task experiences foster important life-long skills: Making principled, informed decisions; proficiently carrying out non-routine processes; assessing and taking measured risks; tolerating ambiguous, conflicting or incomplete information; taking initiative to continuously learn and adapt to changing authentic, complex problems situated in new and unfamiliar contexts. These metacognitive skills are highly prized in today's modern and ever-changing workplaces.

Dimensions of Culture

There is some evidence that cultural dissonance between an educational institution's dominant culture and that of the learner mimic underpreparedness vis-à-vis metacognitive skills:

> Students from [some] third-world countries are accustomed to teacher-led instruction where the teacher is expected to provide unquestionable facts and rote learning and even copying [interpreted by dominantly western cultures as plagiarism] is allowed. The students become confused when the teachers expect them to show initiative, take responsibility for their own learning, and raise questions and create knowledge independently. Concepts of knowledge and understanding are constructed in the educational culture over a long period of time. (Holvikivi, 2007, p. 79)

With increasing diversity in the classroom, sensitivity to cultural nuances assists in understanding and designing instruction that bridges cultural dissonance between individual and institutional (the school's) preferred culture. When this dissonance is too great, as in the plagiarism versus copying scenario described by Holvikivi, accommodation is not the answer; instead, the espoused institutional culture should be effectively modeled and expectations clearly articulated. Situated in overseas workplaces of a large American multinational organization, Hofstede's research (1980, 2003) revealed five important cultural dimensions applicable as much to education as to the workplace: (a) power distance, (b) uncertainty avoidance, (c) collective vs. individual preferences, (d) feminine versus masculine behavioral tendencies and (e) perspective on time.

In the context of instructional design, power distance refers to the degree of formality within the learning community; chiefly between teachers and learners; and, among learners. Many schools are collegial and egalitarian. Eschewing formality, first names are used in many situations. Learners from high power distance cultures may be uncomfortable with this, preferring to address teachers and others with perceived higher status using formal titles and surnames, eschewing personal points of view on matters of controversy or debate, unquestionably deferring to the teacher's perspective.

Uncertainty avoidance is problematic when incomplete or conflicting information is presented. High uncertainty avoiding learners would, under these situations, easily become and stay stuck, not exercising the initiative needed to acquire missing information. They may be so risk averse that they become reluctant to make assumptions or decisions lest they later be found invalid or less than optimal. Finally, they may see all

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decisions as binary or black-and-white, uncomfortable with nuanced, conditional or probabilistic outcomes, shades of gray.

Learners expressing collective tendencies may work much better in group settings. The feminine vs. masculine dimension, alternatively portrayed as concern for people vs. concern for task achievement, respectively, is a related group concept. A project team leader may be a hard taskmaster exhibiting overwhelming concern for task achievement at whatever cost. This may be a very uncomfortable situation for learners with a more dominant concern for people.

Finally, perspectives on time (a) may range from very short-term considerations to the very long term; (b) from precision time keeping to rubber time; and, (c) from a more backwards-looking traditionalist perspective valuing stability and gradual innovation, to a more forward-looking future orientation with revolutionary transformations and big-bang innovations.

Designing Instruction

The heuristics offered by Hofstede (Hofstede, 1980, 2003, 2004; Hofstede & Usunier, 1996) on bridging dissonance between individual learner cultures, the dominant culture of the place in which learners live and the culture of the educational institute or organization, may be used to inform instructional design decisions, For example, in most western countries, the dominant culture tends towards low power distance, lower levels of uncertainty avoidance, individual performance, masculine tendencies (evidenced by assertiveness, focus on accountability as demonstrated chiefly by task completion) and a short to medium term and precision time perspective (Hofstede & Usunier, 1996; University of Texas, 2001). Instruction should be able to reach learners who are high

power distance, highly uncertainty avoiding, oriented towards collective performance, and long term and ‑rubber time" time perspective.

Van Merriënboer and Kirschner (2007) describe a ten-step process, for developing four-component instructional designs. These steps may be undertaken in any order. The first three steps deal with identifying and designing simple-to-complex whole-task sequences; decomposing them into, then sequencing, the constituent tasks. Constituent tasks are further broken out into smaller part-tasks, then into atomistic teaching points. Creating a concept map of the instructional material or using variants of the Frayer model for concept development are helpful in this process.

Object-oriented systems developers sometimes use variants of the CRC the CRC (class, responsibility, collaborator) process (Beck & Cunningham, 1989). Adapting the CRC process to this study, one could reinterpret: (a) Class as (4C/ID) component; (b) responsibility as step within the model of active learning; and, (c) collaboration as the kind of annotation or other informational tool.

Table 5 depicts an organizer to associate teaching points with (a) 4C/ID components, (b) the responsibilities associated with active learning; and (c) the deployment mechanism (whether target content should appear in a possibly multimedia main document or in an annotation thereto).

Table 5. Analysis of instructional design and annotation use

Teaching Point	4C/ID Component	Active Learning Responsibility	Deployment Mechanism
TBA – depends on the subject matter being taught	Simple-to-complex whole-task sequence	Sense	Main document body
		Select	Decorative annotation
may include atomistic teaching points or aggregates right up to whole-tasks	Just-in-time procedural information	Organize	Representative annotation
	Omnipresent supporting information	Collate	Organizing annotation
		Integrate	Interpreting annotation
	Part-task practice		Transforming annotation

Teaching points are, of course, based on the subject matter to be taught and are, therefore, not explicitly shown in Table 5. Each teaching point or aggregate, once identified, may be mapped to its associated 4C/ID component, responsibility and deployment mechanism. Annotations could be designed to deliver supporting or procedural information, or worked-out problems showing end-products and, via dynamic audio-visual demonstrations, the means by which end-products are produced. Such demonstrations may be cut short at the point where the learner is expected to engage in problem-completion activities.

Summary

This review of the literature introduced key elements of this study's theoretical framework, the cognitive theory of multimedia learning and several of the most important effects emerging from cognitive load research, the progression from novice to expert and issues revolving around mathematical underpreparedness. The efficiency constructs were introduced, combining measures of performance and associated cognitive load. An instructional design analysis approach was proposed that maps learning objects (simple-to-complex whole-task sequences, broken down into tasks, constituent tasks and teaching points, presented, perhaps in a concept map) to 4C/ID component (task, procedural information, supporting information, or part-task practice); to roles derived from the active learning model (sense, select, organize, collate, or integrate); to either a host page or type of annotation (decorative, representative, organizing, interpreting, or transformational). This model supports the construction of a mathematics lesson intended for online deployment. Dimensions of culture may mimic mathematical underpreparedness so the described instructional design heuristics become relevant.

Chapter 3 begins by outlining the conceptual framework for this study. Though annotations may be used in many ways, in this study the focus is narrowed to annotations supporting learning of (routine) procedures and (non-routine, context-sensitive) processes. The independent, dependent, control and moderating variables are described and a data flow diagram illustrates how the collected data are combined into efficiency constructs that are used in hypothesis testing. Data collection instruments are described. Finally, the conduct of the study is described and the chapter concludes with a description of data analysis methods and a chapter summary.

CHAPTER 3. METHODOLOGY

Conceptual Framework

The key independent variables in this study were (a) the degree of mathematical preparedness among individuals and (b) annotations used during the multimedia learning activities (treatment or control). Dependent variables were (a) achievement on a post learning activity mathematics performance and (b) the workload experienced by each participant during the mathematical preparedness assessment, the multimedia learning activities (treatment or control), and the post learning activity mathematics performance test.

Two moderating variables were identified: (a) The content of the multimedia learning activities, which was intended to be the same for both treatment and control groups; and (b) sufficiency of experience with the learning management system. A control variable, English-language skill level, was investigated because of a possible relationship or interaction between perceived underpreparedness in mathematics and learners English-language skills.

Population and Setting

The target population for this research was first semester students enrolled in two- or three-year technology programs at an Ontario-based Canadian community college. Most were recent secondary school graduates while less than 10% were learners with one or more years of university experience. Women comprised only about 10% of the enrollment in these programs. Research conducted by Schollen et al. reported that 30 to 40% of first semester learners in technology programs may be at risk of failure due to

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underpreparedness in mathematics (2008) and the target population fit that profile. The number of freshman learners in the target population was 142.

Designing the Treatment and Control Learning Activities

Selecting the Mathematical Whole-Task

In the current Ontario Ministry of Education's grade 12 curriculum (2007), vector concepts are introduced in Mathematics for College Technology (MCT4C) and are covered in more detail in Calculus and Vectors (MCV4U). However, nearly all members of the target population completed a third alternative where vector concepts were not taught: Foundations for College Mathematics (MAP4C). Specific college-level expectations were drawn from the first semester numeric computing subject outline: (a) represent a vector using rectangular or polar coordinates or graphically; (b) convert among these representations; and (c) add two or more two-dimensional vectors.

These learning objectives were chosen because they were unfamiliar (novel tasks) to nearly all members of the target population. Relevant prior knowledge consisted chiefly of the ability to work with right-angle triangles, calculating angles and side lengths; to apply the primary trigonometric ratios, sine law and cosine law to solving problems; general algebraic and calculating skills; problem solving skills and strategies. All expectations were documented in the secondary school mathematics curriculum (Ontario Ministry of Education, 2005b, 2007). Participants in this study exhibited a wide range of mathematical preparedness in these prerequisite skills, consistent with prior studies (Schollen, et al., 2008).

Designing Annotations

A metaphor for the instructional design is, essentially, that of a driver (learner) on an express highway (learning pathway) through the (learning) landscape, with pit-stops providing fuel (procedural and situational insights) on demand, dispensing directional data (supporting information) in much the same way as a global positioning system guides the driver (learner). An experienced driver (expert learner) driving a new car with a full tank of fuel bypasses many pit-stops (needs little procedural help), disregarding the GPS (needs little just-in-time procedural or situational insights) because he knows the way (has prior knowledge) and, indeed may use shortcuts (heuristics) to get there. In contrast, an inexperienced driver (novice learner) driving an old car with little fuel makes regular pit stops (accessing procedural and situational insights), regularly consulting the GPS (accessing supporting information) because he does not know the way (this scaffolding substituting for absent prior knowledge). Inexperienced driver may also need to practice constituent driving skills (part task practice) like parking, performing three-point turns, changing lanes or replacing a flat tire.

Though annotations of many kinds may be developed and used, this study focused on annotations specifically oriented to demonstrating procedures or processes. In the context of the 4C/ID model, annotations were used to provide supporting information, just-in-time procedural information for both part-task practice and linked to rich, simple-to-complex, whole-task sequences.

Research Design

The experimental design used elements of the two-group pretest-posttest control group experimental design with random assignment (Gay & Airasian, 2003; Trochim, 2006b) and is shown in Figure 9. Performance was measured using a pretest, an initial assessment of mathematical preparedness and on a posttest, using a final performance test based on the preceding learning task. Participants provided workload feedback on the pretest, the actual learning activity, and on the posttest. Efficiencies were calculated using performance and workload data.

$$R \; O_{1A} \; O_{1B} \; O_{1C} \; X_1 \; O_{2A} \; O_{2B} \; O_{2C}$$

$$R \; O_{1A} \; O_{1B} \; O_{1C} \; X_2 \; O_{2A} \; O_{2B} \; O_{2C}$$

where:

R	=	random assignment
O_{1A}	=	assessment of mathematical preparedness
O_{1B}	=	assessment of cognitive load experienced during O_{1A}
O_{1C}	=	assessment of English-language skills
X_1	=	multimedia learning treatment with dynamic annotations
X_2	=	multimedia learning control without dynamic annotations
O_{2A}	=	assessment of cognitive load experienced during X_1 and X_2
O_{2B}	=	assessment of mathematical performance and transfer
O_{2C}	=	assessment of cognitive load experienced during O_{2B}

Figure 9. Randomized experimental design.

Data were collected on two days. During the first day, mathematical preparedness data (O_{1A}) was collected using a written test (Appendix D) constructed by extracting representative problems from current secondary school mathematics curriculum documents (Ontario Ministry of Education, 2005a, 2005b, 2007). Each participant then

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completed a self-assessment of the workload associated with the assessment of mathematical preparedness (O_{1B}) using the workload reporter (Appendix B), based on the NASA-TLX instrument (Hart, 2007; Hart & Staveland, 1988; NASA Ames Research Center, 2003; Rubio, Díaz, Martín, & Puente, 2004) Finally, English-language skills were collected (O_{1C}) using the English-language reporter (Appendix C).

On the second data collection day, participants completed online vector addition instruction that incorporated randomly assigned dynamic (X_1) or static (X_2) annotations On completion, participants reported workload experienced thereon (O_{2A}), using the workload reporter. To assess learning achievement (O_{2B}), participants completed a post learning activity performance test (Appendix E), then reported workload during this performance test (O_{2C}), again using the workload reporter.

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Data Collection Instruments

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Data collection instruments were created for participants to report mathematical performance and English-language skill level. The NASA task load index was adapted for use by participants to report on workloads experienced during learning and performance tasks.

Assessing of Cognitive Load

In many studies, participants are asked to self-report cognitive load (sometimes referred to as mental effort) on a five- or nine-point Likert scale (van Gog & Paas, 2008). In contrast, the NASA task load index (NASA-TLX) instrument asks participants to first self-report on the relative importance of each of six dimensions of workload, then to self-report on these dimensions using a Likert scale (Hart, 2007; NASA Ames Research

Center, 2003). ―Three dimensions relate to the demands imposed on the subject (mental, physical and temporal demands) and three to the interaction of the subject with the task (effort, frustration and performance)" (NASA Ames Research Center, 2003, p. 3).

Using the NASA-TLX process participants self-assessed the relative importance of the workload dimensions in the following way. For the six dimensions, there are $\frac{6!}{2!4!} = \frac{6 \times 5 \times 4!}{2!4!} = \frac{30}{2} = 15$ unique pairs of workload dimensions. From every pair, participants chose the dimension that they believe had greater impact on workload. Each dimension was assigned a weight from zero to five depending on the number of times that each dimension was chosen over its partnered alternative. Participants also rated the magnitude of workload according to the six dimensions. Finally, the importance and workload magnitudes were combined into a weighted average to yield an overall workload score.

A recent study compared the effectiveness of the NASA-TLX instrument with two other self-reported cognitive load measures. The NASA-TLX scored strongly along the dimensions of sensitivity, diagnosticity, validity, intrusiveness, reliability, implementation requirements and subject acceptability (Rubio, et al., 2004) and ―after nearly 20 years of use, NASA-TLX has achieved certain venerability; it is being used as a benchmark against which the efficacy of other measures, theories, or models are judged" (Hart, 2007, p. 4). The NASA-TLX is widely and confidently used by governmental, academic and commercial organizations (NASA Ames Research Center, 2006).

Analysis of the NASA-TLX instrument (Hart & Staveland, 1988) resulted in a strong coefficient of determination ($r^2 = 0.86$) for the instrument and confirmation that

paper-and-pencil, orally-administered and computer-based implementations of the instrument produce equivalent outcomes. The paper-and-pencil workload reporter used in this study is closely based on the NASA-TLX instrument.

Wilkinson (2004, p. 85) justified renaming and improving the descriptions of the six NASA-TLX dimensions after her testing revealed that some participants did not understand what was meant by some of these descriptions. Pilot testing confirmed that such adaptations were also appropriate for this study; consequently descriptions for each of the six dimensions were rewritten using language that participants easily and unambiguously comprehended as shown in Table 6. For this study and with similar justification, the adapted NASA-TLX instrument was renamed to Workload Reporter (Appendix B).

Table 6. Renamed dimensions of the NASA-TLX instrument

Original NASA-TLX dimension	Renamed in this study
Cognitive demand	Demands of thinking
Physical demand	Physical demand
Temporal demand	Time demand
Effort	Task effort
Performance	Task success
Frustration	Frustration experienced while on task

Pilot testing surfaced an additional need to simplify data collection process which was initially not well understood and described as tedious; 15 similar comparisons were

required. Consequently, the method of reporting importance of each dimension was amended. Participants ranked the six dimensions from most to least important. When pilot tested, this was found to be easier, less time consuming, and not as fatiguing to participants resulting in informed, high quality and largely complete responses.

For this study, most participants identified physical demands as least important and with a low magnitude. Given the nature of the six dimensions and the absence of meaningful contribution towards the physical demand component of workload, one could reasonably posit that, for cognitive tasks such as those in this study, workload with minimal physical demand was equivalent to cognitive load.

Assessing of Mathematical Preparedness

Secondary school mathematical underpreparedness is strongly indicated as early as grade 6 by weak scores on the Ontario Ministry of Education's Education Quality and Accountability Office's province-wide grade 3, grade 6 and grade 9 mathematics testing (E. Ainslie, personal communication, May 22, 2009). No hard data was provided for this assertion but, if true, then a similar assessment may be used to determine participants' preparedness for college-level mathematics. To assure content validity, ―how well the process of measurement reflects the important content of the domain of interest" (Boslaugh & Watters, 2008, p. 13), the content of this assessment was extracted directly from examples embedded in curriculum documents.

A few items were selected from the grade 1 to 8 curriculum (Ontario Ministry of Education, 2005a) but the main focus was on expectations for mathematics courses along the usual secondary school pathway to college. The grades 9 and 10 applied-level (Ontario Ministry of Education, 2005b), and 11 and 12 (Ontario Ministry of Education,

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2007) college preparation mathematics curricula were surveyed resulting in 44 of the 47 test items (Appendix D). The remaining three test items were drawn from a grade 9 applied mathematics text book (Cooke, Heideman, Keene, Lin, & Reeves, 2007). The rubrics provided in Appendix F and exemplars created during pilot testing assisted scoring the mathematical preparedness test.

Assessing of Post Learning Activity Performance

This assessment measured performance on near-transfer (routine procedure-oriented) tasks and far-transfer (non-routine process-oriented) tasks; solving chiefly part- and whole-tasks, novel problems based on the content of the vector addition online learning activity. For this assessment, good internal consistency was demonstrated (Cronbach's α=0.920). Rubrics provided in Appendix F assisted in scoring this assessment.

Assessing of English-language Skill

In the short self-assessment of English-language skills, participants self-reported strength in reading, writing and listening in English, and indicated the number of school years (starting with grade 1) in which they were students in English medium schools. Each of the four responses was given equal weight when combined into a single English-language score. The English language reporter exhibited an acceptable level of internal consistency (Cronbach's α = 0.728).

Conduct of the Study

Recruitment and Informed Consent

Participants were recruited in person (by the principal researcher or a research assistant) via short verbal group presentations about the study during which the purpose and activities associated with the study were outlined, informed consent forms distributed and questions answered. Those who immediately consented submitted their forms; others were allowed to take the informed consent form away with them while deciding whether to participate. No formal inducements were offered, however some participants needing earphones were given inexpensive ear buds so that they could get full value from the audio dimension of the audio-visual learning materials; they were permitted to keep them.

In subsequent meetings, additional informed consent forms were distributed or collected. Of 142 potential participants, 92 participants were recruited (65%). However, due to attrition (students quitting college) and an outbreak of the H1N1 ―swine flu" during the recruiting and data collection periods, 72 participants (51% of potential participants; 78% of recruited participants) completed all parts of the data collection process.

Data Collection

The study was conducted during a two-week period. Each group of participants met twice for two-hour sessions in a computer lab equipped with networked, Windows-based computers. The focus of the first data collection session was the completion of the mathematical preparedness assessment, collection of workload reporters (providing data

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on participants' workload experienced during the assessment of mathematical

preparedness), and the English language reporters (providing data on participants' level

of skill in the English language.

Between the first and second sessions, two online learning activities were

uploaded into the Blackboard learning management system. Using the built-in selective

release mechanism, two criteria were set for the delivery of the learning materials to

participants' Blackboard menus: first, a start time and date coinciding with their expected

participation; and second, which of two randomly assigned learning activities that each

participant would access.

At the beginning of the second data collection session, earphones were provided

for participants that needed them. They were then directed to login to the Blackboard

learning management system and given instructions on where and how to access their

online learning activity. Intended as a 30 minute activity, no fixed duration was set for

participants' completion of the learning activity; some participants preferred to use the

rewind and replay facilities of the multimedia presentations during their learning

processes while other learners normally offered accommodations on the basis of

disabilities, used extra time.

On completion of their learning activity, each participant completed a workload

reporter providing feedback on the workload experienced during the learning activity.

Though nominally an hour in duration, some participants finished early while others were

afforded extra time. Each participant then completed an assessment based on the content

of the preceding vector addition learning activity. This was also followed by a workload

reporter, this time providing data on workload experienced during this final assessment. All data were collated and stored in a master Excel spreadsheet for subsequent analysis.

Data Analysis

Siegle's Reliability Calculator (2000) was used to calculate Cronbach's α for the two mathematics assessments and the English language reporter. Excel's analysis tools were used to calculate descriptive statistics (means, standard deviations, kurtosis and skewness), perform correlation analysis, Student's t tests of differences between means and analyses of variance. A spreadsheet was developed to perform Levene's analysis of homogeneity of variances between groups (National Institute of Standards and Technology, 2006). Finally, Excel's chart drawing tools were used to produce graphical representations of data relevant to the understanding of the study's efficiency outcomes.

During pilot testing using fictitious but representative data, all calculations were tested and found to yield satisfactory outcomes; correctly calculating 2-dimensional instructional and performance efficiencies; and the 3-dimensional instructional conditions efficiency.

Assessing Performance

Within the assessment of mathematical preparedness, Appendix D, individual parts of simple questions were scored on a 0-1-2 scale. Since their solution required straightforward calculation-oriented procedural knowledge and skills, they were easy to score requiring only one assessor armed with exemplars. The other questions, so-called word problems, were deeper and were assessed by two scorers (the principal researcher and a research assistant) on a 0-1-2-3-4 scale. Assessment rubrics are shown in

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Appendix F. Finally, total scores were calculated and normalized (M=0, SD=1). The same scoring and normalization methods were used to score the assessment on vector addition that participants complete after the learning activity.

Assessing Workload

Workload data were collected on a two-page workload reporter and collated in the master spreadsheet. For each participant, a weighted average was calculated by multiplying the scores on each of the six workload dimensions by their corresponding weights, which were then divided by the sum of the weights (NASA Ames Research Center, 2003). Finally, these scores were normalized ($M = 0$, $SD = 1$) and tabulated.

Assessing English-language Skill Level

Participants self-reported their English-language reading, writing and listening abilities using a 0 to 20 Likert scale. In addition, participants indicated the number of years (starting with grade 1) spent in an English-medium school, also on a 0 to 20 Likert scale. For each participant, the four scores were collated in the master spreadsheet. Finally, these scores were added, normalized (M=0, SD=1) and tabulated.

Hypothesis Testing

A step-by-step summary and worked out example showing how raw performance and workload data scores are transformed into 2D efficiency scores is shown in Clark et al. (Clark, et al., 2006, pp. 331-240). The calculation of the 3D efficiency construct is a straightforward elaboration of this process and is described by Tuovinen and Paas (2004). Efficiency scores are used for all analyses. These are then available for hypotheses testing. Normalized mathematical preparedness scores were used post hoc to cluster

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participants into equal-sized mathematically underprepared and mathematically prepared groups.

Hypotheses related to differences between treatment and control groups were tested using the Student's t test. The null hypotheses were:

$H1_0$: There is no statistically significant difference in two-dimensional performance efficiency when participants use online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.

$H2_0$: There is no statistically significant difference in two-dimensional instructional efficiency when participants use online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.

$H3_0$: There is no statistically significant difference in three-dimensional instructional conditions efficiency when participants use online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.

Hypotheses $H1_0$, $H2_0$ and $H3_0$ were central to this study. The following hypotheses were secondary and tested whether efficiency differences arising from the use of dynamic vs. static annotations, discriminated by mathematical preparedness, were statistically significant. Two-way analyses of variance tested the following null hypotheses:

$H4_0$: Whether prepared or underprepared in mathematics, there is no statistically significant difference in two-dimensional performance efficiency for participants using use online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.

$H5_0$: Whether prepared or underprepared in mathematics, there is no statistically significant difference in two-dimensional instructional efficiency for participants using online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.

$H6_0$: Whether prepared or underprepared in mathematics, there is no statistically significant difference in three-dimensional instructional conditions efficiency for participants using online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.

Finally, correlation analysis was used to investigate whether there are statistically significant relationships or interactions between mathematical preparedness and English-

language skill. This analysis is necessary because such relationships or interactions, if present, may confound the interpretation of experimental results in other hypotheses. This null hypothesis was:

$H7_0$: There is no statistically significant correlation between mathematical preparedness and English-language skill level.

Summary

This chapter introduced the research design, the target population, the independent variables (treatment/control; mathematical preparedness/underpreparedness), dependent variables (performance outcomes from pre and post learning activity testing; workload experienced during performance and learning), the control variable (English-language ability), the moderating variables (level of experience with the learning management system, and equivalent content of the treatment and control learning materials), the instruments used to collect these data (an adaptation of the NASA-TLX for cognitive load and two special-purpose mathematics tests), rubrics, timelines and the conduct of the data collection stage of the study. A data flow diagram was presented summarizing how collected data were combined into efficiency constructs in preparation for statistical testing of the study's hypotheses.

In Chapter 4, data collection and analysis are presented. Beginning with assessments of the normality of the data to be analyzed, followed by the analyses themselves, including analyses relating to the 2D instructional, 2D performance and 3D instructional conditions efficiencies. Finally, hypothesis test outcomes are summarized.

CHAPTER 4. DATA COLLECTION AND ANALYSIS

The purpose of this study was to examine the extent that instructional and performance efficiencies improve when learners, including the underprepared, access online learning materials with embedded dynamic multimedia annotations when learning how to solve complex, real-world mathematical problems. The research was designed to answer the following questions:

1. To what extent does 2-dimensional performance efficiency of the treatment group improve when using dynamic multimedia annotations, compared to using static multimedia annotations?

2. To what extent does 2-dimensional instructional efficiency of the treatment group improve when using dynamic multimedia annotations, compared to using static multimedia annotations?

3. To what extent does 3-dimensional instructional condition efficiency of the treatment group improve when using dynamic multimedia annotations, compared to using static multimedia annotations?

This chapter presents results from the analyses of the data collected to answer the above research questions beginning with Cronbach's α analyses of the data collection instruments. The chapter continues with: an analysis of correlation between degree of mathematical preparedness and level of skill in the English language; descriptive statistics for the data collected including assessments as to whether the underlying data were normally distributed; testing whether differences in efficiencies arising from using dynamic vs. static annotations is statistically significant; and, finally, treatment vs. level

of mathematical preparedness 2-factor analyses of variance. The chapter concludes with

hypothesis testing and a brief summary of efficiency-based observations.

Statistical Analyses

Each of the mathematical assessments indicated good internal consistency

($\alpha = 0.92$). The English language reporter in this study and was found to exhibit an

acceptable level of internal consistency ($\alpha = 0.73$).

Correlations among variables are shown in Table 7. No statistically significant

correlation was found between English language skill and performance on the assessment

of mathematical preparedness. However, a small positive correlation ($r = 0.256, p < .05$)

was found between English language skill and workload experienced during the

assessment of mathematical preparedness.

Table 7. Correlation among variables

Variable	O_{1A}	O_{1B}	O_{1C}	X_1X_2	O_{2A}	O_{2B}	O_{2C}
Assessment of Mathematical Preparedness (O_{1A})	1						
Workload during Assessment of Mathematical Preparedness (O_{1B})	−0.055	1					
English Language Skill Level (O_{1C})	0.054	0.256*	1				
Treatment (X_1X_2)	−0.027	0.021	−0.091	1			
Workload During Treatment (O_{2A})	−0.226†	0.155	−0 003	0.206†	1		
Post Learning Activity Performance Assessment (O_{2B})	0.312**	−0.192	0.052	−0.216†	−0.318**	1	
Workload during Post Learning Activity Performance Assessment (O_{2C})	−0.189	0.180	0.122	0.124	0.604**	−0.302**	1

*$p < .05$, **$p < .01$, †$p < .1$

Those who were mathematically better prepared did better on the post learning activity performance assessment as evidenced by the statistically significant ($p < .05$) medium correlation ($r = 0.312$) between the post learning activity performance assessment and the assessment of mathematical preparedness.

Treatment, a parametric variable with dynamic annotations coded as 1 and static annotations as –1, exhibited a small negative correlation with post learning activity performance assessment ($r = -0.216$); weak evidence ($p < .1$) that those using static annotations performed better than those using dynamic annotations. Another small positive correlation ($r = 0.206$) between treatment and workload experienced during treatment provided further weak evidence ($p < .1$) that dynamic annotation use incurred greater workloads than static annotations. Taken together, both of these observations combine to produce higher efficiency for participants using static annotations.

Two statistically significant ($p < .05$) medium negative correlations were found, between the workload during treatment and post learning activity performance assessment ($r = -0.318$); and between workload during post learning activity performance assessment and post learning activity performance assessment ($r = -0.302$). There was a strong positive correlation between workload experienced during treatment and workload experienced during the post learning activity performance assessment ($r = 0.604$, $p < .01$).

Analysis by treatment, Table 8, shows statistically significant negative skewness for workload during the assessment of mathematical preparation for the static annotations treatment group.

Table 8. Workload and performance, by treatment

Variable	*M*	*SD*	Kurtosis	Skewness		*n*
Assessment of Mathematical Preparedness						
Dynamic	–0.026	0.906	–0.517	–0.282		36
Static	0.026	1.099	–1.026	0.113		36
Workload during Assessment of Mathematical Preparedness						
Dynamic	0.021	0.892	–0.555	–0.623		36
Static	–0.021	1.110	1.471	–1.295	*	36
Workload during Treatment						
Dynamic	0.205	0.882	0.139	–0.743		36
Static	–0.205	1.079	–0.595	–0.111		36
Post Learning Activity Performance Assessment						
Dynamic	–0.215	1.040	–1.365	0.060		36
Static	0.215	0.923	–0.572	–0.602		36
Workload during Post Learning Activity Performance Assessment						
Dynamic	0.123	0.863	0.357	–0.680		36
Static	–0.123	1.120	–0.305	–0.268		36

* $p < .05$ when |kurtosis| > 1.633 or |skewness| > 0.816

There is no evidence that differences in the variances of any of the workload or performance data due to treatment are statistically significant Table 9.

Table 9. Test of homogeneity of treatment variances

Variable	F
Assessment of Mathematical Preparedness	2.008
Workload during Assessment of Mathematical Preparedness	0.563
Workload during Learning Activity	1.625
Post Learning Activity Performance Test	0.730
Workload during Post Learning Activity Performance Test	2.685

$p < .05$ when $F > 3.978$; $df = 1,70$

Analysis by treatment × mathematical preparedness, Table 10, shows statistically significant negative skewness of workload for the static annotation groups and leptokurtic (taller, narrower than normal) distribution of the mathematically prepared static annotations group.

Table 10. Workload and performance, by treatment × mathematical preparedness

Variable		M	SD	Kurtosis	Skewness		n
Assessment of Mathematical Preparedness							
Dynamic	Prepared	0.695	0.474	–0.693	0.159		18
	Underprepared	–0.748	0.600	–0.347	–0 663		18
Static	Prepared	0.938	0.638	–1.345	0.214		18
	Underprepared	–0.885	0.564	–1.496	-0.018		18
Workload during Assessment of Mathematical Preparedness							
Dynamic	Prepared	–0.093	0.832	–0.846	–0.479		18
	Underprepared	0.134	0.959	–0.011	–0.884		18
Static	Prepared	–0.034	1.049	3.378	*	–1.459	*	18
	Underprepared	–0.007	1.198	0.934	–1.282	*	18
Workload during Treatment							
Dynamic	Prepared	–0.018	0.880	–0.102	–0.918		18
	Underprepared	0.427	0.849	0.532	–0.734		18
Static	Prepared	–0.343	1.229	–0.859	0.002		18
	Underprepared	–0.066	0.920	–0.383	0.003		18
Post Learning Activity Performance Assessment							
Dynamic	Prepared	0.012	1.025	–0.974	–0.250		18
	Underprepared	–0.441	1.034	–1.439	0.390		18
Static	Prepared	0.435	1.000	0.174	–1.116		18
	Underprepared	–0.005	0.806	–0.275	–0.339		18
Workload during Post Learning Activity Performance Assessment							
Dynamic	Prepared	0.182	0.636	1.809	–0.829		18
	Underprepared	0.064	1.058	–0.486	–0.505		18
Static	Prepared	–0.292	1.161	–0.821	–0.415		18
	Underprepared	0.045	1.083	0.283	–0.057		18

* $p < .05$ when |kurtosis| > 2.309, |skewness| > 1.155

Table 11 shows no statistically significant evidence that the variances of the independent variables across treatment × mathematical preparedness groups are not homogeneous.

Table 11. Test of homogeneity of treatment × mathematical preparedness variances

Variable	F
Assessment of Mathematical Preparedness	1.466
Workload during Assessment of Mathematical Preparedness	0.157
Workload during Learning Activity	0.343
Post Learning Activity Performance Test	0.201
Workload during Post Learning Activity Performance Test	2.298

* $p < .05$ when $F > 2.740$; $df = 3,68$

Testing Normality Assumptions of Efficiencies

Examining kurtosis and skewness, the distributions of the 2D instructional efficiency, the 2D performance efficiency and the 3D instructional conditions efficiency were each found to be slightly platykurtic with very little skewness (Table 12), though neither was statistically significant.

Table 12. Efficiencies, by treatment

Variables	M	SD	Kurtosis	Skewness	n
2D Performance Efficiency during Assessment of Mathematical Preparedness					
Dynamic	-0.033	0.996	–0.162	–0.310	36
Static	0.033	1.070	–0.195	0.392	36
2D Instructional Efficiency					
Dynamic	-0.297	1.023	–1.095	–0.110	36
Static	0.297	1.202	–0.808	–0.168	36
2D Performance Efficiency during Post Learning Activity Performance Assessment					
Dynamic	-0.239	1.065	–0.913	–0.179	36
Static	0.239	1.179	–0.455	–0.226	36
3D Instructional Conditions Efficiency					
Dynamic	-0.313	1.107	–0.448	–0.165	36
Static	0.313	1.502	–0.625	–0.155	36

* $p < .05$ when |kurtosis| > 1.633 or |skewness| > 0.816

Levene's test, summarized in Table 13, rejects hypotheses that the variances between treatment groups are not homogeneous.

Table 13. Test of homogeneity of variances of calculated efficiencies, by treatment

Variable	F
2D Performance Efficiency during assessment of mathematical preparedness	0.541
2D Instructional Efficiency	0.546
2D Performance Efficiency during post learning activity performance assessment	0.153
3D Instructional Conditions Efficiency	2.344

* $p < .05$ when $F > 3.978$; $df = 1,70$

Though not statistically significant, the distributions of efficiencies grouped by treatment × mathematical preparedness, Table 14, are slightly platykurtic with little negative skewness. There is no statistically significant evidence that kurtosis is not normal.

Table 14. Efficiencies, by treatment × mathematical preparedness

Variable		M	SD	Kurtosis	Skewness	n
2D Performance Efficiency during Assessment of Mathematical Preparedness						
Dynamic	Prepared	0.557	0.713	−0.299	0.169	18
	Underprepared	0.688	0.899	0.575	0.486	18
Static	Prepared	−0.624	0.891	−0.786	−0.232	18
	Underprepared	−0.621	0.803	−0.384	0.653	18
2D Instructional Efficiency						
Dynamic	Prepared	0.021	0.955	−1.217	−0.483	18
	Underprepared	−0.614	1.014	−0.453	0.277	18
Static	Prepared	0.550	1.324	−1.020	−0.295	18
	Underprepared	0.043	1.043	−0.732	−0.464	18
2D Performance Efficiency during Post Learning Activity Performance Assessment						
Dynamic	Prepared	−0.120	0.793	−0.097	−0.528	18
	Underprepared	−0.358	1.295	−1.432	0.096	18
Static	Prepared	0.513	1.240	−0.657	−0.198	18
	Underprepared	−0.036	1.079	−0.545	−0.619	18
3D Instructional Conditions Efficiency						
Dynamic	Prepared	−0.088	0.790	−0.195	−0.739	18
	Underprepared	−0.539	1.338	−0.684	0.318	18
Static	Prepared	0.618	1.624	−0.827	−0.230	18
	Underprepared	0.009	1.347	−0.449	−0.413	18

* $p < .05$ when |kurtosis| > 2.309 or |skewness| > 1.155

Levene's test of homogeneity of variances across groups (Table 15) provided no evidence that the data, grouped by treatment × mathematical preparedness, are not normally distributed.

Table 15. Test of homogeneity of efficiency variances, by treatment × mathematical preparedness

Variable	F
2D Performance Efficiency during assessment of mathematical preparedness	0.389
2D Instructional Efficiency	0.661
2D Performance Efficiency during post learning activity performance assessment	2.152
3D Instructional Conditions Efficiency	1.887

* $p < .05$ when $F > 2.740$; $df = 3,68$

Conclusions on Normality of Data

Analysis of kurtosis and skewness provided no evidence (at $p < .05$) that variables, other than the workload experienced during the assessment of mathematical performance, are not normally distributed. Analyses of homogeneity of variances across groups provided no evidence (at $p < .05$) that variances across groups are unequal. Statistically significant platykurtic distribution of ungrouped scores on the assessment of mathematical preparedness was evident. When analyzed by group, whether by treatment alone or by treatment × mathematical preparedness, no statistically significant evidence was found that the data were not normally distributed. This satisfies prerequisite assumptions for conducting analyses of variance using these variables, that: (a) variables are normally distributed; and (b) variables exhibit homogeneous variances across groups.

There was evidence ($p < .05$) that workload experienced during the assessment of mathematical preparedness was not normally distributed. This was a chance outcome. There was no basis to conclude that experimental design explained this outcome; no participant had yet participated in either treatment. Caution was exercised when relying upon normality assumptions of this variable. It should be noted, however, that the 2D performance efficiency combining the assessment of mathematical preparedness with workload thereon, did appear to be normally distributed.

Testing Differences between Treatment Means

        The testing of differences between treatment means is summarized in Table 16. As expected, no statistically significant difference was found between the means of 2D performance efficiency during the assessment of mathematical preparedness. Both 2D instructional efficiency and 3D instructional conditions efficiency exhibited statistically significant differences in the means due to treatment.

Table 16. Differences between efficiency means

Variable	Dynamic $M(SD)$	Static $M(SD)$	t
2D Performance Efficiency during Assessment of Mathematical Preparedness	−0.033 (0.996)	0.033 (1.070)	−0.273
2D Instructional Efficiency	−0.297 (1.023)	0.297 (1.202)	−2.254 *
2D Performance Efficiency during Post Learning Activity Performance Assessment	−0.239 (1.065)	0.239 (1.179)	−1.805 †
3D Instructional Conditions Efficiency	−0.313 (1.107)	0.313 (1.502)	-2.015 *

* $p < .05$, † $p < .1$; $df = 70$

        Finally, analysis of the means of 2D performance efficiencies during the post learning activity performance assessment yielded weak evidence that the differences between means is due to treatment ($p < .1$).

Analyses of Variance

An analysis of variance (Table 17) confirms that performance efficiency during the assessment of mathematical preparedness shows no statistically significant evidence that the groups are different along the dimension of treatment. Of course, the strong evidence of group differences along the dimension of mathematical preparedness is expected since this was used as the basis for post hoc assignment to prepared and underprepared groupings.

Table 17. Analysis of variance of 2D performance efficiency during assessment of mathematical preparedness

Source of Variation	SS	df	MS	F	
Mathematical Preparedness	27.898	1	27.898	40.518	**
Treatment	0.080	1	0.080	0.116	
Interaction	0.073	1	0.073	0.106	
Within	46.819	68	0.689		

* $p < .05$, ** $p < .01$

Efficiencies combine performance with workload. Consider the following scenarios: (a) low workload with modest performance; (b) modest workload with high performance; and, (c) very low workload with poor performance. Looking only at efficiency score, each of these scenarios is indistinguishable from the other as demonstrated, respectively, by the following workload-performance ordered pairs: (0.5, 1.5); (−0.5, 0.5); and (−1.5, −0.5). Though in different quadrants and subject to dissimilar interpretations, each workload-performance ordered pair results in the same 0.7

efficiency score. A graphical representation relating workload and performance is useful when discriminating among these different outcomes.

In Figure 10, the solid markers represent performance efficiency grouped only by treatment. Hollow markers represent performance efficiency grouped by treatment × mathematical preparedness. Round markers represent performance efficiencies for dynamic annotations; square markers represent performance efficiencies for static annotations. This visualization confirms that the behavior of both treatment groups appears very similar, supporting the conclusion that the two groups, prior to treatment, are comparable.
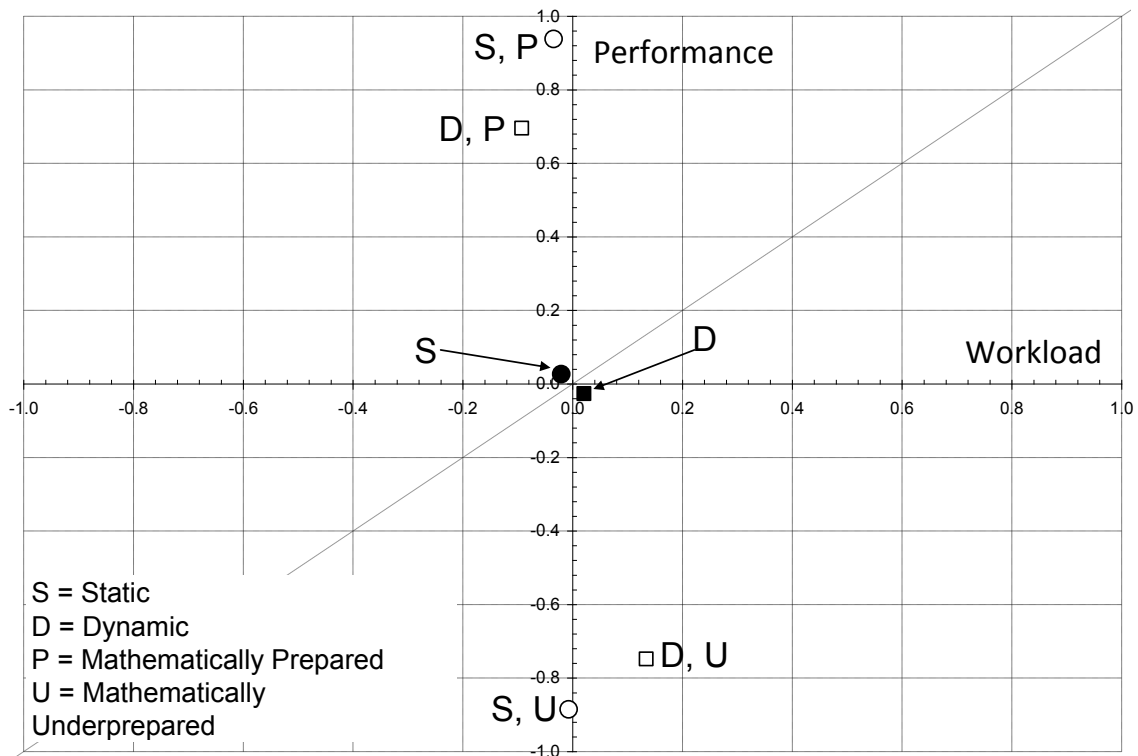

Figure 10. 2D performance efficiency during assessment of mathematical preparedness

An analysis of variance of 2D instructional efficiency is shown in Table 18 and reveals statistically significant outcomes for both treatment and mathematical preparedness.

Table 18. Analysis of variance of 2D instructional efficiency

Source of Variation	SS	df	MS	F	
Mathematical Preparedness	5.879	1	5.879	4.918	*
Treatment	6.332	1	6.332	5.298	*
Interaction	0.074	1	0.074	0.062	
Within	81.280	68	1.195		

* $p < .05$

The graph in Figure 11 uses the corresponding performance and workload means to locate 2D instructional efficiencies on a two-dimensional workload × performance grid. The result is a visualization usefully exhibiting the characteristics of instructional efficiency. A number of observations surface. First, prepared learners tend to perform better and incur a smaller workload than underprepared learners, regardless of treatment. Second, static annotation usage resulted in both a higher level of performance and lower workload than dynamic annotation usage. Third, the performance and workload of prepared learners using dynamic annotations is comparable to underprepared learners using static annotations. Fourth, for all participants regardless of group, those that performed better incurred a lower workload.
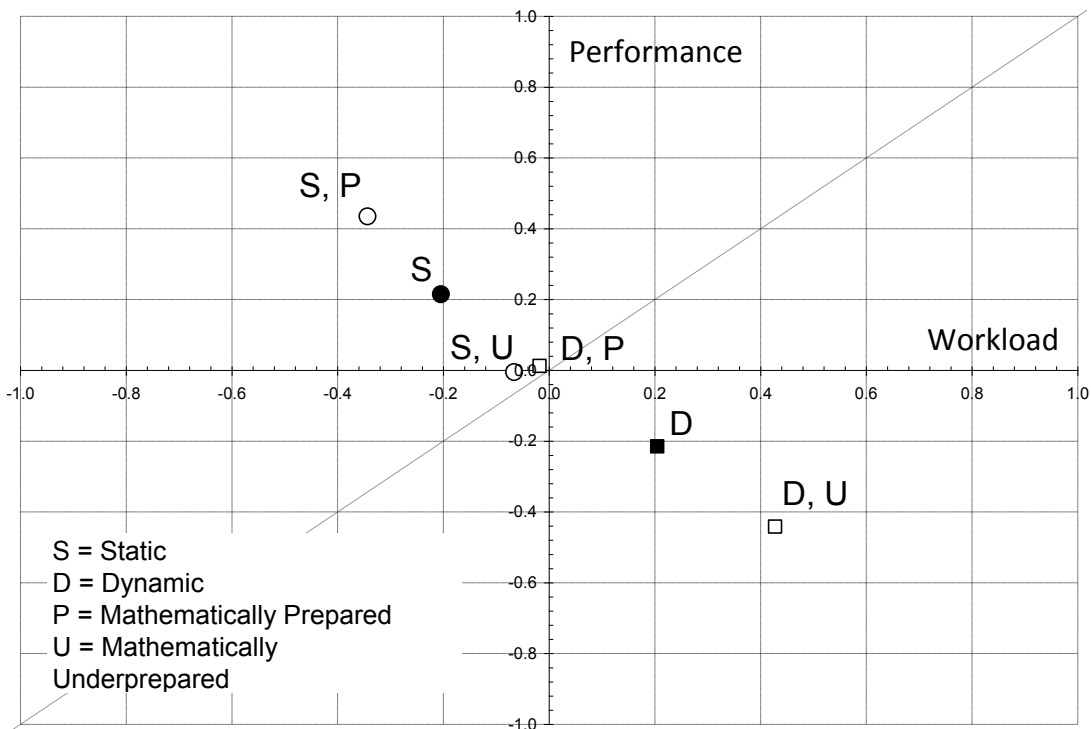
Figure 11. 2D instructional efficiency

An analysis of variance of 2D performance efficiency is shown in Table 19. There is no statistically significant evidence ($p < .05$) that mathematical preparedness or treatment accounts for the observed variation.

Table 19. Analysis of variance of 2D performance efficiency

Source of Variation	SS	df	MS	F	
Mathematical Preparedness	2.783	1	2.783	2.224	
Treatment	4.110	1	4.110	3.284	†
Interaction	0.437	1	0.437	0.349	
Within	85.111	68	1.252		

* $p < .05$, † $p < .1$

It is interesting to observe the patterns in Figure 12. Whereas the pattern of performance efficiencies closely mimics the pattern of instructional efficiencies for static annotations shown in Figure 11, the pattern associated with dynamic annotations differs. For performance efficiency, the mathematically prepared using dynamic annotations performed better incurring a higher level of performance workload in contrast to the mathematically underprepared that performed worse incurring a lower level of workload.
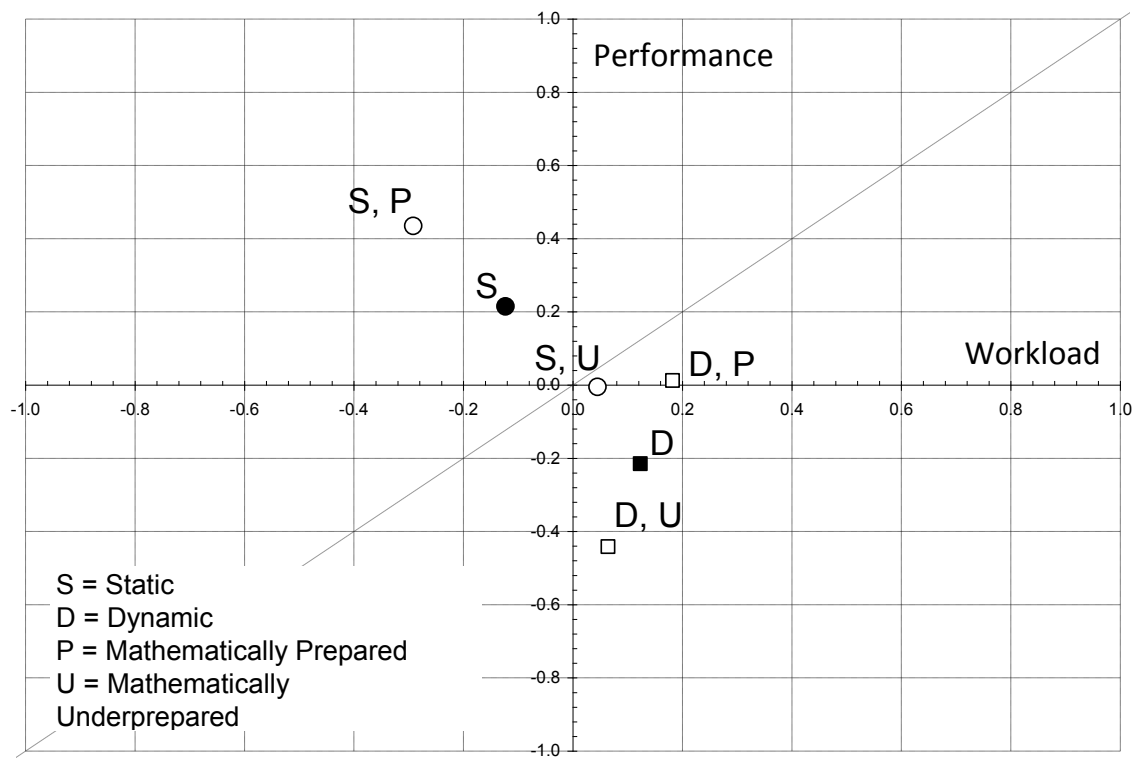

Figure 12. 2D performance efficiency during post learning activity performance assessment

Regardless of treatment, the mathematically underprepared incurred a similarly low level of workload. In contrast, the prepared-static group incurred a considerably lower level of workload and performed better than the dynamic-static group. Comparing

Figure 11 and Figure 12 graphically, lines from dynamic-prepared to dynamic-underprepared are very nearly perpendicular to each other.

Table 20 shows an analysis of variance of 3D instructional conditions efficiency. Though there is evidence that treatment is statistically significant ($p < .05$), the evidence that mathematical preparedness is statistically significant is weaker ($p < .10$).

Table 20. Analysis of variance of 3D instructional conditions efficiency

Source of Variation	SS	df	MS	F	
Mathematical Preparedness	5.052	1	5.052	2.944	†
Treatment	7.067	1	7.067	4.118	*
Interaction	0.112	1	0.112	0.065	
Within	116.689	68	1.716		

$* p < .05$, † $p < .1$

Instructional conditions efficiency is a three-dimensional construct and combines both instructional efficiency and performance efficiency, but considers all three projections simultaneously.

Figure 13 shows three orthographic projections showing, pair-wise, the three constituent elements: workload experienced during instruction; performance; and, workload experienced during performance.
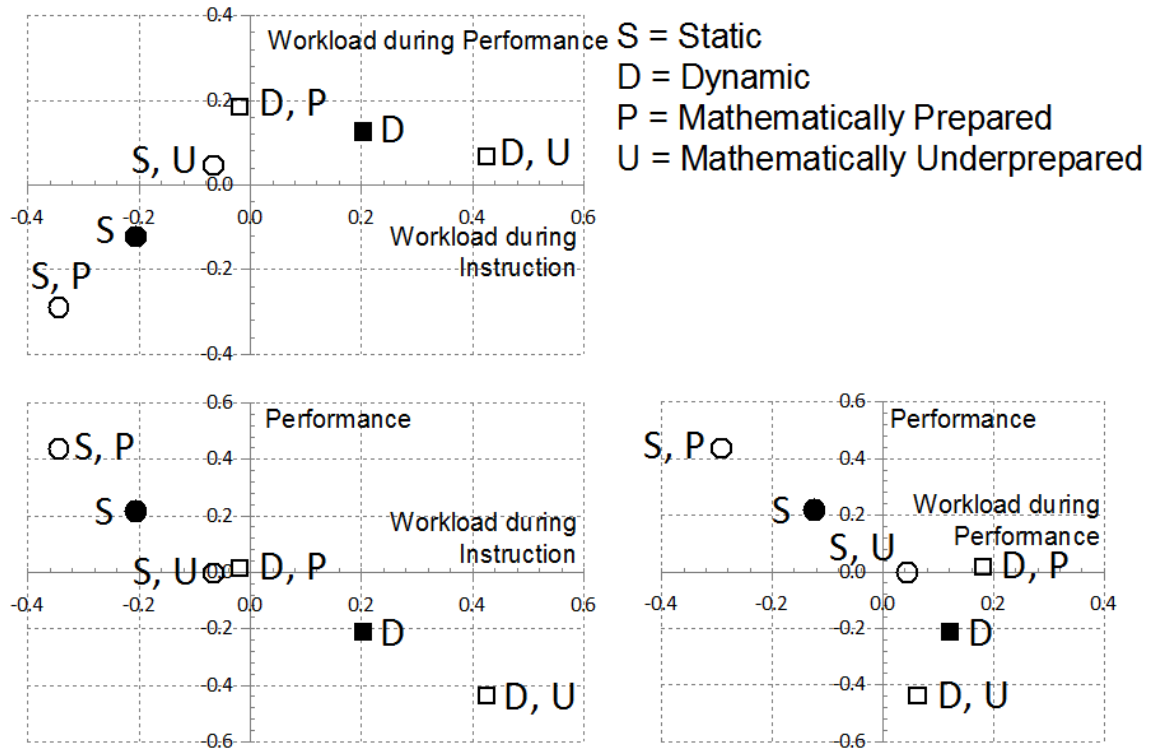

Figure 13. 3D instructional conditions efficiency graph

Figure 13 embeds the 2D instructional efficiency graph (Figure 11) as the lower-left projection and the 2D performance efficiency (Figure 12) as the lower-right projection. Since the 2D constructs have already been considered, focus now shifts to the remaining projection (top-left) representing potential interactions or patterns between workload experienced during instruction and workload experienced during performance.

Power Analysis

A Type II error, β, occurs when failing to reject a false null hypothesis and is ―a function of significance level, α, sample size, and population effect size" (Faul, Erdfelder, Buchner, & Lang, 2009, p. 1149). Statistical power, $1 - \beta$, reflects ―the odds of saying that there is a relationship … when in fact there is one" (Trochim, 2006a, Figure 1), correctly rejecting a false null hypothesis. The G*Power 3.1.2 calculator (Faul, Erdfelder, Lang, & Buchner, 2009) was used post hoc to compute achieved powers of Student's *t* tests and analyses of variance. These are summarized, with achieved effect sizes, in Table 21.

Table 21. Power of statistical tests

Test	Differences in	Due to	Power	Effect Size	
t	instructional efficiency	treatment	0.72	0.53	medium
	performance efficiency	treatment	0.56	0.43	small
	performance conditions efficiency	treatment	0.64	0.47	small
F	instructional efficiency	preparedness	0.61	0.27	medium
		treatment	0.65	0.28	medium
	performance efficiency	preparedness	0.33	0.18	small
		treatment	0.45	0.22	small
	performance conditions efficiency	preparedness	0.41	0.21	small
		treatment	0.54	0.25	medium

Summary

Table 22 summarizes the chief outcomes of this study's hypothesis testing. Though there was weak evidence of treatment differences for 2D performance efficiency, but strong evidence of treatment differences for both 2D instructional efficiency and 3D instructional conditions efficiency. Generally, the outcomes support hypotheses that efficiency differences were associated with the use of dynamic vs. static annotations.

Table 22. Summary of hypothesis testing

	Hypothesis	Outcome	
$H1_0$	There is no statistically significant difference in 2D performance efficiency when participants use online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.	$p < .1$	ACCEPT
$H2_0$	There is no statistically significant difference in 2D instructional efficiency when participants use online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.	$p < .05$	REJECT
$H3_0$	There is no statistically significant difference in 3D instructional conditions efficiency when participants use online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.	$p < .05$	REJECT

Three subordinate hypotheses tested whether differences were evident when the data are grouped by treatment × mathematical preparedness (Table 23). 2D instructional efficiency differences were statistically significant ($p < .05$) both for treatment and level of mathematical preparedness. In contrast, no statistically significant 2D performance efficiency differences were found. As expected, 3D performance conditions efficiency, a linear combination of the 2D efficiencies, exhibited a more conservative, blended outcome; with the finding that only differences arising from treatment were statistically significant.

Table 23. Summary of hypothesis testing, by mathematical preparedness

Hypothesis	Outcome	
	Dynamic vs. Static Annotations	Mathematical Preparedness
$H4_0$ Whether prepared or underprepared in mathematics, there is no statistically significant difference in 2D performance efficiency for participants using use online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.	$p < .1$ ACCEPT	$p \geq .1$ ACCEPT
$H5_0$ Whether prepared or underprepared in mathematics, there is no statistically significant difference in 2D instructional efficiency for participants using online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.	$p < .05$ REJECT	$p < .05$ REJECT
$H6_0$ Whether prepared or underprepared in mathematics, there is no statistically significant difference in 3D instructional conditions efficiency for participants using online instructional materials with dynamic annotations compared to participants using online instructional materials with static annotations.	$p < .05$ REJECT	$p < .1$ ACCEPT

Finally, Table 24 confirms rejection of the hypothesis that relationships or interactions between English language skill level and mathematical preparedness were statistically significant.

Table 24. Summary of hypothesis testing, correlation between English language skill and mathematical preparedness

	Hypothesis	Outcome	
$H7_0$	There is no statistically significant correlation between mathematical preparedness and English-language skill level.	$r = .054$	ACCEPT

Chapter 5 begins by revisiting the research questions. Findings and discussion follow, chiefly about 2D instructional efficiency, 2D performance efficiency and the 3D instructional conditions efficiency. A number of observations are described and cognitive load theory based discussion suggesting possible explanations are presented. The chapter concludes with a discussion of technological issues and associated recommendations, discussions on the limitations of the study and, finally, implications and recommendations for further research.

CHAPTER 5. RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

This chapter reports and interprets the chief research outcomes, then discusses limitations of this study, suggesting areas for future research based on the cognitive load theory and outcomes from this study. The research questions for this study were:

1. To what extent does 2-dimensional performance efficiency of the treatment group improve when using dynamic multimedia annotations, compared to using static multimedia annotations?

2. To what extent does 2-dimensional instructional efficiency of the treatment group improve when using dynamic multimedia annotations, compared to using static multimedia annotations?

3. To what extent does 3-dimensional instructional condition efficiency of the treatment group improve when using dynamic multimedia annotations, compared to using static multimedia annotations?

In this discussion, the study's participants are referred to as learners; strong evidence is based on $p < .05$; weak evidence $p < .1$; and, no evidence $p \geq .1$. Though weak evidence cannot be fully relied upon, useful conjectures or hypotheses may arise from weak evidence subject to verification in subsequent studies. Efficiencies were calculated using normalized values for workload and performance, each having a zero sum. This limits analyses to comparisons; efficiency being greater or less for one comparand than for another. Efficiency scores cannot themselves discriminate among different combinations of workload and performance each potentially in a different quadrant or octant but having the same efficiency score. Thorough analysis requires

inclusion of performance and workload components of efficiencies. Visualizations showing relationships among efficiency, workload and performance, Figure 10 to Figure 13, will, therefore, be referred to in this discussion.

Findings and Discussion

Learners using dynamic annotations and learners using static annotations exhibited similar workload, performance and efficiency scores on the assessment of mathematical preparedness. No instruction had as yet taken place, and given this study's definition of extraneous cognitive load as: ―the load placed on working memory by the instructional design itself" (Ayres, 2006, p. 389), the extraneous cognitive load of each groups was zero. The remaining cognitive loads, comprising intrinsic and germane components, are, therefore comparable. There was no evidence that English language skills were correlated with mathematical preparedness, therefore English language skills level is not considered in this discussion.

Instructional Efficiency

Table 25 shows an overall summary of workload and performance. Learners using dynamic annotations exhibited lower instructional conditions efficiency placing them in the undesirable high workload, low performance octant. In contrast, learners using static annotations incurred less workload during instruction and performance and performed better, placing them in the low workload, high performance octant (Tuovinen & Paas, 2004). Because the intrinsic and germane components of the two groups of learners are comparable, the workload differences observed here are attributable to extraneous cognitive load factors.

Table 25. Workload and performance summary, by annotation usage

Annotations	Workload during Instruction	Workload during Performance	Performance
Static	Low	Low	High
Dynamic	High	High	Low

Delivery of Instruction. Both instructional designs were delivered in a playback window. Learners used rewind, replay and fast-forward to manage the pace of delivery supporting the conclusion that the nominal difference in durations—6.6 minutes for static annotations and 11.3 minutes for dynamic annotations—did not significantly affect the study's outcomes.

Unlike static annotations that were displayed all at once, dynamic annotations were displayed little by little. This study revealed strong evidence that instructional

efficiency of learners using static annotations was greater than that of learners using dynamic annotations. Performance was greater and workload smaller than for learners using dynamic annotations. A cognitive load theory based analysis suggests that a kind of temporal split attention effect may have arisen when learners prefer to process visual stimuli at a tempo different from the pace of delivery governed by the narration, though it was observed that many learners modified the pace of presentation using pause, rewind and replay controls to slow down or repeating salient parts of the presentation. No learning benefit accrued from fastforwarding. For the better prepared, fastforwarding mitigated the expertise reversal effect.

Faux Expertise Reversal Effect. For the underprepared, fastforwarding resulted in bypassing key parts of the instruction including essential new knowledge and skills. Misplaced confidence in mal-rules reduced motivation to participate fully in the online learning and increased propensity to fast-forward. The resulting faux expertise reversal effect is similar to what was observed when knowledge workers discontinued using expert systems, their own knowledge and skills substituting for the expert content embedded in expert systems (Liker & Sindi, 1997). The resulting lower level of performance is Vygotsky's zone of proximal development, ―the difference between what a learner can do independently and what can be [or, in this case, what could have been] accomplished cognitively with scaffolding" (Hadjerrouit, 2007, p. 112).

Activation Effect. One could conjecture that key underlying mathematical concepts presented all at once as static annotations early in a learning episode activates prior learning more effectively than dynamic annotations delivered little by little. The resulting activation effect (Ontario Ministry of Education, 2006a; Schraw, 1998) makes

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prerequisite vocabulary, facts, concepts, procedural and supporting information accessible as prior learning is recalled from long term memory into working memory. The result is a constructivist framework for learning, one that provides hooks for integrating new with prior learning. This frees cognitive resources to focus, not so much on the prerequisite elements which, through activation, were recalled from long-term memory, but on new learning and big-picture understanding. This increases the prospect for is deep, relational understanding (Reason, 2003) of underlying principles and processes that could, in future, be applied to novel problems in unfamiliar contexts.

Cognitive Gap. Both instructional designs were underpinned by the same instructional objectives on adding vectors and were targeted at novice learners defined, in this study, as those having mastered prerequisite competencies. Pre-novices, the mathematically underprepared, experienced a cognitive gap which Jablokow & Booth (2006) define as the ―differences between the nature and difficulty of the problem at hand and the cognitive resources of the problem solvers tasked with its solution; … [or] differences between the cognitive abilities and approaches of the problem solvers" (p. 313). This is supported by the patterns in Figure 11 showing that, regardless of whether learners used static or dynamic annotations, the mathematically underprepared performed worse and incurred greater workload than the mathematically prepared ($p < .05$); confirmed by analysis of variance of static vs. dynamic annotation use × mathematical preparedness.

Remediation. Remediation can reduce the cognitive gap but substantial overt remediation along the main instructional trajectory risks: (a) incurring the expertise reversal effect among the mathematically prepared (Kalyuga, et al., 2003); (b) eroding

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entry level expectations, reducing prerequisite competency requirements to mere recommendations; and, (c) adequate covering new learning because of time and resources being redirected towards remediation. An alternative is to incorporate sidebar on-demand remediation, scaffolds focused on prerequisite competencies. An unresolved need state must be created (Kamradt & Kamradt, 1999) to initiate a new learning task and motivate underprepared learners to access remedial learning; some underprepared learners confidently (but unreasonably) rely on mal-rules when solving problems (Self, 1990) and, consequently, may be unaware that remediation is needed.

Adaptive Delivery of Remediation. An adaptive delivery approach (van Merriënboer & Ayres, 2005) to remediation uses ―an internal model of a [learner‘s] current knowledge to adjust the navigational affordances and presentation order of material … updated as the [learner] demonstrates mastery by completing exercises and tests" (Agarwal, Edwards, & Pérez-Quiñones, 2006, p. 259) acting, essentially, as a traffic light: green for the prepared to move on; red for the underprepared to pause and undertake sidebar remediation; and yellow to proceed with caution when sufficient prerequisite competencies were learned and mal-rules, if evident, were corrected. Because of the stigma associated with ―remediation", care should be taken to position prerequisite learning in a favorable light, for example, ―foundation" learning, otherwise some learners may balk.

Depth of Remediation. Instructional designers usually make some assumptions about the characteristics of the learner vis-à-vis their experience and competency in prerequisite skills. When prerequisites are not well met, time and content flexibility and layers of remediation extend beyond what is required to directly support an instructional

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episode. Mathematical concepts are interconnected and remedial scaffolding may require scaffolding, etc., thereby bridging not only the cognitive gap but also gaps in cognitive gaps; extending recursively to the most elementary of mathematical facts, concepts, procedures, processes and principles. Though not advocating an impossible theory of everything, it is sensible to implement remedial learning instruction prioritized according to learner needs. A suite of reusable learning objects may benefit a very large number of learners. Per capita development and maintenance costs are reduced when broadly shared by science, technology and engineering as well as other areas like business studies.

      Channeling of Procedural and Supporting Information. An outcome of the instructional design using static annotations is channeling: visual images contributed mostly procedural information; and, audio narration contributed chiefly supporting information relating to problem solving skills. Both procedural and supporting information were needed for deeper learning and, in the mind of a learner using static annotations, this pattern of information delivery may have aided in organizing and collating the visual with auditory signals during active learning. Essentially, cognitive information was channeled to the visual pathway, and metacognitive information to the auditory pathway. Dynamic annotations mixed procedural with problem solving information and may have appeared less organized and more difficult to assimilate with prior learning. Thought processes appeared blurred making it difficult to distinguish cognitive from metacognitive concerns.

Learner Differences. A greater power distance is evident when relationships—in this study, between learner and instructional design—are formal (Hofstede, 2003). Static annotations presented as word processed text or equations are more formal which learners perceived as authoritative and prescriptive procedural steps. In contrast, handwritten dynamic annotations are informal and a narrower power distance results. Learners may perceive dynamic annotations as advisory or heuristic to be treated less seriously as more formally expressed content.

A learner with a strong aversion to uncertainty likely performed better using static annotations delivering procedural information all at once (Hofstede, 2003) followed by audio narration describing how that information was to be used to solve the problem at hand. Dynamic annotations used by uncertainty avoiders may increase extraneous cognitive load due to frustration about perceptions of missing or incomplete information, time pressure or pressure to perform; three of the NASA-TLX dimensions of workload (Hart, 2007; Hart & Staveland, 1988). Unlike the activation effect that awakens prior learning, one could conjecture an alternative to uncertainty avoidance; that a conditioning effect occurs, where static annotations presented in advance of imminent new instruction condition (prepare) the learner for the next learning steps. The conditioning mechanism may be as simple as a read-ahead buffer where the learner's visual pathway inputs and preprocesses the content of the annotations. A few moments later, the audio narration describing how the content of the annotations are used are collated with the visual input, the sense making stage of active learning.

Performance Efficiency

While instructional efficiency is ―more suited for situations in which the intention is to reduce extraneous load" (de Jong, 2009, p. 17), performance efficiency aims ―to increase germane load" (p. 17). Performance efficiency embeds post instruction performance assessment and workload thereon, reflecting the degree of learning achieved. No instruction takes place during post instruction performance assessment so the workload excludes extraneous cognitive load; intrinsic and germane cognitive loads remain. All learners completed the same post instruction performance assessment, therefore, learners using static annotations and learners using dynamic annotations should have experienced equivalent intrinsic cognitive loads. For performance efficiency, therefore, differences in workloads are attributable to differences in germane cognitive load.

This study found weak evidence of greater performance efficiency for learners using static annotations than learners using dynamic annotations. Paradoxically, performance was greater for learners using static annotations and germane cognitive load was greater for learners using dynamic annotations. Learners using static annotations performed better, but expended less germane cognitive load suggesting achievement at a level closer to instrumental than relational understanding. Cognitive load theory suggests that expending greater germane cognitive load results in greater performance. Learners using dynamic annotations expended greater germane cognitive but performed worse. One explanation for this observation is that relational (deep) understanding takes time to develop (Schraw, 1998).

Though not statistically significant, the patterns associated with dynamic and static annotations (Figure 12) support this supposition. Prepared learners using dynamic annotations performed better expending greater germane cognitive load than underprepared learners. Because they were better prepared to begin with, prepared learners were more able to integrate new with prior learning, resulting in relational understanding. The pattern associated with of static annotations was perpendicular. Prepared learners performed better but expended less cognitive load than underprepared learners. They may have achieved a level of instrumental understanding of the subject matter that allowed them to perform at a higher level. In contrast, underprepared learners using static annotations needed to expend more germane cognitive load but fell short of instrumental understanding on account of their underpreparedness. Neither pattern is supported by statistically significant data so conclusions based on them are tentative, requiring verification in follow-up studies.

The minimal time between instruction and post instruction performance assessment preempted necessary reflection and other key metacognitive processes so necessary to achieving relational understanding, thereby resulting in the observed lower performance. De Jong (2009) agrees: ―short study times and with students who have no direct engagement with the domain may very well be used to test the basic cognitive mechanisms of cognitive load theory but raise problems when these results are translated into practical recommendations‖ (p. 20).

Instructional Conditions Efficiency

Instructional success is reflected in instructional efficiency and learning success in performance efficiency. An alternative perspective of the latter is offered by task

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involvement. 3D instructional conditions efficiency encapsulates all of these

simultaneously, requiring the three dimensional view of Figure 13. Two of these views

are exactly those that correspond to the graphs of 2D instructional and 2D performance

efficiencies (the lower two graphs of Figure 13).

The focus of this section, therefore, dwells on the third perspective: germane

cognitive load during post-instruction performance vs. extraneous cognitive load during

instruction; excised and reproduced in Figure 14.

Figure 14. Graph of germane cognitive load during performance vs. extraneous cognitive
load during instruction.

There was strong evidence that instructional conditions efficiency was greater for learners using static annotations than for learners using dynamic annotations. For learners using static annotations, both extraneous cognitive load during instruction and germane cognitive load during post-instruction performance were lower and performance higher than for learners using dynamic annotations.

Technological Issues

Though a learner could actively scan visual content during fastforwarding, the audio channel would muted and therefore unavailable. This suggests a technology-motivated role for annotations. To provide a visual cue that important new information follows is not itself anything new or unusual, but for such an annotation to be evident during fastforwarding, it must be of sufficient duration (due to time compression) and durability (static rather than dynamic) to be observable. The presence of such annotations, would provide learners opportunities to alter fastforwarding strategies to dwell on constituent tasks flagged by annotations as important and worthy of learner attention. However, overuse of such a construct may encourage some learners to simply hop from one important and worthy teaching point to another. Under these circumstances, learning is limited to discrete chunks as seemingly unrelated constituent tasks are learned; missing is the broader whole task perspective afforded by the intervening content that serves to bind the chunks into a cohesive, sensible whole.

It could be argued that the visual highlighting of keystrokes helped learners struggling with calculator skills. A part of dynamic annotations, audible clicks accompanied visual highlights but contributed to increasing the noise to signal ratio resulting in increased extraneous cognitive load as evidenced by informal exit polling.

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Several learners commented that the clicks were annoying, distracting or unnecessary; their feedback is consistent with the redundancy effect.

Limitations of the Study

This study followed a data collection plan similar to those of many other studies; learners completed workload self assessment immediately after instruction then completed a performance task. The resulting instructional efficiency, is, therefore at best an approximation of the actual instructional efficiency where both workload and performance data would be obtained during. There is a danger of systemic error in that data collected after instruction skews workload assessments towards the most recent, more memorable or most difficult learning experience even though many elements of the instruction, such as heavily scaffolded learning early in a simple to complex whole task sequence, may have incurred a very low workload (T. van Gog, personal communication, November 13, 2009). An alternative is to prompt learners frequently during instruction thereby adding a temporal dimension to workload surfacing workload fluctuations become evident during active learning. Frequent assessment of workload (and performance for that matter) may offer evidence based understanding of how scaffolding of different kinds aid in the learning process and how this changes as scaffolds are faded during a simple to complex whole task sequence.

Frequent performance and workload assessments during learning likely preempt the use of the NASA-TLX instrument due to its complexity. There was some evidence of participant fatigue due to the effort associated with providing twelve workload related responses each time it is used. This was evident in this study; a number of later workload reporters were left blank, akin to spoilt ballots at election time. A subjective Likert scale

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is easier to administer more frequently at various times during instruction, though it still relies on subjective feedback; each learner reporting workload measured using a different personal yardstick. It may be useful to research ―new ways to measure cognitive load based on neuroscientific techniques" (de Jong, 2009, p. 22) or other objective biometric feedback mechanisms such as heart rate, blood pressure, body temperature, breathing rate or eye movement as potential indicators of increased workload, stress or frustration.

The minimal time between instruction and post instruction performance assessment preempted necessary reflection and other key metacognitive processes so necessary to achieving relational understanding, thereby resulting in the observed lower performance. De Jong (2009) agrees: ―short study times and with students who have no direct engagement with the domain may very well be used to test the *basic* cognitive mechanisms of cognitive load theory but raise problems when these results are translated into practical recommendations" (p. 20).

Task involvement, where germane cognitive load and performance are added rather than subtracted (F. Paas, Tuovinen, van Merriënboer, & Darabi, 2005), may be a better construct to use for the present analysis than performance efficiency. Greater task involvement arises when germane cognitive load and performance are greater. The data points for task involvement are the same as for performance efficiency, but distance is measured from data points to the line $performance = -workload$. Revisiting Figure 12, it is evident that all three points associated with static cognitive loads are quite near this line resulting in small task involvement scores. In contrast, prepared learners using dynamic annotations resulted in the greatest task involvement scores. This has

implications not only for the choice of annotations but also for instructional designs used by underprepared learners.

Implications and Recommendations for Future Research

The three main recommendations that come from cognitive load theory are: present material that aligns with prior knowledge of the learner (intrinsic load), avoid non-essential and confusing information (extraneous load), and stimulate processes that lead to conceptually rich and deep knowledge (germane load). (de Jong, 2009, p. 22)

If a form of continuous cognitive load reporting were available and if researchers were able to distinguish among intrinsic, extraneous and germane cognitive loads, then changes in the magnitude and composition of total cognitive load could be analyzed at different stages of active learning or problem solving (performance). Research in these areas could yield greater and richer insight and understanding of active learning and the impact of the various cognitive load effects thereon.

Further research is needed to confirm whether, as conjectured in this study, dynamic annotations facilitate relational understanding. This requires modification to the data collection process to allow sufficient time for relational understanding to develop; delaying or supplementing data collection days or weeks after the learning event. There is a danger; data collected days or weeks after learning may be contaminated due to other learning or experiences occurring between learning and data collection. At first glance, one might have a similar concern over learner forgetfulness, but this could simply be an outcome resulting from failing to achieve relational understanding. In this study, assessment of performance occurred minutes after instruction. It is unclear how much of

what was learned was retained after weeks or months and whether what was retained was instrumental understanding or relational understanding.

Hofstede's five dimensions of culture (1980, 2003, 2004) help describe the dissonance between the target culture of the learning environment and the source cultures of learners. Some of these dimensions, like uncertainty avoidance and power distance directly impact on instructional designs and can be accommodated by the 4C/ID process. These or the other dimensions—individual vs. group orientation, task vs. people orientation or perspectives on time—also impact on online instructional designs but in different more personal ways. Further research may confirm that consideration of Hofstede's five dimensions of culture may improve instruction particularly when cultural dissonance is evident.

It may be that too much information is lost when efficiency or task involvement are calculated. Many different scenarios may generate the same efficiency or task involvement scores. Further research is needed to determine whether efficiency or task involvement add value to understanding research outcomes vis-à-vis using two or three separate scores—workload during learning (reflecting intrinsic cognitive load), workload during post learning performance assessment (reflecting germane cognitive load), and performance—provide richer insights. Further research is needed to find ways of measuring the different elements of cognitive load, intrinsic, extraneous and germane, *during instruction* when investigating instructional design alternatives.

Conclusions

Learning successes can improve if learners ―spend a sufficient amount of time applying the targeted skills in a meaningful context, … have the opportunity to observe skilled experts … [and] have access to an expert's reflection on what he or she is doing" (Schraw, 1998, pp. 122-123). It is exactly these principles that underlie the use of dynamic annotations that demonstrate processes accompanied by narration describing the rationale underlying the expert's reasoning.

The four component instructional design model, in part, formalizes what many teachers already do. Countless text books, many in mathematics or physics, present solved problems for study, then require learners to engage in a sequence of task completion and part task practice, all key elements of 4C/ID (van Merriënboer & Kirschner, 2007; van Merriënboer, et al., 2003). But 4C/ID also places learning in much more of a real world context with a focus on whole tasks and fading of scaffolds, during a series of elaborations during a simple to complex sequence and supported by just-in-time procedural information and supported by information relating to problem solving and other metacognitive strategies.

Media conversion efforts to adapt textbook learning materials to electronic form must consider such theories as the cognitive theory of multimedia learning (Mayer & Moreno, 2001) and cognitive load theory generally to produce compelling visual, auditory and indeed audiovisual learning resources while resisting the urge to dilute the learning focus with seductive content. This does not mean that instructional designs need to be bland and there may be a role for content of a motivational nature preceding actual

learning events as recommended in the three part lesson plan (Ontario Ministry of Education, 2006b).

Hofstede's dimensions of culture (Hofstede, 1980, 2003), though not sufficient to satisfy an anthropologist's curiosity on culture and cultural differences, do provide quite interesting and useful heuristics that can be applied to instructional designs to define a desired target culture for both physical or virtual classrooms, to bridge cultural dissonance, and perhaps also to untangle cultural differences from the quite separate issue of subject matter underpreparedness evident when prerequisite competencies are not met,

Audiovisual resources have been used to support educational efforts for many years. Today's inexpensive production tools and high capability computer hardware make it easy for educators and learners to create narrated video tutorials in real time and to publish these as a value-added alternative to static learning resources such as text books. Annotations serve to motivate and focus attention, and add supplementary information to underlying learning materials. There is a difference in learning outcomes when dynamic annotations are used vis-à-vis static annotations. Though not reflected in instructional efficiency, performance efficiency, or for that matter task involvement, the quality of learning outcomes needs to be understood as well—do learning outcomes result in instrumental —rules without reason" mechanical understanding resulting in replication of learned procedures or did learning outcomes result in deep, relational understanding? Metacognitive processes such as self-monitoring learning progress, adapting strategies, self-reflection, self-responsibility, initiative, goal setting and time management (Halter, 2003) are necessary to achieve relational understanding that, with experience, ultimately leads to acquisition of expertise.

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In conclusion, the cognitive load theory, cognitive theory of multimedia learning, active learning and problem solving models, the dimensions of culture and the four component instructional design model together provide a rich tool set for instruction designers and researchers.

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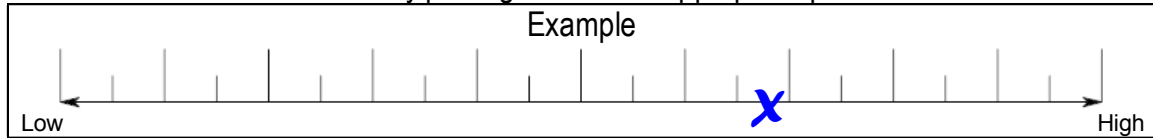
Workload Reporter (Part 1)

Research by NASA (the National Aeronautics and Space Administration) identifies six factors that contribute to workload associated with challenging tasks: demands of thinking, physical demand, time demand, task effort, task success, and frustration experienced while on task.

Please take a moment and rank each of the following contributors to workload from most important to least important contributors to your workload while performing the previous task.

	1=Most important 2 : 3 : 4 : 5 : 6=Least Important
Demands of Thinking **How much thinking was necessary to perform the task?** *How much looking, searching, thinking, calculating, deciding, remembering was there?* *Was the task easy or demanding? simple or complex? exacting or forgiving?*	The importance of demands of thinking is:
Physical Demand **How much physical work was required to perform the task?** *How much pushing, pulling, turning, controlling, activating?* *Was the task easy or demanding? slow or brisk? slack or strenuous? restful or laborious?*	The importance of physical demand is:
Time Demand **How much time pressure did you feel due to the pace of the task?** *Was the pace slow and leisurely or rapid and frantic?*	The importance of time demand is:
Task Effort **How hard did you have to work to accomplish your level of performance?**	The importance of task effort is:
Task Success **How successful do you think you were?** *Did you accomplish the goals of the task? How satisfied were you with your performance?*	The importance of task success is:
Frustration experienced while on Task **How frustrated were you while completing the task?** *How secure/insecure were you? discouraged/gratified? irritated/content? stressed/relaxed? annoyed/complacent?*	The importance of frustration while on task is:

Workload Reporter (Part 2)

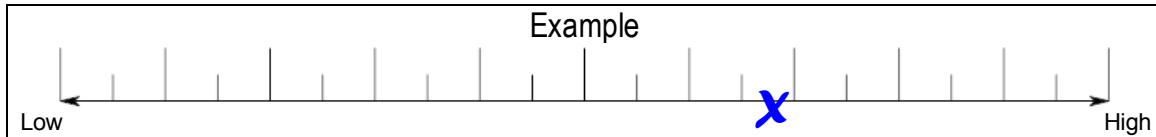Rate each of the factors by placing an X at the appropriate position on the scale.

Example

Low   **X**   High

Demands of Thinking
How much thinking was necessary to perform the task?

very little thinking   a lot of thinking

How much looking, searching, thinking, calculating, deciding, remembering was there?
Was the task easy or demanding? simple or complex? exacting or forgiving?

Physical Demand
How much physical work was required to perform the task?

very little physical activity   much physical activity

How much pushing, pulling, turning, controlling, activating?
Was the task easy or demanding? slow or brisk? slack or strenuous? restful or laborious?

Time Demand
How much time pressure did you feel due to the pace of the task?

little time pressure   a lot of time pressure

Was the pace slow and leisurely or rapid and frantic?

Effort
How hard did you have to work to accomplish your level of performance?

not hard at all   very hard

Success
How successful do you think you were?

not at all successful   very successful

Did you accomplish the goals of the task? How satisfied were you with your performance?

Frustration
How frustrated were you while completing the task?

noit frustrated at all   very frustrated

How secure/insecure were you? discouraged/gratified? irritated/content? stressed/relaxed? annoyed/complacent?
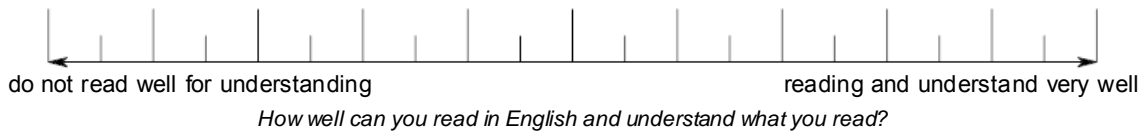
English-Language Reporter

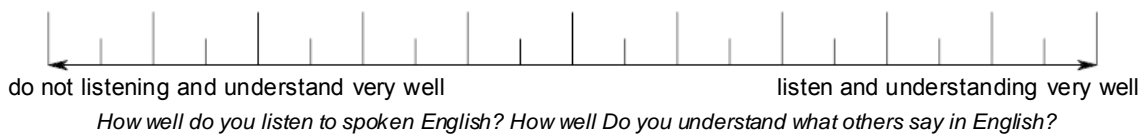Rate each of the factors by placing an X at the appropriate position on the scale.

Example

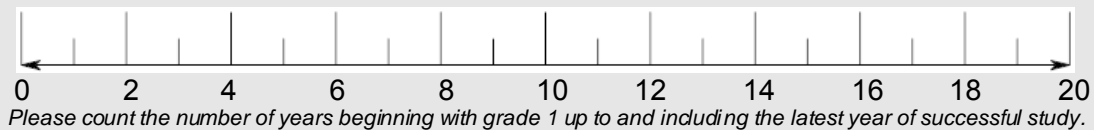Low ———————————————————————————— **X** ———— High

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Reading Skills in English

do not read well for understanding   reading and understand very well

How well can you read in English and understand what you read?

Writing Skills in English

do not write well for others to understand   write very well for understanding

How well can you write in English? How well can others understand what you write in English?

Listening Skills in English

do not listening and understand very well   listen and understanding very well

How well do you listen to spoken English? How well Do you understand what others say in English?

Years of Education in a School where English is the language of instruction

0   2   4   6   8   10   12   14   16   18   20

Please count the number of years beginning with grade 1 up to and including the latest year of successful study.

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APPENDIX C. MATHEMATICAL PREPAREDNESS ASSESSMENT

Please answer what you can in an hour. Thank you.

1. Evaluate.

a. $(2^3)(2^5)$

b. $(-6)^3$

c. $(5^3)^2$

d. 2^{-3}

e. 1.01^{120}

f. $\left(\dfrac{1}{2}\right)^3\left(\dfrac{1}{2}\right)^2$

g. $27^{\frac{1}{3}}$

2. Perform these calculations. *Do not use negative exponents in your final answers.*

a. $\left(\dfrac{1}{2}x+1\right)(3x-2)$

b. $5(3x-1)^2$

c. $a^7 \times a^4$

d. $(2x)(3x)$

e. $2x(x+3)$

f. $x^3 \div x^5$

g. $\dfrac{a^2 b^5 c^5}{ab^{-3}c^4}$

h. $(3a^2b^5 \div c)^0$

i. $(2x+1)+(x^2-3x+4)$

j. $(2x+1+y)-(-7x+3+y)$

3. Solve.

a. $\dfrac{x}{4}=\dfrac{15}{20}$

b. $2x+7=6x-1$

c.

$x^3-2x^2-8x=0$

4. Round these numbers to **three** significant digits.

a. 14260

b. 6.493×10^{-12}

c. 9.99999

5. A skateboard ramp has a ratio of height to the base of 2:3. What expression may be used to determine the length of the base of the ramp if the height is 4.5 m? *(no calculation required)*

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6. Which of the following is the better value: 500 ml of juice costing $2.29 or 750 ml costing $3.59? Explain your answer.

7. One container is a cube with an edge length of 8.1 cm. Another is a cylinder with radius 4.5 cm and height 8.0 cm. Which container holds more popcorn? Show your work.

8. The perimeter of a rectangle is given by $P = 2l + 2w$. If the perimeter is 59 cm and the width is 12 cm, what is the length of the rectangle? Show your work.
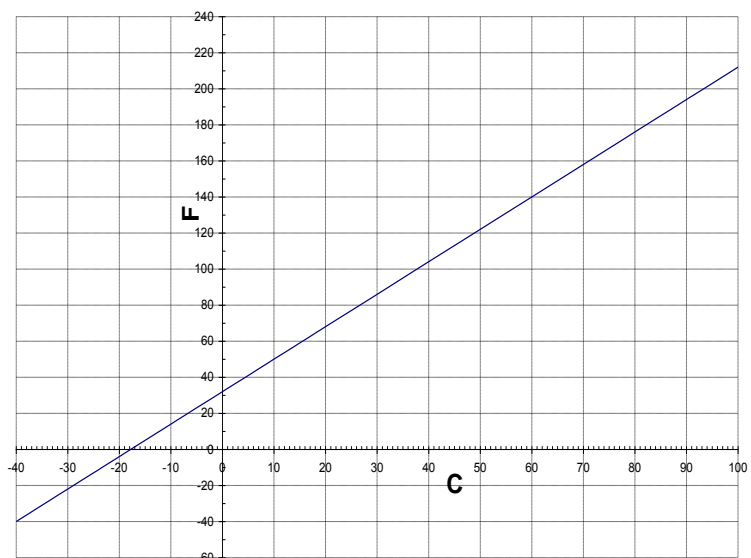
9. Maria's annual salary is represented by $s = 32500 + 500y$, where y is the number of years on-the-job. Ruth's annual salary is represented by $s = 28000 + 1000y$. After how many years will their salaries be the same? What is their salary at that time? Show your work.

10. How many cubic yards of concrete are required to pour a concrete pad measuring 10 feet by 10 feet by 1 foot? If the cost per cubic yard is $110, what is the cost of a driveway requiring 6 pads? Show your work.   (1 yard = 3 feet)

11. Refer to the graph.

a. If the temperature is $-5°C$, what is the equivalent temperature in degrees Fahrenheit?

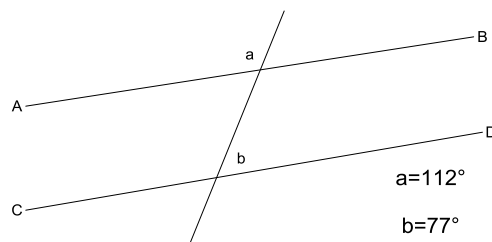b. If the temperature is $130°F$, what is the equivalent temperature in degrees Celsius?

12. Mei is raising funds for a charity walk-a-thon. The course is 25 km and she walks at 4 km/h. Set up an equation that describes the distance she has left to walk (d) as a function of time (t), the number of hours since she started the walk. *(no calculation required)*

$d = f(t) =$

13. $h = 300 - 60t$ is the height of a hot-air balloon, initially at height 300 m, and descending at a rate of 60 m/min. What is the height of the balloon at 3.5 min?

14. Are the lines AB and CD parallel? Explain your reasoning.

a=112°

b=77°

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15. Bill noticed it snowing and measured that 5 cm already fell. During the next hour, another 1.5 cm falls. If snow continues to fall at this rate, how many hours will it take until a total of 12.5 cm of snow has accumulated?

16. A breakfast cereal is sold in a small box. Ralph believes that he doubles the volume by doubling each dimension of the original box. Is he correct? Explain your answer.

17. Match each description with the lines on the graph. The cost of producing a yearbook is:

a. $1000 plus $6 per copy

○ A   ○ B   ○ C   ○ D

b. $1200 plus $6 per copy

○ A   ○ B   ○ C   ○ D

c. $1200 plus $8 per copy

○ A   ○ B   ○ C   ○ D

d. $15 per copy

○ A   ○ B   ○ C   ○ D

18. The revenue generated by the sale of tennis shoes is given by the function $r(s) = -10s^2 + 1500s$ where s is the selling price. Which of the following results in the greater profit?

○ $r(29.95)$ ○ $r(130)$ ○ $r(90)$ ○ $r(75)$ ○ $r(60)$

19. Construct a table of values and a graph to represent a monthly cell phone plan that costs $25 per month plus $0.10 per minute for air time.
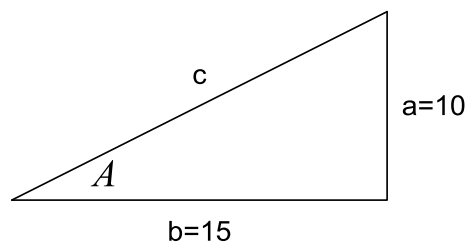

20. The height (in m) of a bouncing ball after n bounces is given by $h = 2(0.6)^n$. Determine the height of the ball after three bounces.
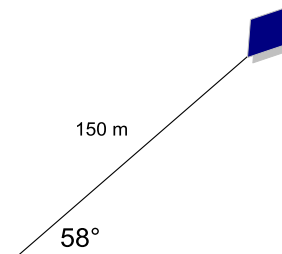
21. Refer to the diagram. Evaluate each of the following:
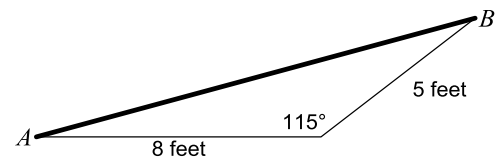
$\sin A =$

$\cos A =$

$\tan A =$

22. Refer to the diagram of a kite being flown on a windy day. If the length of the string is 150 m, what is the height of the kite?

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23. The future value of an investment is given by $FV = PV(1+i)^n$ where PV is the amount of money being invested now, i is the interest rate per compounding period, and n is the number of compounding periods. What is the future value of $10000 invested at 6% per year compounded quarterly, for three years? Show your work.

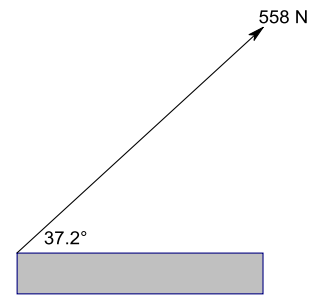24. A plumber must cut a piece of pipe to fit from A to B. How long is the pipe? Show your work.

25. On planet *Xero* the height in meters, h, of an object fired upwards from the ground is given by $h = 48t - 16t^2$, where t is time in seconds.

a. At what times is the object 32 m above the ground? Show your work.

b. At what time does the object hit the ground? Show your work.

c. At what time is the object at maximum height? Show your work.

26. A cable exerts a force on a street sign, 558 N at an angle of 37.2° as shown in the diagram. Resolve (split) this force into its vertical and horizontal components. Show your work.

558 N

37.2°

END OF TEST

Please now complete the

Workload Reporter

and the

English-Language Reporter.
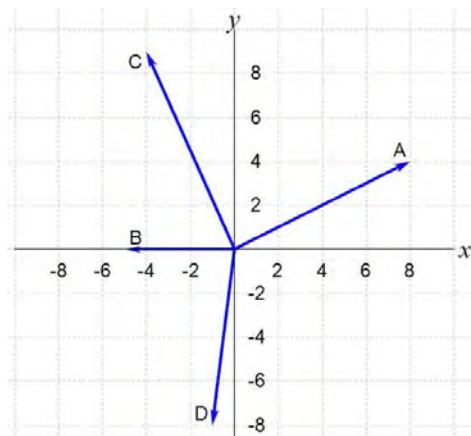
Thank you.

APPENDIX D. PERFORMANCE ASSESSMENT

1. Express the following vectors in rectangular (x, y) format:

a. $A($, $)$

b. $B($, $)$

c. $C($, $)$

d. $D($, $)$

2. Add the following vectors, showing your work.

a. $A(4,3) + B(6,2.5)$

   $=$

   $= R($, $)$

b. $C(-2,4) + D(6,-9)$

   $=$

   $= R($, $)$

c. $S(4,5) + T(6,-3) - U(10,2)$

   $=$

   $= R($, $)$

d. $2U(4,2) + 3V(3,-2)$

   $=$

   $= R($, $)$

3. Imagine stepping up from two-dimensional (x, y) to three-dimensional (x, y, z) vectors. Add the following vectors, showing your work.

a. $A(2,4,3) + B(4,-2,2) + C(-1,3,3)$

   $=$

   $= R($,   , $)$

b. $P(1,0,1) + Q(1,-1,2) + S(0,1,4)$

   $=$

   $= R($,   , $)$

4. Convert the following vectors from polar $r\angle\theta$ format to rectangular (x, y) format. Show your work.

a. $\vec{a} = 3.5\angle 55.5° =$

b. $\vec{q} = 3.5\angle -155.5° =$

c. $\vec{c} = 7.15\angle 0° =$

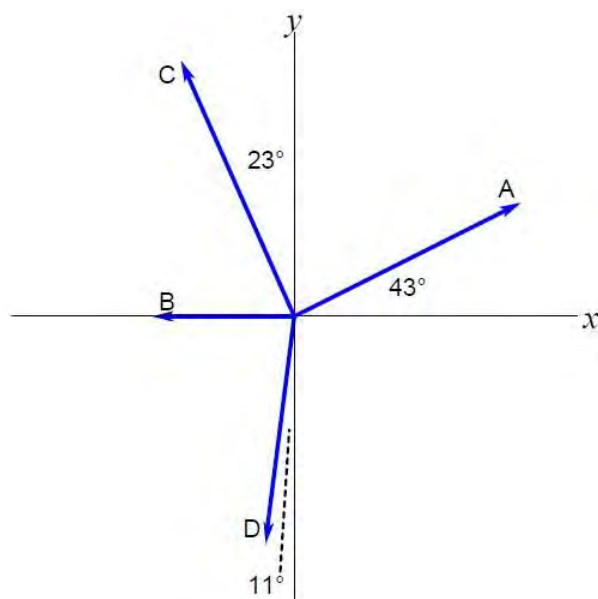5. Convert the following vectors from rectangular (x, y) to polar $r\angle\theta$ format. Show your work.

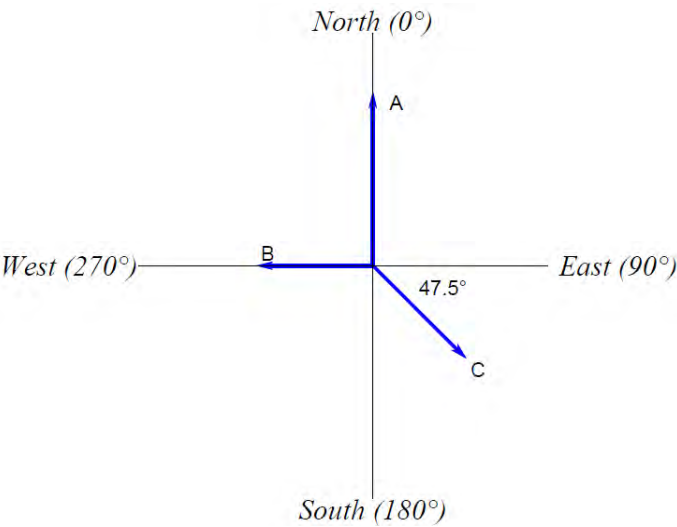a. $A(3,4) =$

b. $V(-3,-7) =$

c. $J(0,0) =$

d. $Q(1.53,-3.73) =$

6. Add the following vectors. Show your work.

Vector #	r	θ	Δx	Δy	Show work here:
A	8.93				
B	5.00				
C	9.98				
D	8.11				
		Σ			
Resultant:					

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7. Add the following vectors. Show your work.

North (0°)

A

West (270°)————B————East (90°)

47.5°

C

South (180°)

Vector #	r	θ	$\Delta east$	$\Delta north$	Show work here:
A	3.5				
B	2.5				
C	2.8				
		Σ			
Resultant:					

8. In the *mathematics world*, 0 degrees is to the right (along the *x* axis) and angles increase counter-clockwise. In the above *navigation* problem, north is zero degrees and angles increase clockwise. These are two *frames of reference*. How many frames of reference are there? Explain.

9. What adaptations would you make to add 3-dimensional vectors expressed in polar format given the magnitude (r), direction (θ), elevation (φ) of each?

END OF TEST

Please now complete the

Workload Reporter

Thank you.

APPENDIX E. MATHEMATICAL ASSESSMENT RUBRICS

0-1-2 Assessment Rubric

Applicable to short answer questions:

0	1	2
None of the requirements of the solution are met	Some requirements of the solution are met	All requirements of the solution are met
No evidence of mathematical reasoning or problem solving	There is some evidence that incorrect mathematical rules (mal-rules) are used or correct mathematical rules may be misapplied	Correct mathematical rules are applied; there is no evidence of mal-rules
No meaningful results were obtained	Partially correct results were obtained	Meaningful and correct results were obtained; where necessary, results were correctly rounded with units shown

0-1-2-3-4 Assessment Rubric

Applicable to all other questions:

0	1	2	3	4
Question is wholly unanswered	None of the requirements of the solution are met	Some (a third or less) of the requirements of the solution are met	Most (two-thirds or more) of the requirements of the solution are met	All requirements of the solution are met
No evidence of mathematical reasoning or problem solving	There is strong evidence that incorrect mathematical rules (mal-rules) are used	There is some evidence that incorrect mathematical rules (mal-rules) are used	Correct mathematical rules are used but may be are misapplied	Correct mathematical rules are applied; there is no evidence of mal-rules
No results were obtained	No meaningful results were obtained	Partially correct results were obtained	Meaningful and correct results were obtained though not necessarily correctly rounded; units may be missing	Meaningful and correct results was obtained; where necessary, results were rounded with units shown