CONCEPTUAL MODEL DESIGN FOR BETTER UNDERSTANDING

by

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ABSTRACT

The consistent underperformance of information systems developments (ISD) projects over the last 30 to 40 years has lead researchers and practitioners to recognize that there is significant room for improvement in the development process. Tools used for ISD have evolved in the continuous search for improved project success rates. The introduction of structured methodologies, object oriented methods, the unified modeling language (UML), and agile development have resulted in incremental advances. However, it is believed that problems persist because of the difficulties of understanding systems requirements.

ISD research has traditionally focused on introducing tools that better represent the system under development but has largely ignored the user's cognitive abilities to understand the representation. This results in miscommunication between analysts and users. This study takes a user-centric approach to investigate presentation techniques of conceptual models that can facilitate users' understanding of complex representations.

The research extends theories from cognitive psychology to the field of Information Systems Development. The cognitive load theory describes sources of cognitive load that either impede learning and understanding (extraneous or intrinsic cognitive load) or promotes understanding such as germane cognitive load. The Cognitive Theory of Multimedia Learning (CTML) introduces presentation techniques that can reduce extraneous cognitive load.

Two experimental studies were conducted to measure the effectiveness of applying CTML principles to the requirement gathering phase of ISD projects. The experiments manipulated popular modeling methods (entity-relationship diagrams and the UML diagrams) to show that applying design principles to reduce extraneous cognitive load can lead to better understanding.

Contributions include the introduction of a user-centric approach to ISD research, extending cognitive theories to systems analysis, and proposing design updates to CASE tools to take advantage of presentation techniques uncovered during the experiments.

Keywords: cognition, cognitive theory, extraneous, germane, conceptual models, UML

To my beloved Wafaa

To my amazing children: Lynn, Mona, and Kareem

To my loving parents: Abdallah and Souad

This one is for you!

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CHAPTER 1
INTRODUCTION

1.1 Introduction

Information system development (ISD) is a complex set of activities that involves many people in differing roles within an organization. High profile ISD project failures have prompted many researchers to investigate factors that influence the success and failures of ISD projects (Fortune & Peters, 2005; Sauer, 1993; Warne, 2003). While the definition of ISD project success is changing (Kohli & Grover, 2008), a project is generally considered successful if it is completed on budget, on time, and with the desired functionality. The research program detailed in this thesis addresses the general issue of improving ISD project success rates specifically by improving the communication of information system requirements across stakeholders involved in the ISD process.

The 1995 'Chaos Report' publicized the difficulties of completing ISD projects when it suggested that only 16% of these projects could be considered successful (Standish Group, 1995). Lack of user participation and incomplete requirements were cited as the top two reasons for failed or challenged projects. The term "software crisis" was also used to describe the difficulty in consistently completing successful ISD projects (Gibbs, 1994). In 2000, the Standish Group's 'Extreme Chaos' (Standish Group, 2001) reported improvements in overall project success rates, but at 28% continued to be far lower than desired. Once again, user involvement and firm basic requirements were

among the top factors influencing project success. Slight improvements in performance continued in 2006 with project success rates measured at 35% (Rubinstein, 2007).

Critics of the Standish group question the methodology used to produce these statistics. A lack of transparency in the private, for profit, research firm's definitions and analysis is cited as a potential bias toward failed projects (R. Glass, 2005, 2006). Other critics believe the survey instruments are biased towards exaggerating some statistics such as cost overruns, especially those found in the early Chaos reports (Jørgensen & Moløkken-Østvold, 2006). Different studies suggest that information technology projects perform far better than is implied by the Standish group (Sauer, Gemino, & Reich, 2007). Sauer et al. indicated that only 33% of projects can be classified as failed or challenged. The numbers vary widely depending on how one classifies a successful project (Schwartz, 2004), but regardless whether the actual success rate is closer to 35% or 67%, it is clear that ISD projects still have considerable room for improvement.

Practitioners also recognize there is considerable room for improvement in system development projects (Ambler, 2007). As Marasco (2006, p. 1) notes *"we are not getting better fast enough, despite spending billions of dollars on software development technology and tools."* There has been progress in the basic tools for ISD. The progress has resulted in development methodologies such as functional decomposition, structured analysis (DeMarco, 1978; Gane & Sarson, 1979; Yourdon & Constantine, 1979), object oriented methods (Coad & Yourdon, 1990, 1991; Jacobson, 1991; Rumbaugh, Blaha, Premerlani, Eddy, & Lorensen, 1991), Unified Modeling Language (UML) (Jacobson, Booch, & Rumbaugh, 1999) and agile development (Highsmith, 2000). Development tools have also shown considerable progress with enterprise software development

platforms and sophisticated programming languages such as C++, Java, and C#. What is important to note is that despite the positive impact of these tools and methods on overall system development productivity, ISD continues to experience less than stellar success rates.

Many believe that the challenges of ISD are not simply the result of improper tools or methodologies (Brooks, 1987, 1995). Problems persist because of the difficulties of understanding the requirements for a system. Information system requirements can be defined as *"the discipline for developing a complete, unambiguous specification – which can serve as a basis for common agreement among all parties concerned – describing what the product will do (but not how it will do it; this is to be done in the design specification)"* (Boehm, 1976, p. 1227). Concern about successful requirements engineering is not a recent phenomenon. Research about the importance of requirements engineering can be traced back to the 1970s when it was concluded that software requirements are important and that problems associated with requirements are similar across project types (Bell & Thayer, 1976). The problem clearly persists as noted by Marasco (2006, p. 3) *"requirements are often ambiguous, unclear, incomplete, or contradictory."* It seems that little has changed even with the progress made in methodology and tools.

Ambiguous or incomplete requirements are a difficult challenge to address, which is a likely reason why problems with requirements persist. The challenge cannot be addressed directly by improving software engineering tools. These tools focus on improving the quality of software once requirements are identified. The problem of requirements occurs earlier in the process. Tools better able to elicit and communicate

requirements are needed to communicate these requirements between various stakeholders in the system development process. Dramatic improvements in ISD project success rates can only be achieved by improving the process of requirements gathering. This will lead to improved understanding by all parties earlier in the development process which has the potential for a more organized and effective design process.

Improved requirements will enable projects teams to more efficiently and effectively devote resources to developing system solutions well understood by stakeholders, system analysts and system integrators/developers. Many outside of the field of ISD would suggest improving requirements is an obvious solution. Indeed, researchers have been calling for this mutual understanding for some time (Brooks, 1995). The important question to address is what barriers deter and even prevent communication between the various people involved in ISD projects?

1.2   Difficulties with ISD Requirements Communication

The general purpose of ISD projects is to improve "Work Systems" defined as *"...a system in which human participants and/or machines perform work using information, technology, and other resources to produce products and/or services for internal and external customers"* (Alter, 2003, p. 368). Elements of a work system include: participants, information, technologies, work practices, products and services, and customers (Alter, 2003). An effective work system addresses the needs of human participants and organizational requirements using relevant technologies. Work systems are not simply technology artefacts but rather a combination of technology and people working within organizations to deliver something of value to the customer.

The fact that most ISD projects focus on enhancing work systems suggests that ISD necessarily involves cross-functional teams that require integration of technical knowledge with knowledge of business processes (Debrabander & Edström, 1977). Researchers have recognized that managing knowledge through cross-functional teams can improve the ability to innovate, but there are difficulties in sharing knowledge across boundaries within occupational communities (Bechky, 2003; P. R. Carlile, 2002). An occupational community is defined as "*a group of people who consider themselves to be engaged in the same sort of work; whose identity is drawn from the work; who share with one another a set of values, norms and perspectives that apply to but extend beyond work related matters; and whose social relationships meld work and leisure*" (van Maaned & Barley, 1984, p. 287). Based on this definition, several occupational communities may be involved in a large ISD project including an analyst community, a developer community, and potentially several user/stakeholder communities.

Requirements gathering entails knowledge transfer across the multiple occupational communities to create an effective work system. Difficulties encountered during requirements gathering may be partially explained by the competing social and technical needs of the occupational communities (Davis, 1982). The knowledge sharing difficulties between the technical and non-technical communities tend to be rooted in their work context (Bechky, 2003) as it differs on the basis of language and conceptualization of the system. Managers, users, and other stakeholders tend to specify the system based on social aspects such as job design objectives, work process objectives, personal responsibilities, and organizational polices. Analysts, designers, and developers specify the system on technical aspects such as inputs, outputs, data structure, data

processing, and interface design. When presented with the same information, it is likely that the technical and non-technical communities interpret this information differently based on their work context. This leads to the notion that "*information presented is not necessarily information understood*" (Gemino & Wand, 2003, p. 79). This becomes problematic during ISD projects when validating requirements on misinterpreted information.

This research considers the usability of techniques through which knowledge of system requirements are shared between the business/system analysts and other work system stakeholders by considering the effectiveness of what Carlile (1997) defines as a "boundary object." The following sections suggest the most natural boundary object, in the case of IT enabled work systems analysis, between business/system analysts and system stakeholders is a ***conceptual model*** of the work system.

1.3   Operational Communities in the ISD process

It is important to recognize the difference in knowledge across the operational communities of work system analysis to understand the importance of conceptual models as boundary objects in the analysis process. Analysis of a work system can be viewed as a four phase process (Y.-G. Kim & March, 1995). In practice, it is an iterative cycle without phases. Figure 22 - adapted from (Y.-G. Kim & March, 1995) and (Juhn & Naumann, 1985) - is a high-level overview of this analysis cycle.
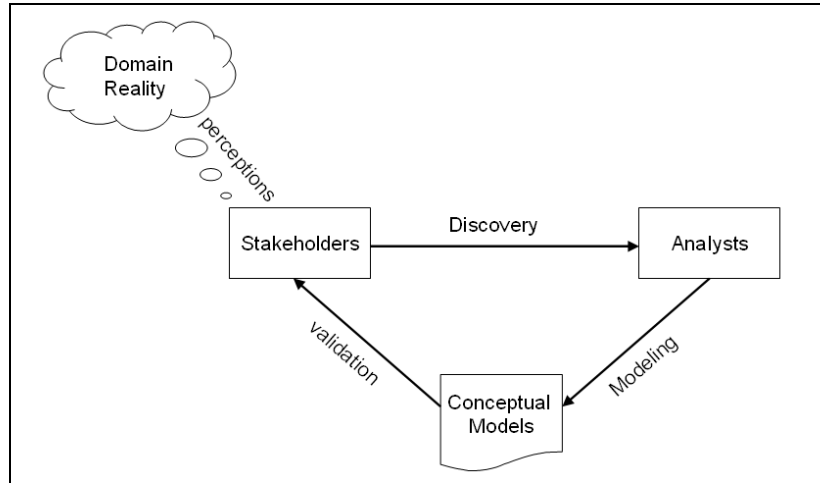
Figure 1: The Work System Analysis Cycle (Adapted from Kim & March, 1995)

Stakeholders include executives, managers and users of the work system who are active participants in the process and possess varying degrees of knowledge of work practice, documents used to verify and perform work in the work system, and policies and strategies supporting the business processes. While it is recognized that analysts and developers can also be viewed as stakeholders, separating analysts and developers is necessary as their occupational communities differ from the broad spectrum of business-focused stakeholders. Analysts are individuals with the knowledge of the capabilities of information technology, some basic knowledge of the work practice, and knowledge of how to represent work system elements in abstract models. Stakeholders convey their perceptions of the work system to the analysts. Analysts then document this knowledge and create conceptual models of the work system using several tools including diagramming techniques. Stakeholders and analysts review the models to reconsider the work system and verify that the analysts have accurately interpreted stakeholder's views of the work system. Table 1 presents the differences in knowledge across the two

occupational communities adapted from Bechky's analysis of work context (Bechky, 2003).

Work Context	Stakeholders	Analysts	Developers
Work	Actively participate in business process	Create diagrams and translate into requirements	Build the system by writing code
Locus of Practice	Physical	Conceptual	Physical and conceptual
Conceptualization of the Issue	Documents and flow of work	Information structure and process dynamics	Process and software logic
Language	Language of the Business Process	Modelling Language	Development language

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Table 1: Key Differences in Work Context in the ISD Process

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The challenge of effective work systems analysis is to find ways to integrate knowledge across these occupational communities in a way that develops a high quality of pragmatic understanding of the work system across the groups. The difficulty arises when the communities attempt to communicate. This research addresses communication issues between stakeholders and analysts. Future research will include developers.

In her study of shared work contexts, Bechky (2003) noted that the lack of a shared work context suggests that analysts and stakeholders will have difficulty communicating because members of the different communities tend to describe elements of the work system in different ways using context that is familiar to each of them. She labelled this issue "decontextualization." Bechky noted that "*decontextualization*

occurred when people from different groups met to discuss a problem, and brought different understandings of the problem to their discussion." As a result, the "*situation was presented in language that was assumed to be universal and unproblematic, but in fact the words were incomprehensible to those who did not share an understanding of the context of the situation*" (Bechky, 2006, p. 320). The notion of decontextualization clearly applies when considering the communities involved in information systems analysis.

1.4   Boundary Objects and Conceptual Modeling

Boundary objects facilitate the transfer of knowledge when operational communities have the need to communicate (Carlile, 1997). Different communities tend to develop and use tools within their work context. The tools, or objects, are sufficient to develop new ideas and generate and share knowledge within the community. However, sharing these objects across communities is problematic since different communities rely on different tools and use different languages. Therefore, an object created for use within a community will have different meaning and be interpreted differently by another community (Star & Griesemer, 1989). Boundary objects are tools designed to share knowledge across communities by satisfying the informational requirements of participating communities. Boundary objects can be described as:

> *"...objects which are both plastic enough to adapt local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual-site use. These objects may be abstract or concrete. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is a key process in*

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developing and maintaining coherence across intersecting social worlds."
(Star & Griesemer, 1989, p. 393)

The question of interest, in relation to the ISD process, is determining what artefact could serve as a useful boundary object across the analyst and stakeholder communities. Hardware and software associated with an information system are not likely to be useful boundary objects since stakeholders are not technology experts. Business artefacts, such as documentation and policies, represent fragments of the work system. These are not enough to communicate details about the work system as a whole. A suitable boundary object would need to be abstract enough to represent the logic of an entire work system and realistic enough that stakeholders easily recognize its business elements.

In the ISD process, conceptual models of a work system play a natural role as a boundary object that can bridge discussion between the occupational communities. Effective communication becomes dependent on two factors: 1) the quality (accuracy) of the conceptual model (Lindland, Sindre and Solvberg, 1994) and 2) the ability of both communities to accurately interpret and understand information presented in the model.

Modeling is a widely used approach to create abstract representations of real-world objects. It is practiced by many disciplines including mathematics, biology, architecture, and software development. Normative modeling explains phenomena and/or makes predictions about the phenomena whereas descriptive modeling is used for decision making and/or to communicate knowledge of the phenomena (Schichl, 2004).

Schichl (2004) identified four specific functions for using models: to explain phenomena, to make predictions, to make decisions, and to communicate. Models are

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used to explain phenomena in fields as diverse as physics (e.g., Newton's mechanics), biology (e.g., predator-prey model), and finance (e.g., demand-price adjustment model). Avalanche researchers use predictive models to calculate probabilities of avalanches being triggered. Examples of models used for decision making include visual and numerical simulations to optimize layout of manufacturing facilities. Finally, examples of models for communication include using hand-drawn sketches to guide visitors to a particular location using easy to follow street directions. Use of these visual models communicates the creator's knowledge to the recipient about the location of interest.

Conceptual modeling in information system development is a category of descriptive modeling used to represent elements of a work system domain and their inter-relationships. These models communicate system specifications to facilitate the ISD process. System analysts create and distribute models to verify the system specifications before being used as a formal blue-print for system development. Failure to accurately capture the system specifications may result in a delayed or failed project implementation. Conceptual models used during software development serve a similar purpose as providing roadmap directions to communicate the analyst's knowledge of the system to users. The use of conceptual modeling in system analysis and design can be traced back to the early 1970's.

1.4.1 Conceptual Modeling in ISD

Parnas (1972) introduced the importance of simple yet precise system specification by presenting a formal text based approach to specify program segments while reducing the need to use overly technical language. The objectives were to provide users and implementers with information necessary to use or build software without

additional irrelevant information and to discuss the software through language and terms normally used by user and implementer. In other words, the objectives were to improve communication and understanding by reducing ambiguity during system analysis and design.

In 1974, IBM introduced Data Flow Diagrams (DFD) as the means "*to review program design in a walkthrough environment*" (Stevens, Myers, & Constantine, 1974, p. 138). The introduction of the DFD was expected to produce reusable code libraries but it was also used as a communication tool to describe data processing procedures during system analysis. In 1976, Peter Chen introduced the Entity Relationship Diagram (ERD) (Chen, 1976) as the first graphically based tool to describe data structure. The ERD and the DFD quickly became the main set of conceptual models used by the structured approach to communicate systems specification (DeMarco, 1978; Yourdon & Constantine, 1979).

Hundreds of information systems development methodologies and related modeling techniques were proposed during the 1970s and 1980s despite the general acceptance of the structured approach as a standard for system analysis and design (Oei, van Hemmen, Falkenberg, & Brinkkemper, 1992). Differences between some of these methodologies are terminological while others were more foundational. Oei et al. (1992) noted that the availability of many modeling techniques and methodologies, coupled with a lack of unified approach to systems analysis and design, was frustrating for practitioners leading to valuable effort expensed on selecting a method appropriate for individual projects.

Conceptual modeling enjoyed another major evolution during the early 1990s as object-oriented programming languages gained acceptance among developers. The need to represent systems using methodologies compatible with object-oriented programming languages spurred researchers and practitioners to introduce yet another group of competing object-oriented methodologies and modeling techniques. Some of these methodologies were championed by leading researchers and practitioners such as Ivar Jacobson, Peter Coad, Edward Yourdon, James Rumbaugh, and Grady Booch (Booch, 1994; Coad & Yourdon, 1990, 1991; Jacobson, 1991; Rumbaugh, et al., 1991).

The field of systems analysis and design was once again flooded with proposed object-oriented methodologies that could further confuse users. A need for developing a standard methodology became apparent. Grady Booch, Jim Rumbaugh and Ivar Jacobson collaborated during the mid 1990s to introduce the unified modeling language (UML) version 1.0 (http://www.uml.org). Its introduction marked the first milestone in standardizing object-oriented system analysis and design methodologies allowing users to concentrate on learning a standard technique while tool manufacturers could focus on developing useful features to facilitate adopting the UML. UML has evolved over the past dozen years to include expanded grammar and notation with the intention of facilitating the analysis and design process. Like the structured approach and countless other competing object-oriented methodologies, the UML has not addressed its suitability as a communication tool during system analysis and requirements gathering.

The necessary evolution of conceptual modeling grammar and methodologies addressed the quality factor of conceptual models as boundary objects. Advances in grammar allow the analyst to combine constructs to model real world domains, while

advances in methodology provides procedures to model the domain using a prescribed

grammar. However, these advances were primarily geared toward the analyst community

to facilitate the process of creating conceptual models. The second goal of improving the

ability of all communities, specifically the stakeholder community, to accurately interpret

the information presented by the models remains largely unaddressed.

1.5   Cognition and Communication in ISD

Conceptual models are situated as excellent boundary objects in ISD because of

their ability to replace community specific verbal language with diagrams under the

assumption that pictures convey more meaning than words alone. Conceptual models

allow participating communities to interpret diagrams using their own contextual

language. However, conceptual models are subject to misinterpretation or a lack of

understanding of the intended meaning of the model without appropriate guidance.

Studying what impacts understanding, specifically related to graphical representation of

information, allows researchers the ability to investigate methods to improve

understanding and effectiveness of conceptual models.

This research investigates factors that may impact understanding of conceptual

models by stakeholders and proposes methods to take advantage of the findings to

strengthen the effectiveness of conceptual models as boundary objects between the

technical and non-technical communities in the ISD process. Therefore, it is important to

ground the research in cognitive theories that explain how individuals process

information for understanding. Two relevant theories from educational psychology

provide the background necessary to support the objectives of the research program.

These are the cognitive load theory and the cognitive theory of multimedia learning. The

cognitive load theory (Sweller, 1988, 1989; Sweller & Chandler, 1994; Sweller, van Merriënboer, & Paas, 1998) suggests that overloading working memory impacts our ability to process information required for learning and understanding while the cognitive theory for multimedia learning (Mayer, 1989, 2001, 2009; Mayer, Heiser, & Lonn, 2001; Mayer & Moreno, 2003) provides design considerations to reduce cognitive loads for improved understanding. The research extends both theories to investigate design considerations to improve understanding of conceptual models by stakeholders.

1.5.1 Cognitive Load Theory

The main premise behind the cognitive load theory (CLT) is to provide a framework to enhance learning and understanding by considering the structure of information presented as well as cognitive architecture that allows effective processing of this information. Extending the CLT to conceptual modeling in ISD provides a theoretical rationale to evaluate the effectiveness of the conceptual model as a communication tool between analysts and stakeholders and to suggest methods to improve its effectiveness. The CLT addresses whether the presentation style of conceptual models impacts cognitive processes necessary for learning and understanding.

The CLT originated more than two decades ago with a specific aim to improve student learning of complex cognitive tasks such as those in math and science by changing the way information is presented to students. The CLT suggests that effective learning and understanding is most likely to occur under conditions that are best aligned with human cognitive architecture (Paas, Renkl, & Sweller, 2004).

The main assumptions of the CLT revolve around the interaction between working memory and long term memory (Sweller & Chandler, 1994). It is accepted that working memory has limited capacity (Miller, 1956; Simon, 1974) with short duration (Peterson & Peterson, 1959) while long term memory has seemingly endless capacity (Von Neumann, 1958). Information being reviewed must be encoded as schema into long term memory for understanding to occur. The process starts as information enters the sensory memory through visual (eyes) and auditory (ears) senses (Paivio, 1986). Sensory memory passes the information to working memory. Working memory processes the information by integrating the contents in working memory with information from long term memory. Learning occurs when the processed information is passed to long term memory for permanent storage. Learning fails when working memory does not process the information due to either a cognitive overload or lack of a sufficient cognitive load necessary for knowledge construction (Paas, et al., 2004).

Working memory can process about five to seven chunks of information at any given time (Miller, 1956; Simon, 1974). Working memory becomes over burdened when processing information that exceeds its capacity. A schema is a cognitive construct used to organize related elements of information presented to working memory for processing (Sweller & Chandler, 1994). Schemas allow the learner to combine various elements of information to produce complex chunks for processing in working memory. Schemas reduce the cognitive load by permitting working memory to process multiple related pieces of information as one chunk; thereby, allowing working memory to ignore most of the information impinging on our senses (Sweller & Chandler, 1994). Schemas are stored in long term memory and distinguish between experts and novices.

For example, Adriaan De Groot (1965) discovered that memory was an important factor for chess players. Experienced chess players recognized more chess board configurations than amateur players and selected a move suitable for the present configuration. The board configuration is viewed as one chunk of information related to a stored scheme for an expert. This enables experienced players to process multiple board configurations simultaneously in working memory while solving the problem of selecting the next move. Novice players may see the board as individual playing pieces such that each piece is considered as a separate chunk of information. This causes difficulty, or cognitive overload, in processing a complete board configuration in one instance due to the number of elements and their interconnectivity. The CLT focuses primarily on complex cognitive tasks where the number of informational elements and their interaction may overwhelm the viewer. In ISD, this can occur with detailed conceptual models such as the entity-relationship diagram with its potentially large number of entities and attributes or with the many different unified modeling language diagrams used to describe one business process. The CLT proposes that properly designed information delivery methods enable learners to use material stored in long term memory to improve understanding by reducing the cognitive load on working memory. The CLT presents three sources of cognitive load: intrinsic, extraneous, and germane. These three sources have cumulative impact.

1.5.1.1   Intrinsic Cognitive Load

Intrinsic cognitive load is the cognitive burden imposed on working memory by the interactivity of elements in a message. The simultaneous processing of related elements and their interactivity is necessary for understanding to occur. Elements vary in

complexity depending on schema stored in long term memory. Schema from long term memory can be brought into working memory (e.g., a chess board configuration) to allow processing of multiple low-level interacting elements by treating them as one element (Paas, Renkl, & Sweller, 2003); in essence, this reduces intrinsic cognitive load.

Relying on schema stored in long term memory is feasible for experienced learners only. It is generally accepted that intrinsic cognitive load cannot be reduced by message manipulation only (Gerjets, Scheiter, & Catrambone, 2004; Paas, Renkl, et al., 2003; Sweller & Chandler, 1994). It becomes necessary to present a simpler task by removing some of the interacting elements in the message which may compromise sophisticated understanding (Gerjets, et al., 2004; Paas, Renkl, et al., 2003). Introducing omitted elements in subsequent tasks allows full understanding to occur. Full understanding causes the message viewer to acquire and store new schema in long term memory.

In ISD, conceptual models represent complex sets of interacting elements of information. For example, classes, attributes, relationships and methods represent the different elements of information present in a class diagram. The intrinsic cognitive load increases as more classes and relationships are used to represent the problem domain. Omitting some of the information by presenting smaller segments at different intervals may reduce the intrinsic cognitive load.

1.5.1.2 Extraneous Cognitive Load

Extraneous cognitive load is a cognitive burden imposed on working memory by activities not necessary for understanding or schema construction (Paas, et al., 2004; Sweller, 1993). It usually involves searching for and organizing information necessary

for processing. For example, visually searching for related pieces of information on a page or several pages imposes extraneous cognitive load on working memory. Extraneous cognitive load reduces our ability to understand by diverting valuable cognitive resources away from schema construction to an information gathering and filtering process.

In ISD, extraneous cognitive load occurs as stakeholders review multiple conceptual models and other documentation to retrieve relevant information about a business process for validation. Extraneous cognitive load may be reduced if relevant information is grouped closer together in time and space.

1.5.1.3   Germane Cognitive Load

Germane cognitive load is the effort put forth by the learner to understand the material. While intrinsic and extraneous cognitive loads impede understanding, germane cognitive load is necessary for understanding to occur. In other words, regardless of how easy the material is (low intrinsic cognitive load), or how well the information is presented (low extraneous cognitive load); full understanding cannot be achieved if the individual lacks motivation or dispenses little effort to learn the material (Paas, Tuovinen, Tabbers, & Van Gerven, 2003). Germane cognitive load is the cognitive process devoted for schema construction leading to understanding.

Germane cognitive load can only be applied if there are surplus cognitive resources after accounting for intrinsic and extraneous cognitive loads. It is not adequate that extraneous and intrinsic loads not exceed available cognitive resources. They must be sufficiently less than available resources to allow the individual to impose germane loads. Therefore, it is important to reduce extraneous and intrinsic cognitive loads to

make additional resources available for schema construction. However, it is important to recognize that germane cognitive load is not applied spontaneously based on resource availability (Paas & van Gog, 2006). It becomes important for message designers to consider methods to stimulate recipients of information in order to apply cognitive load necessary for understanding. Moreno and Mayer (2007) suggest *guiding* and *pacing* recipients of the information. Guiding promotes individuals to engage in the selection, organization, and integration of the information. Pacing reduces the amount of information presented by allowing recipients to process smaller chunks of information in working memory.

In ISD, static conceptual models are delivered to the stakeholders for review. They are static in the sense that they are delivered on a page or computer screen in their entirety. Some supporting documentation may be provided as well in the form of reports or detailed explanation of the process. The size of the model and quantity of diagrams and other documentation may overwhelm even the seasoned stakeholder to the point of loss of motivation to review the documentation. Guiding and pacing may reduce the apparent complexity of the information presented to encourage stakeholders to conduct a comprehensive review. Guiding may include additional information that directs the stakeholder's review process to specific diagrams or sections of a diagram whereas pacing may involve reducing diagrams to smaller and more manageable chunks.

The cognitive load theory proposes that understanding occurs when individuals exert cognitive effort without overloading working memory. Consequently, it is important to reduce intrinsic and extraneous cognitive loads while increasing germane cognitive load. Intrinsic cognitive load is difficult to reduce as it is highly dependent on

the recipient's prior knowledge and experiences despite research that demonstrates the possibility to reduce the load by segmenting the message (Gerjets, et al., 2004; Pollock, Chandler, & Sweller, 2002). This implies that reducing extraneous cognitive load becomes necessary for understanding to occur when intrinsic cognitive load cannot easily be reduced. Reviewing conceptual modeling can be classified as a high intrinsic activity due to the large number of elements to be processed in each model. Therefore, improving stakeholder understanding should first involve reducing extraneous cognitive load. The cognitive theory of multimedia learning presents several principles that guide designers to develop low extraneous load messages.

1.5.2   Cognitive Theory of Multimedia Learning

The cognitive theory of multimedia learning (CTML) introduces several principles of message design revolving around the need to reduce extraneous cognitive load for scientific learning material (Mayer, 1989, 2001). It was motivated by the increasing use of "multimedia" tools for learning. Multimedia, according to the CTML, is not limited in scope to the popular definition of multimedia representing videos and recorded music. It is defined as the use of more than one format to present information. "Media" can be text such as words on a page or computer screen, images such as pictures on a page or computer screen, animation such as videos and other moving images, and sound such as narration of a topic. This is an important distinction as Mayer (2001) refers to multimedia presentations as material using words and pictures. Books with text and images are classified as multimedia presentations. Conceptual modeling in ISD can also be classified as multimedia presentation due to the significant use of diagrammatic representations and text based descriptions.

The CTML bases its principles and assumptions on multi-modal processing of information. Allan Paivio's dual coding theory suggests that individuals process information through two non-competing sensory channels: auditory and visual (Paivio, 1986, 1991). The information enters sensory memory through our eyes and ears. Visual information such as text or pictures being reviewed on a page enters sensory memory through the eyes whereas auditory information such as spoken words or other sounds enters through the ears (see Figure 2). The information is held very briefly before being selected for processing through working memory. The major premise behind the CTML is that information entering through the two channels simultaneously results in more information for knowledge construction than information entering through one channel because humans have limited capacity to process information at any given time (Baddeley, 1992). More information results in a more complete mental model developed in working memory for the purposes of knowledge construction and integration with long term memory. Therefore, the CTML advocates the use of multimedia information to enhance learning and improve understanding.
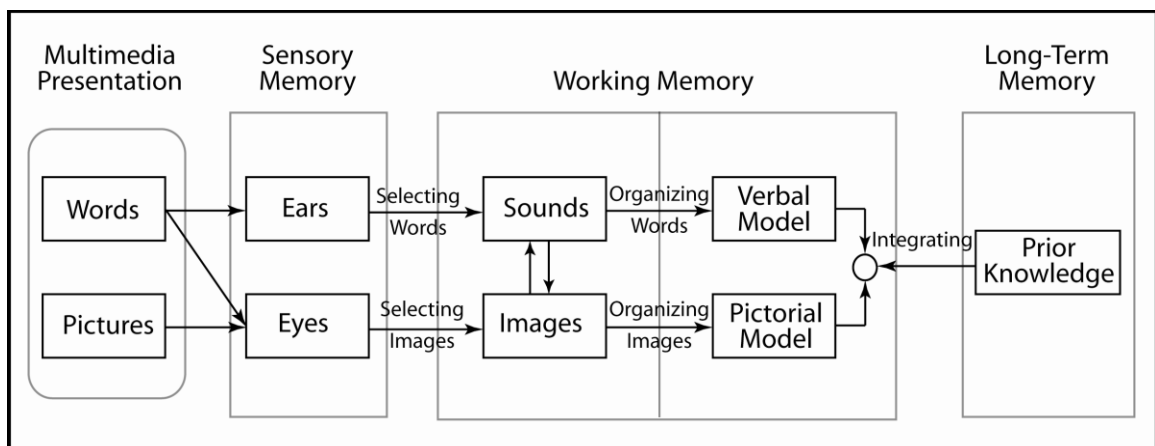
Figure 2: The Cognitive Theory of Multimedia Learning (Mayer, 2001)

The CTML assumes that knowledge construction is best achieved when the presented material has a coherent structure, and the material has guidance to help the viewer with knowledge construction. These assumptions are consistent with the cognitive load theory. Lack of a coherent structure transforms the message to a collection of isolated facts thereby increasing the extraneous cognitive load. The extraneous load is increased as the viewer will need to mentally re-organize the information for processing. Lack of guidance may overwhelm the recipient to a point where germane cognitive load is no longer exerted for knowledge construction. Based on these assumptions, Mayer (2001) introduced seven principles to help message designers present information in a coherent and guided structure. In 2009, Mayer revised the CTML to include 3 new principles (Mayer, 2009): signaling, segmenting, and pre-training. The articles in chapters two through four of this dissertation are based on the original CTML principles. Implications of the revised theory are discussed in more detail in Chapter 5. The following sections provide detailed discussions of all the principles.

1.5.2.1   Multimedia Principle

The first principle discussed is based on the central theme of the CTML. The multimedia principle suggests that viewers construct more complete mental models when receiving information through the two sensory channels. Mayer (1989a, 2001) presents the argument that words and pictures representing the same topic are not informationally equivalent because words "…describe material in an interpreted or abstracted manner that requires some mental effort to translate" (Mayer, 2001, p. 67) while pictures "depict material in a form that is more intuitive and closer to our visual sensory experience. Pictures allow holistic nonlinear representations of information" (Mayer, 2001, pp. 67-

68). Although text and pictures may describe the same topic, differences in interpretations suggest that the methods are not informationally equivalent. Therefore, having two representations of the same topic in working memory improves knowledge construction and integration with long term memory for better understanding. The same argument can be applied to suggest that combining other forms of presentation, such as animation and narration, can be equally effective (Mayer & Anderson, 1991).

Conceptual models can be classified as multimedia presentations due to the use of graphical grammatical representations and some textual elements (Figure 3). Graphical elements in conceptual models present an abstract view of the problem domain which may not be informationally different from text based representations. Adapting conceptual models to take advantage of multimedia presentations could include adding pictures (Figure 4) or narration to the models. Research evaluating effectiveness of both suggestions is described in chapters 2 and 4 of this document.
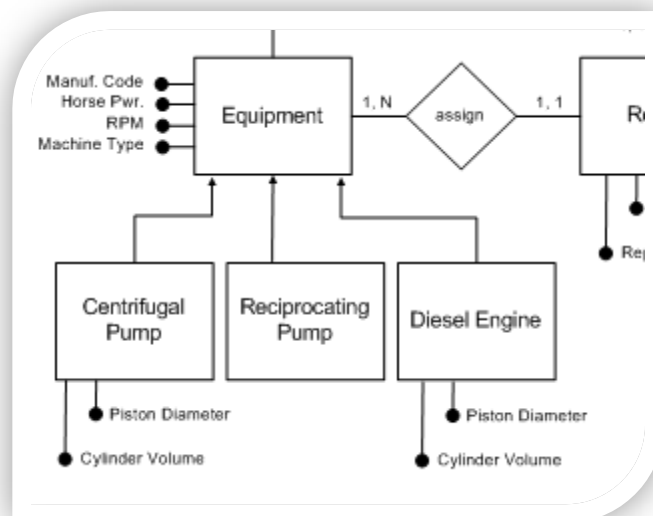
Figure 3: Portion of an Entity-relationship diagram depicting graphical and textual representations
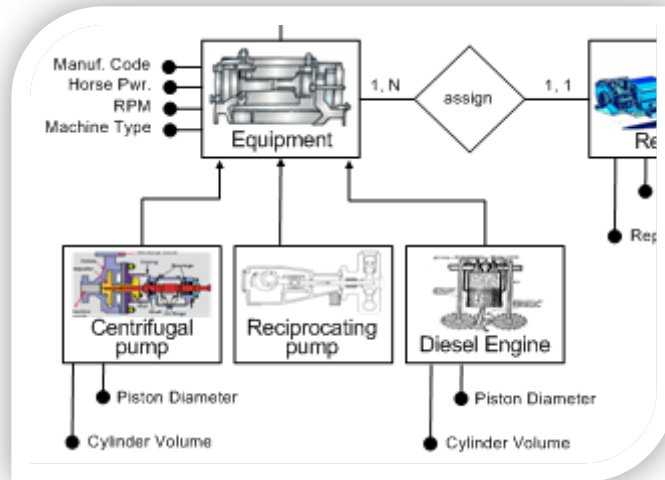
Figure 4: Portion of an Entity-relationship diagram depicting pictorial representations

1.5.2.2   Spatial Contiguity Principle

The cognitive process of searching for related elements of information consumes valuable cognitive resources (Chandler & Sweller, 1991). The cognitive effort expended is a source of extraneous load that does not add value to knowledge construction nor understanding. The CTML suggests that related information should be as close together as possible in a presentation to reduce extraneous cognitive load attributed to searching for related elements.

Distance becomes problematic when conceptual modeling methodology requires the use of multiple diagrams such as the unified modeling language. The CTML and the CLT suggest that stakeholders reviewing multiple diagrams on separate pages depicting related information experience higher extraneous cognitive load compared to reviewing related information on one page. The effort to reduce spatial contiguity in the use of multi-model methodologies by combining smaller segments of the models is discussed in Chapter 3 and experimental results presented in Chapter 4.

1.5.2.3 Temporal Contiguity Principle

The temporal contiguity principle is similar to the spatial contiguity principle but with a focus is on temporal distance rather than spatial distance. The CTML assumes that a full mental model can be developed by integrating information from the two sensory channels with knowledge stored in long term memory. This can only occur when information from the two channels is in working memory at the same time. Information presented successively (such as displaying a text description of a business process followed by a flow chart representation of the same process) may require working memory to process the first stream of information before the complementary second stream is introduced. Additional cognitive load is therefore necessary to integrate the two streams of information presented separately at the same time for full knowledge construction.

Temporal considerations become a factor in ISD when stakeholders must review several documents to validate requirements. The documents are reviewed in succession or with a need to continuously flip back and forth between them. This, according to the CTML, leads to excessive extraneous cognitive load that may impact understanding. Conceptual model presentations should consider methods to present information at the same time and on the same page to reduce extraneous load imposed by spatial and temporal distances. The same effort to reduce spatial contiguity can also be applied to reduce temporal contiguity as described in Chapters 3 and 4.

1.5.2.4 Coherence Principle

The coherence principle is based on the extraneous cognitive load introduced by the Cognitive Load Theory suggesting that irrelevant words, pictures, and sounds will

cause unnecessary extraneous load on working memory leading to lower levels of understanding. Mayer proposed three elements to the coherence principle (Mayer, 2001, p. 113): "1) Learning is hurt when interesting but irrelevant words and pictures are added to a multimedia presentation; 2) learning is hurt when irrelevant sounds and music are added to a multimedia presentation; and 3) Learning is improved when unneeded words are eliminated from a multimedia presentation."

The element of interest to conceptual modeling techniques is the first, which suggests that understanding is impeded by adding irrelevant words and pictures to the model. The other elements, though interesting for other areas, are not an issue for model design since music or extraneous sounds are neither used nor likely to be incorporated in a model. However, adding irrelevant pictures may play a very important role when experimenting with adding pictures to conceptual models under the guise of taking advantage of the multimedia principle. According to the coherence principle, choice of pictures not relevant to the model can be harmful to understanding. This implies that careful selection of embedded images is necessary to maximize reduction of extraneous load.

1.5.2.5   Signaling Principle

The objective of the signaling principle is the reduction of extraneous cognitive load by using cues to highlight important information presented in the message being learned (Mayer, 2009), Signaling guides the viewer's attention to key elements in the material under review. This reduces the need for the viewer to expend cognitive resources to locate the information of interest. Mayer classifies signaling cues into two categories: verbal signaling and visual signaling.

Verbal signaling uses cues applied to written or spoken words. Features of verbal signaling include outline sentences, headings, emphasis on key words, and pointer words. Outline sentences are phrases used at the beginning of the presented information (either spoken or written) that highlight key terms to follow. Headings are a feature used to organize the written information into distinct sections viewers can use to quickly access the information of interest. Emphasis on key words involves using distinct formatting features such as bold face or italics to distinguish key words from the rest of the material, whereas vocal emphasis involves saying key words using a distinct voice (such as louder or slower). Pointers imply using words that organize or create an order of the information to follow such as "first…second…third." Experimental support of using signaling was demonstrated in a study conducted by Mautone and Mayer (Mautone & Mayer, 2001)

Visual signaling cues include the use of distinctive visual features placed in diagram or in animations to draw the viewer's attention to areas of interest. These include the use of arrows, distinctive colors, flashing, pointing gestures, and graying out.

This principle suggests that visual cues can be used effectively to promote understanding of complex conceptual models. Preliminary research supports the use of visual cues to facilitate understanding of systems represented by multiple diagrams (J. Kim, Hahn, & Hahn, 2000). Elements of this principle are considered in Chapters 4 and 5.

1.5.2.6   Segmenting Principle

The segmenting principle aims to reduce the potential of overloading working memory when presented with complex set of information. The principle suggests dividing the information into user-paced segments promotes understanding. Working

memory has limited capacity (Baddeley, 1992) such that viewers presented with information exceeding working memory's capacity will be unable to integrate the information with long term memory to fully understand the material. Segmenting allows viewers to integrate a cognitively manageable amount of information before moving on to the next set of information. Understanding each segment facilitates the learner's ability to integrate other segments that follow.

Prior research supports the use of segmenting to promote understanding using animations as well as static complex diagrams. In one study, participants provided with a user-controlled segmented animation demonstrated deeper understanding than the control group (Mayer & Chandler, 2001). The user-controlled animation required the users to click a "next" button to view the next segment of an animation, providing the users with the opportunity to process the information before moving on. The two and a half minute animation was broken into 16 segments. The control group Research had to watch the full animation without interruption.

In another experiment, participants provided with a user controlled graph divided into several layers outperformed users given the complete graph for review (Mautone & Mayer, 2007). Both groups had unlimited time to review the material. The control group received the graph as an image on a computer screen whereas the other group received a series of PowerPoint slides that built the graph by adding one layer of information at a time. Participants controlled the pace by choosing when to move to the next slide.

Modular UML proposed in Chapter 3 and examined further in Chapter 4 is based partially on reducing cognitive load in working memory according to the segmenting principle. The experiment provides some support to the notion of segmenting conceptual

models but requires further study to evaluate the impact of various segmenting techniques.

1.5.2.7   Modality Principle

The modality principle suggests that taking full advantage of the two modes of communication (auditory and visual) leads to better knowledge construction understanding. Mayer (2001) argues for the case of using pictures or animation with narration instead of pictures or animation with printed text. The modality principle might appear to somewhat contradict the multimedia principle but it actually builds upon it. The multimedia principle encourages the development of messages using two complementary media such as pictures and words. However, according to the CTML (Figure 2), words can be associated with both communication channels: staring at the words can be assimilated through the visual channel, while the auditory channel may be used to integrate the words by reading them. Despite using both channels to process the information, text will exert some extra load on the visual channel. The modality principle justifies the use of narration instead of printed text by arguing that the information will be assimilated using the auditory channel only therefore reducing extraneous load on the visual channel (Mayer & Moreno, 1998).

This principle develops an argument for removing printed text from conceptual models. It will be necessary to use computerized solutions to present conceptual models using narration to enable tight integration of recorded spoken descriptions and visual aspects of the model. Arguments presented here do not negate research required into effects of pictures and words on understanding since paper based presentations of conceptual modeling techniques may still be preferred by analysts and stakeholders for

communication purposes. However, it will provide another guideline for the delivery of conceptual models with the aim of further improving understanding.

1.5.2.8   Redundancy Principle

The redundancy principle presents an argument that using pictures or animation along with narration will lead to better understanding than using pictures or animation along with narration *and* text description. The argument is presented by suggesting that two competing media of communication will lead to increased extraneous cognitive load on working memory. Text relies on both sensory channels to transfer information; therefore, text competes with animation/picture for available limited working memory capacity increasing extraneous load. Empirical mental load ratings were used to support arguments presented by the redundancy principle (Kalyuga, Chandler, & Sweller, 1999).

Guidelines developed for improving conceptual modeling techniques need to consider the possibility of overburdening working memory.

1.5.2.9   Individual Differences Principle

The individual difference principle suggests that design effects such as adding pictures, animation, and narration will be stronger for individuals with low prior knowledge compared to those with high prior knowledge and will be stronger for high spatial learners compared to low spatial learners. Mayer suggests prior knowledge reduces the amount of intrinsic cognitive load on working memory since knowledge construction as described by the CTML is the integration of the mental model in working memory with schema stored in long term memory. High knowledge recipients rely on developed schema to reduce intrinsic cognitive load whereas low knowledge recipients

will have high intrinsic loads. High spatial learners will benefit from the multimedia additions to the presented message.

This principle suggests that designing multimedia presentations based on the CTML may not necessarily lead to better understanding for high knowledge recipients. Stakeholders involved in ISD design are expected to be fairly proficient in the business processes being modeled and described within their work context; however, it is likely that the same stakeholders may have difficulty understanding these same processes described in a technical context different from context used within the stakeholder community. Therefore, intrinsic cognitive load may be sufficiently high that reducing extraneous load in conjunction with increasing germane load may lead to better understanding of conceptual models.

1.5.2.10   Pre-training Principle

The pre-training principle first appeared in the second edition of "Multimedia Learning" (Mayer, 2009) primarily as an update to the individual differences principle. The latter was removed completely from the updated CTML.

The pre-training principle suggests that individuals familiar with concepts and terms will develop a deeper understanding from a multimedia message. Specifically, viewers pre-trained in the material will have lower intrinsic cognitive load allowing them to more effectively construct a mental model of the system under investigation.

Pre-training, according to Mayer, familiarizes the viewer with the names and characteristics of key concepts in the material to follow. For example, pre-training in systems analysis requires familiarizing viewers with the grammatical representations of

objects found in conceptual models. This allows users to exert cognitive resources to construct knowledge and understanding of the relationships between objects in the model instead of exerting valuable cognitive resources to comprehend what the object (such as boxes and arrows) represent.

The experiments discussed in this thesis applied the pre-training principle to all groups (control and experimental) to isolate possible bias introduced by this principle and to more effectively evaluate the impact of reducing extraneous cognitive load via other experimental means.

1.6   Objectives and Scope of the Research

The research program presented in this thesis seeks to improve communication between the user/stakeholder and analyst/developer communities by extending theories from educational psychology to design more effective methods for presenting work system information to users. The research is considered user-centric as the aim is to investigate the user's abilities and capabilities to comprehend the conceptual models delivered during the early systems analysis cycle. "User-centric" suggests the research will primarily consider process and techniques that enhance the user's interaction with the modeling tools rather than the analysts' processes to develop the model. The research extends the theories to suggest and empirically test conceptual modeling presentation guidelines that promote higher levels of user understanding to reduce possibilities of misinterpreting information shared during requirements gathering and validation. The general question to be addressed by the research program is:

How can accepted conceptual modeling techniques be adapted to provide better user/stakeholder understanding?

Cognitive theories, such as the Cognitive Theory of Multimedia Learning (Mayer, 2001) and the Cognitive Load Theory (Sweller, 1988, 1989; 1994) provide the foundation for the research. Richard Mayer (2001) advocates the use of multimedia in presentation material to enhance information acquisition and knowledge construction to promote meaningful learning and better understanding. In conjunction with John Sweller's cognitive load theory (1988, 1989; 1994) and Mayer's related research (Mayer, 1989, 1996, 2001, 2009; Mayer & Gallini, 1990), Mayer introduced seven principles of presentation design to increase learner understanding (Mayer, 2001). Some of these principles along with fundamentals from the cognitive load theory formed the basis of the guidelines tested this thesis in a series of experiments to improve user understanding of two popular conceptual modeling techniques. The experimental design used by Mayer was adapted to show that adding graphics to conceptual models and combining segments of related conceptual models have a positive impact on user understanding. Understanding was operationalized using three measures advocated by Mayer: comprehension, retention, and transfer (Mayer, 2001).

The intention of the research is to provide a general set of guidelines to improve communication capabilities for any conceptual modeling methodology via enhanced presentation techniques. The research does not address the suitability of a particular method nor does it compare effectiveness of competing grammars. In an effort to generalize the findings, the experiments investigate the proposed guidelines using two

popular conceptual modeling methodologies: the structured methodology with Entity-relationship diagrams, and the Unified Modeling Language.

The results of this research should be of interest to researchers, practitioners, and CASE[1] tool developers. Researchers can build upon the guidelines to generate theories related directly to information systems, and to improvise and introduce new modeling techniques that promote understanding. Practitioners will use these guidelines along with future research findings to improve efficiency of the requirement engineering phase leading to more successful and efficient projects. Finally, CASE tool developers will be encouraged to create software compatible with the guidelines to promote understanding.

1.7   Structure of this thesis

This thesis uses the three-paper format to present the research. Each of chapters 2, 3, and 4 consists of one complete paper that has been double-blind peer reviewed and published in an academic journal or presented at an academic conference. Each paper is a self-contained complete set of research that includes an abstract, background information, literature review, research description, discussion, and conclusions. The cognitive load theory and the cognitive theory of multimedia learning form the foundation of all three papers and directly link the results in all three to the general research question discussed in the previous section. Some of the background information found in the papers, specifically related to CLT and CTML, may appear in all three papers along with this introductory chapter. This is necessary since the papers are complete and independent

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[1] CASE: Computer Aided Software Engineering. These are specialized software packages used by systems analyst to create conceptual models used in Systems Analysis and Design.

research articles. Chapter 5 combines the findings of all three papers into a general discussion about the implications of the research program and future directions.

Appendices include selected experimental content not included in the original articles due to length limitations demanded by journals and conference proceedings. Each chapter has a separate citations references list. A comprehensive bibliography of all five chapters is included at the end of the dissertation for the benefit of the readers. The following sections provide a synopsis of each of the research papers.

1.7.1 Chapter 2: "Using Iconic Graphics in Entity Relationship Diagrams: The Impact on Understanding"

The exploratory research presented in Chapter 2 was designed to test the applicability of the CLT and CTML to information systems conceptual modelling. The objectives of the research include applying principles from the CTML to entity-relationship diagrams (ERD), using the CLT to analyze the results, and extending Mayer's experimentation technique to conceptual modelling in ISD.

The research applied the multimedia principle by including iconic graphics to entities in the ERDs. The research was encouraging as results implied significant differences between the treatment conditions. The success of the exploratory research allowed the research program to extend its scope to the Unified Modelling Language (Chapters 3 and 4).

Some interesting findings were uncovered related to native language of the participants in the experiment. The results indicate that inclusion of graphics in ERDs has a stronger effect on participants whose native language matches the documentation of the

system. Arguments from the CLT provided a possible explanation for these results that further solidified the notion of extending cognitive theories to conceptual modelling.

The last objective was to adapt Mayer's experimentation technique to conceptual modelling research in ISD. There is extensive use of Mayer's methodology in education (Mayer, 1989, 1997; Mayer & Anderson, 1991; Mayer & Gallini, 1990; Mayer & Moreno, 1998; Mayer, Moreno, Boire, & Vagge, 1999; Mayer & Sims, 1994; Moreno, 2007; Moreno & Durán, 2004). Custom software was developed to conduct the experiment for the purposes of collecting accurate participant inputs and providing enhanced procedural control mechanisms.

1.7.2   Chapter 3: "Modular UML for Better Understanding"

This paper proposes a unique presentation technique to improve understanding of UML conceptual models defined as "Modular UML." UML encourages the use of multiple diagrams to model a problem domain. Cognitive theories imply that extraneous cognitive load tends to increase as viewers sift through multiple diagrams to find related information. Modular UML advocated in this paper suggests partitioning diagrams into smaller segments for the purposes of combining related sections of the diagrams to reduce extraneous cognitive load. The CTML provided theoretical guidance for the process.

The paper includes a conceptual description of Modular UML as well as the process to apply it. An example using a functioning human resource scheduling system demonstrated the process of creating diagrams using modular UML. The paper concludes with an introduction to the Modular UML Interface (MUI) system. MUI is custom

software developed to demonstrate the use of Modular UML. The final research paper in the thesis presents results of experiments conducted using MUI to test the effectiveness of Modular UML.

1.7.3   Chapter 4: "Combining UML Diagrams to Enhance Understanding of Conceptual Models"

The final research paper uses Modular UML and abstract observations from the ERD experiments to test the effectiveness of combining several conceptual model design characteristics. The objectives included reducing extraneous cognitive load and increasing germane cognitive load. The Modular UML Interface was an important component of the experiments. Participants interacted directly with the software to learn about the work system and answer questions to quantify understanding.

Results of the study supported the CLT's implication that germane cognitive load can be increased by guiding participants to interact with the models. However, it is important to increase germane cognitive load while reducing extraneous cognitive load to achieve maximum impact on understanding.

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CHAPTER 2
USING ICONIC GRAPHICS IN ENTITY RELATIONSHIP DIAGRAMS: THE IMPACT ON UNDERSTANDING

2.1 Abstract

This study reports on an experiment examining the impact of iconic graphics on participants' understanding of domains represented by entity relationship diagrams. Cognitive Load Theory and the Cognitive Theory of Multimedia Learning are used to hypothesize that iconic graphics reduce cognitive load of model viewers leading to more complete mental models and consequently improved understanding. Results, as measured by transfer (problem solving) tasks, confirm the main hypothesis. Additionally, iconic images were found to be less effective in improving domain understanding with English as second language (ESL) participants. ESL results are shown to be consistent with predictions based on the Cognitive Load Theory.

2.2 Introduction

Conceptual models, such as the Entity Relationship Model (Chen, 1976), remain important tools during the analysis phase of information systems development projects (Batra, 2005). Conceptual modeling supports the communication between developers and users; helps analysts understand the domain; provides input for the design phase; and documents system requirements (Kung & Solvberg, 1986). The importance of conceptual

modeling has prompted calls for increased research in this area (Topi & Ramesh, 2002; Wand & Weber, 2002).

This study is directed toward research opportunities identified by Wand & Weber's (2002) framework. Specifically, we rely on cognitive theory to investigate the effects of using iconic images embedded in entity relationship (ER) diagrams on model viewer's understanding. Although our findings are specific to ER diagrams, these findings suggest the potential for further research into the use of multimedia elements in other conceptual modeling techniques.

The following section provides a brief overview of conceptual modeling and comparative research in the field. Next, descriptions of the Cognitive Load Theory (Sweller, 1988; Sweller & Chandler, 1994) and the Cognitive Theory of Multimedia Learning (Mayer, 2001) are presented. This is followed by an overview of the experimental procedures including hypotheses generation, method, and results. Finally, a discussion of the results along with research implications and conclusions are provided.

2.3   Comparative Research in Conceptual Modeling

Conceptual modeling provides the means to organize requirements for a system to form a meaningful whole (Andrade, et al., 2004). Approaches to IS development often include conceptual modeling tools to communicate and validate requirements. Curtis, Krasner and Iscoe (1988) found that problems of fluctuating and conflicting requirements in software design projects can be associated with communication breakdown. They identified a need for increased communication in requirements development. The breakdown in communications can happen across many levels.

Figure 5 offers a generic model of interactions between parties involved during

systems development projects. The three parties are: 1) Stakeholders of the to-be system

(e.g. end-users, managers), 2) Systems Analysts (intermediaries), and 3)

Developer/Designers of the to-be system. Stakeholders often have the best understanding

of the business process and the needs of the new system. Systems analysts are typically

responsible for determining *what* should be built (requirements) via direct

communication with stakeholders, while developers/designers are responsible for *how* the

system will be put together to meet business objectives. Communication between systems

analysts and stakeholders involves a two stage iterative process: *requirements gathering*

and *requirements validation*. Stage 1, requirements gathering, is a process that analysts

use to understand the business and technical requirements of the system; whereas, stage

2, requirements validation, is the process stakeholders use to approve requirements as

conceptualized and documented by the analysts. Understanding documentation, which

often includes conceptual models, presented to stakeholders is important for the overall

success of a development project.
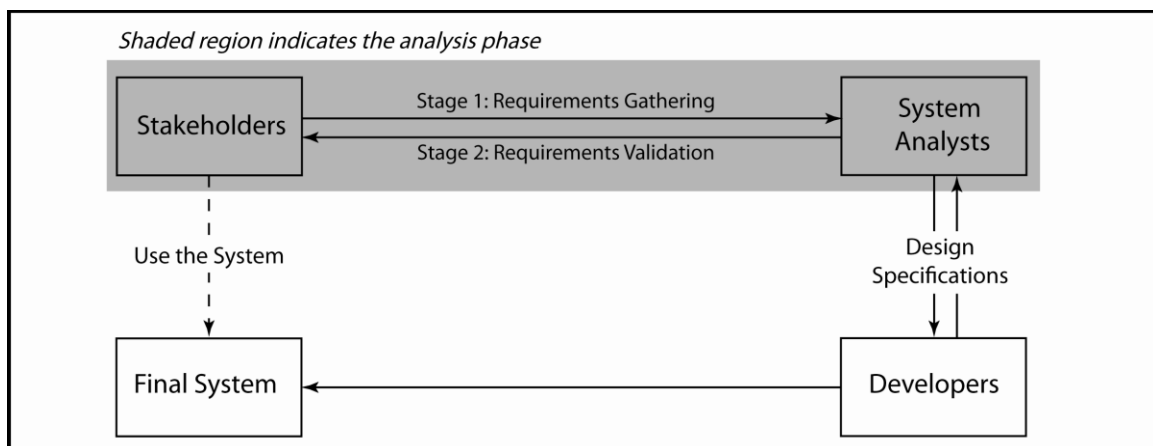
Figure 5: Interaction among the various players during the SDLC

Research in requirements gathering and validation has focused on the importance of conceptual modeling (Topi & Ramesh, 2002; Wand & Weber, 2002) which occurs early in the analysis phase of information systems projects. The large number of techniques available to analysts suggests that comparison of conceptual modeling techniques is of particular importance. Comparative research can be separated into three major categories (Gemino & Wand, 2004; Rockwell & Bajaj, 2005): 1) product comparisons (modeling effectiveness), 2) process comparisons (modeling efficiency), and 3) understanding-level comparisons (readability efficiency).

Product comparison research focuses on comparing modeling effectiveness of competing techniques from model designers' perspective. Some research considered modeling dimensions such as syntactic, semantic, communicability and usability (Y.-G. Kim & March, 1995; Yadav, Bravoco, Chatfield, & Rajkumar, 1988), while others consider abilities of analysts to learn competing techniques (Jarvenpaa & Machesky, 1989; Wang, 1996) or abilities of end-users to produce the models (Batra, Hoffer, & Bostrom, 1990).

Process comparisons focus on *how* conceptual models are created or analyzed and place less attention on the ensuing products generated from the process. For example, Vessey & Conger (1994) compared three different techniques by documenting the cognitive processes novice systems analysts use to produce the models by closely monitoring participants as they created the models. Kim, Hahn & Hahn (2000) studied the cognitive processes involved in understanding multiple diagrams representing different elements of the same system. They tested the hypothesis that visual cues and contextual information relating diagrams to each other enable viewers to better identify

problems embedded within the diagrams. Their results supported the hypothesis

suggesting that visual cues increased the probability of model viewers identifying

problems with the model but did not attempt to measure users' understanding.

The third category of research investigates effectiveness of modeling techniques

from a problem solving (understanding) perspective which is often overlooked by the

first two categories. Understanding-level comparisons focus on the final outcome of the

conceptual modeling process; that is, whether or not the person viewing the system

understands the domain being represented. This category has attracted more attention

recently.

Understanding-level research often relies on cognitive theory or ontological

models to predict and explain documented effects. Agarwal, De, & Sinha (1999) used the

theory of cognitive fit (Vessey, 1991) to compare the comprehensibility of object-

oriented and process oriented models. Bodart, Patel, Sim, & Weber (2001) generated

propositions using the theory of semantic networks (Collins & Quillian, 1969) to

conclude that optional properties in ER diagrams impede deep-level understanding of

users. The cognitive theory of multimedia learning (Mayer, 2001) provided the

theoretical background to investigate additions of animation and narration in

requirements validation (Gemino, 2004), and to reach similar conclusions as Bodart et al.

(2001) regarding the impact of optional properties in ER diagrams (Gemino & Wand,

2005). Finally, Wand & Weber's (1990) representation model based on the theory of

ontology was used to investigate how model decomposition impacts analysts'

understanding of a domain (Burton-Jones & Meso, 2006) and the effect the number of

concepts within a model has on the readability of the model (Bajaj, 2004). Following the

lead of these studies, we rely on the cognitive theory of multimedia learning (Mayer, 2001) and the cognitive load theory (Sweller, 1988; Sweller & Chandler, 1994) to investigate the effects of embedding iconic images in ER diagrams.

This study details an experiment designed to test the level of understanding developed by model viewers reading ER diagrams with and without iconic graphics. Cognitive load theory and the cognitive theory of multimedia learning are used to hypothesize that embedding iconic graphics will increase the sophistication of mental models developed by viewers leading to higher scores on transfer tasks. The transfer task involves participants answering a set of problem solving questions as a measure of the level of domain understanding attained by the viewer (Mayer, 1989, 1996, 2001). Consequently, improved understanding as measured by the transfer task may lead to improved requirements validation (Figure 5). It is important to note that the research is designed to measure domain understanding only. It does not address task efficiency.

Research exists to support the use of icons in the field of Human-Computer Interaction which can be used to support the structure of our research. For example, combining icons with text labels was found to be more effective in facilitating learning of application programs than using labels or icons alone (Wiedenbeck, 1999). Pictorial icons were found to enhance learning in a computer-based training exercise (Kunnath, Cornell, Kysilka, & Witta, 2007). Finally, contextualizing the problem domain increased performance of interpreting icons (Siau, 2005).

The use of iconic images in system analysis was suggested by Moody (1996) who introduced the idea of a graphical entity relational model to simplify the ER model for non-technical users. The graphical entity relational model had multiple levels of

abstractions that included context data models using entities to represent subject areas, subject area data models consisting of detailed ER models, and foreign entities used to relate the different subject areas. Images were only included in the context data model and their effectiveness on user understanding was not directly measured. Our research is differentiated from Moody (1996) by directly measuring the effects of embedding iconic images into detailed ER diagrams on user understanding while grounding the research in cognitive theory. This theory is discussed next.

2.4   Theoretical Background

Davis (1982) provided three reasons to explain problems encountered in requirements gathering and validation: 1) the constraints on humans as information processors and problem solvers, 2) the variety and complexity of information requirements, and 3) the complex patterns of interaction among users and analysts in defining requirements. It is not surprising that complex conceptual models will result from complex systems requirements. In addition, requirements validation can be considered a learning process (Gemino & Wand, 2003) where stakeholders use information presented in the model, coupled with prior knowledge of the problem domain (Khatri, Vessey, Ramesh, Clay, & Park, 2006), to build understanding. Theories of how humans develop understanding from presented information are therefore important in improving our understanding of the conceptual modeling process.

2.4.1   Cognitive Load Theory

We have focused on two related cognitive theories to develop our hypotheses. Cognitive Load Theory (Sweller, 1988; Sweller & Chandler, 1994) defines the cognitive

constraints associated with humans. The Cognitive Theory of Multimedia Learning (Mayer, 2001) provides principles to improve messages and promote learning. The main assumptions of the Cognitive Load Theory (CLT) are limited working memory and its interaction with a practically unlimited long term memory (Sweller & Chandler, 1994). Working memory has the capacity to process approximately seven items of information at any given time (Miller, 1956). However, schema construction allows the individual items used by working memory to vary in complexity without using additional working memory space (Sweller & Chandler, 1994).

For example, a "dog" can be considered a single element occupying one of the seven locations in working memory for an individual familiar with dogs; or, a dog can be decomposed into its various descriptive elements (paws, eyes, ears, tail, etc) with each element occupying one of the working memory locations for an individual not familiar with dogs. Schema acquisition relies on prior experiences and knowledge that enables individuals to construct bigger chunks of information to use as single elements in working memory. This supports the evidence that long term memory provides the basis of intellectual performance and differentiates the problem solving skills (i.e., speed and accuracy) between novices and experts. The CLT suggests properly designed learning mechanisms will enable learners to use material stored in long term memory to reduce the burden (cognitive load) on working memory. The CLT proposes two sources of cognitive load: intrinsic and extraneous. It argues that using learning mechanisms structured to reduce one or both of these sources of cognitive load should lead to improved learning and understanding.

2.4.1.1   Intrinsic Cognitive Load

Intrinsic Cognitive Load is strongly related to the interactivity of elements in the task being learned. Sweller and Chandler (1994) argue the more elements that need to be simultaneously assimilated in a particular task, the greater the intrinsic cognitive load on working memory thus reducing an individual's overall ability to process information. The definition of an element is subjective and dependent on the learner's prior knowledge. For example, when viewing the same ER diagram, an element might be a property of an entity to a novice viewer whereas a more experienced viewer might view an entity with all its corresponding properties as an element.

Intrinsic cognitive load is determined by the interactivity of elements in an instructional message. Conceptual models present elements of the system (e.g., entities and attributes) and their associated interactivity (e.g., relationships) to describe the problem domain. Intrinsic cognitive load is expected to be high with more complex models. Element interactivity and its associated cognitive load can be influenced by model design by omitting some interacting elements (Paas, Renkl, et al., 2003; Sweller & Chandler, 1994). For example, the choice of using optional or mandatory properties in ER diagrams can influence element interactivity.

2.4.1.2   Extraneous Cognitive Load

The intrinsic nature of the task involves schema acquisition and knowledge construction by combining new information with prior knowledge. The process of manipulating the elements of the message to construct knowledge (such as locating and mentally arranging the elements of a conceptual model) involves extraneous cognitive activity. This manipulation is not relevant to the schema acquisition and knowledge

construction. The CLT argues that reducing this irrelevant cognitive activity by carefully presenting the information will facilitate learning (Sweller & Chandler, 1994). We propose that embedding iconic images into conceptual models helps to reduce extraneous cognitive load by supporting the process of efficiently manipulating model elements in preparation for knowledge construction.

Intrinsic and extraneous cognitive loads are additive and consume working memory capacity. Remaining capacity is used for knowledge construction (developing understanding) (Paas, Tuovinen, et al., 2003). Balancing intrinsic and extraneous cognitive activity is therefore essential to maximizing the efficiency of working memory. Challenging tasks like reading ER diagrams, with high intrinsic cognitive loads, are susceptible to extraneous cognitive overload. In these situations, extraneous cognitive load will reduce cognitive resources available for knowledge construction, significantly impeding the learning process. Reducing extraneous cognitive load therefore becomes essential to promote learning and understanding. A primary goal in requirements validation should be to minimize the effects of extraneous cognitive load on complex modeling tasks for model viewers.

2.4.2   Cognitive Theory of Multimedia Learning

The Cognitive Theory of Multimedia Learning, CTML, was developed by Mayer using a variety of empirical research (Mayer, 1989, 1996, 2001). The theory's main objective is to use multimedia presentations to reduce cognitive load, primarily by reducing extraneous cognitive load.

The CTML is founded on three major assumptions: 1) Dual Channels, 2) Limited

Capacity, and 3) Active Processing. The dual channel assumption is based on the Dual

Coding Theory (Paivio, 1986, 1991). Individuals are assumed to have two separate

processing channels for interpreting visual and auditory information. The two channels

complement each other since receiving simultaneous information through each channel

improves overall recall compared to receiving information through only one channel

(Paivio, 1986). The theory of working memory (Baddeley, 1992) along with assumptions

from the cognitive load theory (Sweller, 1988) provide the framework for the limited

capacity assumption. Baddeley's theory states that individuals have limits to the amount

of information processed by each channel and held in working memory. Finally, the

active processing assumption is based on generative theory (Wittrock, 1990) that suggests

people are active processors of information rather than passive processors. Active

processing implies individuals pay attention, organize incoming information, and

integrate the information with knowledge stored in long term memory (prior knowledge).

The implications for multimedia message design are that information presented must

have a coherent structure. The messages should provide the receiver guidance for

building structure.

Multimedia presentation, as defined by Mayer (1989) is "the presentation of

material using both words and pictures" (Mayer, 2001, p. 2). Unlike the popular

definition of "multimedia," Mayer's definition is not connected to the media (such as

computers) used to deliver the message nor to the presentation mode (such as animation);

instead, he connects it to the sensory mode. According to the sensory modality

description, a textbook with pictures would be considered multimedia as readers will

visually process pictures and convert words into sounds for verbal processing (auditory processing). Adding iconic images or pictures to static conceptual models would produce multimedia diagrams that fit the description defined by Mayer (1989). An overview of the CTML is shown in Figure 6.
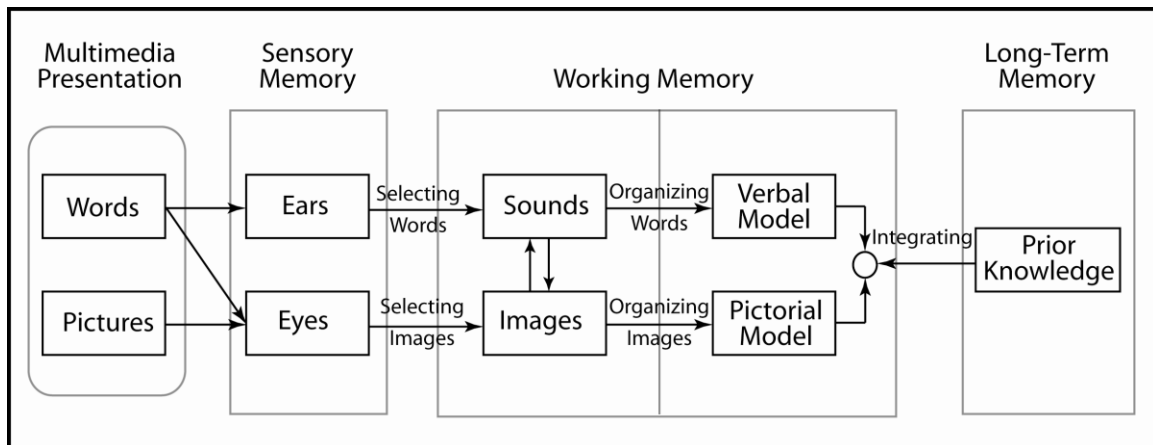
Figure 6: The Cognitive Theory of Multimedia Learning

The CTML suggests three cognitive processes are employed by learners to make sense of a message. First, incoming information is selected into one of two available channels where verbal information is processed through the auditory channel and visual information is processed through the pictorial channel. Second, the information is organized in working memory to form verbal and pictorial based models. These models are created by building connections among pieces of information received through either channel. The third process involves integration of the two models to create a single integrated representation of the information to be assimilated with prior knowledge from long term memory. This implies the level of understanding of the message will depend on the learner's prior knowledge.

The foundations of the CTML enabled Mayer (2001) to suggest seven design principles to assist designers to create effective multimedia presentations. The principles with a description of each are presented in Table 2.

Design Principal	Description
Multimedia Principle	Recipients learn better from words and pictures than from words alone.
Spatial Contiguity Principle	Recipients learn better when corresponding words and pictures are presented near rather than far from each other on a page or screen.
Temporal Contiguity Principle	Recipients learn better when corresponding words and pictures are presented simultaneously rather than successively.
Coherence Principle	Recipients learn better when extraneous material is excluded rather than included in the presentation.
Modality Principle	Recipients learn better from animation and narration than from animation and on-screen text (spoken text rather than printed text).
Redundancy Principle	Recipients learn better from animation and narration than from animation, narration, and text.
Individual Differences Principle	Design effects are stronger for low-knowledge learners than for high-knowledge learners, and for high-spatial learners rather than for low-spatial learners.

Table 2: The Seven Principles of the Cognitive Theory of Multimedia Learning

2.5   Hypothesis

Having developed our theoretical background, we are now able to consider the research hypotheses. Standard methods for presenting entities in ER diagrams use an entity name surrounded by a simple box as shown in Figure 7. The use of iconic graphics, as a substitute for the standard entity in an ERD is illustrated by Figure 8. We argue below that incorporating a relevant graphical icon with an entity name instead of a standard box with an entity name can increase the domain understanding developed by model viewers.

Hypotheses for this experiment are based on the multimedia principle from the CTML (Table 2). The multimedia principle suggests that incorporating graphical images in messages will improve learner understanding. Words and pictures are qualitatively

different as words describe information in an abstract manner while pictures present information in an intuitive manner (Mayer, 2001). The iconic graphic provides more content and reduces the extraneous cognitive load associated with the ER diagram. Lowering the extraneous load allows more cognitive capacity to be used for knowledge construction to increase the sophistication of the cognitive model developed by the model viewer. Model viewers who are provided with iconic graphics should therefore perform better on tasks related to domain understanding than module viewers provided with standard boxes for entities.

The level of understanding is assessed using three variables. Multiple variables are necessary as three learning outcomes are associated with any learning process: 1) no learning, 2) retention (remembering), and 3) understanding (Mayer, 2001). No learning is self evident. Retention is the ability to reproduce presented information. Understanding is the ability to apply constructed knowledge for use in new situations. Mayer (2001) suggests using recognition and recall tasks to measure retention, and transfer tests to measure understanding.

The goal of this study is to identify the impact of embedded iconic images on understanding, but it is important to test the impact of iconic images on retention as well as understanding to be consistent with research grounded in the CTML. The research hypotheses are:

> **H1:** Participants using conceptual models with embedded iconic graphics will show higher levels of retention (higher scores on recognition and recall) than participants using standard ER diagrams.

H2: Participants using conceptual models with embedded iconic graphics will develop higher levels of understanding (higher transfer scores) than participants using standard ER diagrams.

H1 is necessary to establish a framework for interpreting the results of the primary hypothesis H2. Care must be taken when evaluating modeling techniques to carefully control for informational equivalence (Siau, 2004). Siau (2004) introduced the notion of informational and computational equivalence (Larkin & Simon, 1987) as mechanisms for evaluating effectiveness of modeling techniques. Comparison of different techniques is more valid if these techniques are informationally equivalent since any significance detected will not be attributed to the different information provided by the technique. Informational equivalence is defined as "two representations are informationally equivalent if all the information in the one is also inferable from the other, and vice versa" (Larkin & Simon, 1987, p. 67).

Hypothesis H2 suggests that higher transfer scores result from incorporating iconic graphics into the ERD. But different transfer scores might also result from having additional information. Retention is defined as the ability to reproduce presented information. Retention therefore provides a baseline for informational equivalency. If the information provided by both treatments is not equivalent, i.e. has significantly different retention scores, then differences in transfer score may be related to differences in retention instead of a lowered extraneous load. Since representations in both treatments groups are identical except for the icons, we expect differences in understanding (H2) to be attributed to the use of embedded iconic images. Significant differences in H1 may indicate that the treatment condition is not informationally equivalent to the control group

leading to concerns whether differential information in the treatment is the cause of measured significant differences in H2.

2.6   Method

2.6.1   Participants

A total of 206 valid responses from 211 participants were collected. Undergraduates were paid $10 to participate in the experiment. Previous research has established differences between novice and expert modelers (Batra & Davis, 1992; Lee & Truex, 2000; Shanks, 1997). Gemino & Wand (2004) note participants with high domain or modeling technique knowledge may have difficulty in overcoming developed expertise leading to biases. Students with similar expected levels of modeling and domain experience were therefore considered an appropriate population. Table 3 lists a breakdown of key pretest variables by treatment group.

	Case: Far East		Case: Voyager	
	Graphic	Standard	Graphic	Standard
N	52	51	51	52
Age (mean)	20.2	20.3	20.7	20.7
Gender (% Male)	67.3%	52.9%	54.9%	50.0%
ESL (%)	50.0%	58.8%	62.7%	65.4%
ERD Courses (mean)	0.92	0.90	1.20	1.27
Used ERD (Total)	4	2	2	3
Case Knowledge[1] (mean)	1.77	1.43	1.76	1.83
PDK[2] (mean)	0.36	-0.36	0.07	-0.07

[1] Mean of question 5 listed in Table 4 where 1 indicates no knowledge on a seven point self reporting scale
[2] standardized means of questions 5 to 10 listed in Table 4

Table 3: Summary of important pretest variables

2.6.2 Instruments

Two business cases, "Voyager Bus Company" (Voyager) and "Far East Repair" (Far East), were used. Two cases adapted from previous studies (Batra, et al., 1990; Bodart, et al., 2001; Gemino & Wand, 2005) were used to control for case effect bias. Four experimental groups were created: two treatment groups (one for each case), and two control groups. Participants received a one page text description of the case, an ER diagram with or without the treatment condition, and a training page that explained the grammar used. The ER diagrams for the Far East case are shown as Figure 7 and Figure 8. The graphics used for the treatment conditions were obtained from clipart.com (all images embedded in the ER diagrams are © 2006 JupiterImages Corporation).

2.6.3 Procedures

The procedure used for the study is based on Mayer (2001) and follows examples of previous research (Bodart, et al., 2001; Burton-Jones & Meso, 2006; Gemino, 2004; Gemino & Wand, 2005; Khatri, et al., 2006). A computer laboratory, equipped with 27 workstations and customized software, was used to collect the data. Sessions varied in size from 11 to 26 participants lasting approximately one hour. Experimental material was distributed randomly. Participants seated next to each other did not receive the same case or treatment condition. Participants were monitored and asked to work independently.

Sessions began with a brief training period to review the one page explanation of the grammar. This training was followed by a pretest to capture demographics, prior experiences, prior domain knowledge, and prior knowledge of ER diagrams (Table 4).
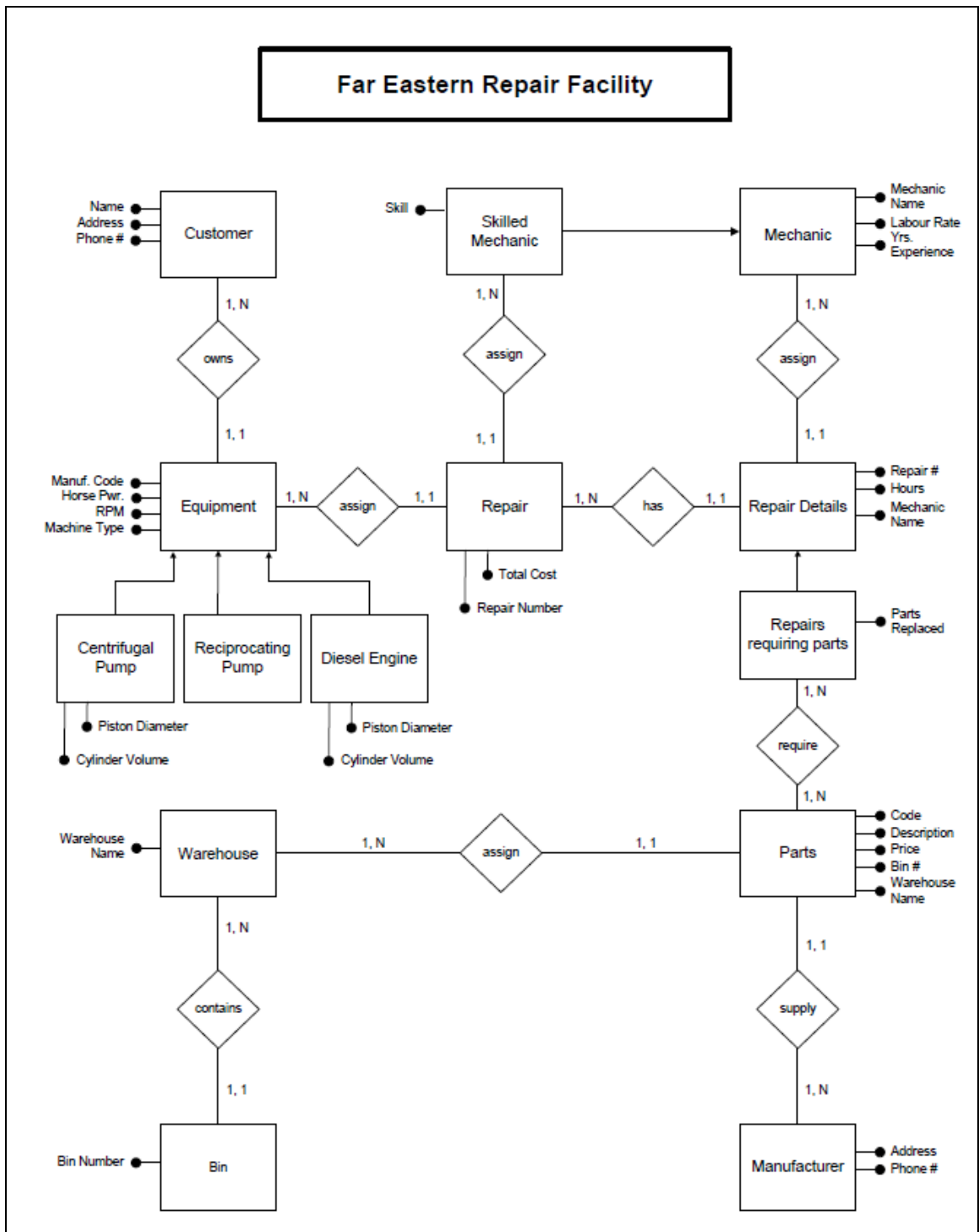
Figure 7: The Far East standard ERD used during the experiment
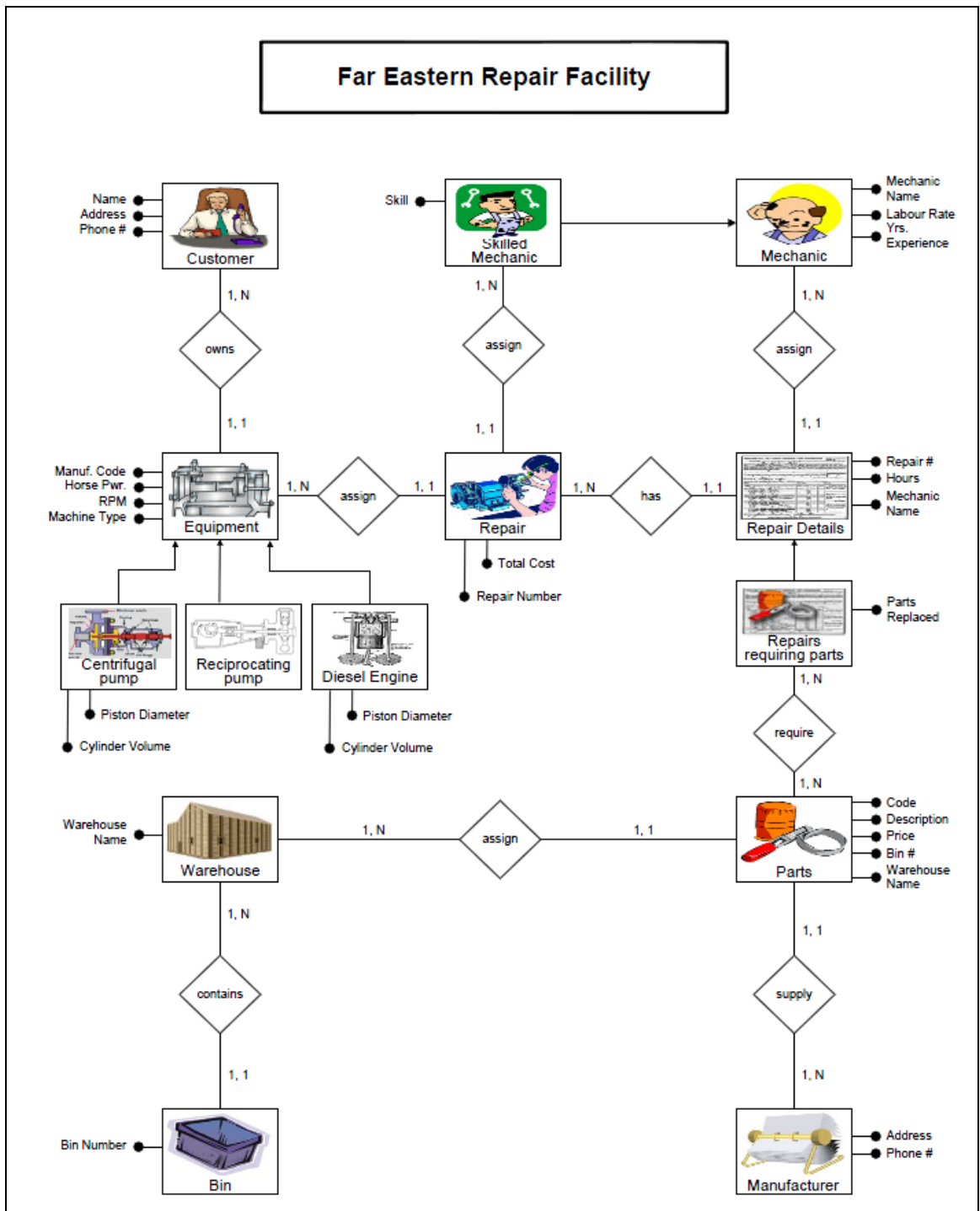
Figure 8: The Far East treatment condition ERD used during the experiment

Voyager Case	Far Eastern Case
1. Number of System Analysis courses taken	1. Number of System Analysis course taken
2. Level of ERD knowledge (1 to 7)	2. Level of ERD knowledge (1 to 7)
3. Used ERD in a business setting (Yes/No)	3. Used ERD in a business setting (Yes/No)
4. English as first language (Yes/No)	4. English as first language (Yes/No)
5. Level of knowledge of a bus tour company (1 to 7)	5. Level of knowledge of a machine repair facility (1 to 7)
6. Taken a bus tour (Yes/No)	6. Worked as a mechanic (Yes/No)
7. Worked as a bus driver (Yes/No)	7. Worked in a warehouse (Yes/No)
8. Made reservations for a bus trip (Yes/No)	8. Replaced a part of an engine (Yes/No)
9. Traveled by bus to a special event (Yes/No)	9. Had your engine overhauled (Yes/No)
10. Organized a set of short bus trips (Yes/No)	10. Helped to organize a repair shop (Yes/No)

Table 4: Information collected during the pretest for each case

The three experimental tasks were administered immediately after the pretest. The recognition task was first. Participants had 15 minutes to review the material and answer 12 "Yes/No/Unknown" questions listed in Table 5. The recognition score was defined as the number of correct answers. The participants were told all case materials would be taken away at the conclusion of the first task. In this way, participants were ensured of working on the final two tasks using only their mental models. Participants could not revisit completed tasks.

The recall task followed. Participants were asked the following question: "Using what you have learned about this company, please write down an explanation of how the company operates." Six minutes were allotted to complete the recall exercise. The recall score was defined as the total number of distinct and correct idea units listed. One rater scored the recall responses using scoring procedures from previous research (Mayer & Moreno, 1998). The treatment condition was hidden from the rater to eliminate rater bias.

The final task was the transfer task composed of four questions, each describing a specific problem. Examples are provided in Table 6. Participants were asked to record as many solutions as they could think of for each question. Two minutes were allotted per question. The total number of responses as well as the number of acceptable responses for all four questions was determined by a single rater. A template of possible acceptable answers was prepared. Examples of acceptable answers for the first question (Table 6) included: parts not available, mechanics with required skill not available, and machine already repaired but customer not yet contacted.

1. Do all repairs require parts?
2. Can a repair be worked on by more than one mechanic?
3. Are all repairs assigned to at least one mechanic
4. Are there parts stored in the warehouse that are not used for repairs?
5. Does Far Eastern collect different information for different machine types?
6. Does Far Eastern differentiate their local customers in any way?
7. Can a mechanic who does not have a special skill be assigned to more than one repair?
8. Do all the mechanics related to the same repair, pool their hours to create a single entry for hours worked?
9. Can a piece of equipment undergo more than one repair?
10. Can more than one part be listed in a single repair detail?
11. Is the cylinder volume recorded for all pumps that are repaired?
12. Can a part be supplied by more than one manufacturer?

Table 5: Recognition Questions used for the Far Eastern Repair Facility case

The open-ended nature of these questions allowed participants to provide answers based either on information attained from the case material or from other experiences. One example of a solution to question (1) (Table 6) that would be outside the case information was "Far Eastern burned down." The structure of the transfer task may have encouraged participants to record solutions regardless whether these solutions were based on knowledge from the case or otherwise. We worked to isolate this effect from transfer

scores. We chose to compute the ratio of acceptable answers provided by each participant

to the total number of solutions noted. Analysis of this ratio provides a more accurate

analysis of the differences between treatment groups.

1. A customer of Far Eastern has called to complain that the machine they sent for repair has not been repaired yet. What possible reasons can you provide for what might have gone wrong?

2. Far Eastern is experiencing a very large increase in the number of machines that they should repair. What problems might Far Eastern experience because of this increase in repairs?

3. Customers of Far Eastern are not happy when the actual repair price is higher than the estimated repair price. The sales person says that it is not his fault because the estimation is so difficult. Provide as many possibilities as you can think of that make the accurate estimation of the total repair price difficult.

4. Far Eastern is considering investing in a machine that can be used to repair large turbine engines. How would the current data structure be affected by the purchase of the new machine? Try to think of as many affects as possible.

Table 6: Problem solving questions used for the Far Eastern Repair Facility case

2.7 Results

The means and standard deviation for the three dependent variables (recognition,

recall, and transfer) as well as total number of responses and ratio of acceptable to total

for the transfer task (T*ransfer Ratio*) are provided in Table 7.

Dependent Variable	Case: Far East		Case: Voyager	
	Graphic n=52	Standard n=51	Graphic n=51	Standard n=52
Recognition	7.08 (1.79)	7.04 (1.84)	7.08 (1.41)	7.27 (1.68)
Recall	6.92 (3.31)	6.20 (3.18)	8.82 (4.83)	9.52 (5.85)
Transfer (Acceptable)	10.00 (4.39)	7.90 (4.09)	10.73 (4.53)	9.37 (4.08)
Transfer (All Responses)	14.87 (5.59)	13.92 (4.86)	15.12 (5.11)	15.81 (5.31)
Transfer Ratio: *Acceptable/All Responses*	0.67 (0.22)	0.55 (0.19)	0.70 (0.22)	0.59 (0.18)

Table 7: Means and Standard Deviations of the dependent variables (by case and treatment condition)

Multivariate Analysis of covariance (MANCOVA) was used to test for statistical significance. MANCOVA was chosen because of multiple dependent variables and the need to control for covariates. MANCOVA assumptions were investigated prior to analysis. Histograms and P-P plots were constructed and used to verify the normality assumption. The homogeneity of variances assumptions was verified using the Box's statistic.

Two covariates were used in the model: previous domain knowledge (PDK), as defined in Table 3, and English as a second language (ESL). Both covariates were found to be significant for some of transfer ratios and recall scores although the level of significance varied between cases. Table 8 provides complete results of the MANCOVA analysis.

	Case: Far East			Case: Voyager		
	Treatment:	Covariates:		Treatment:	Covariates:	
		ESL	**PDK**		**ESL**	**PDK**
	F (Sig.)	F (Sig.)	F (Sig.)	F (Sig.)	F (Sig.)	F (Sig.)
Recog.	0.04 (0.84)	1.72 (0.19)	1.05 (0.31)	0.35 (0.56)	0.37 (0.54)	1.08 (0.30)
Recall	1.65 (0.20)	5.87 (0.02)	2.78 (0.10)	0.48 (0.49)	6.08 (0.02)	1.02 (0.31)
Transfer Ratio	11.16 (0.00)	4.41 (0.04)	6.10 (0.02)	8.73 (0.00)	4.30 (0.04)	1.17 (0.28)

Table 8: MANCOVA results for the treatment condition and covariates (ESL and PDK)

2.7.1 Covariates

Previous research (Shaft & Vessey, 1995, 1998) has indicated important differences between application experts and novices. Differences are also expected through considerations of the cognitive load theory (Sweller & Chandler, 1994), the cognitive theory of multimedia learning (Mayer, 2001), and findings of Khatri et al.

(2006). The CLT suggests that high PDK will lower the intrinsic cognitive load. The individual differences principle outlined by the CTML again suggests that design effects will have a lower impact for those with high PDK. Khatri et al. (2006) suggests the level of previous domain knowledge has an effect on the level of understanding achieved. Results in Table 8 suggest that PDK may have some effect on understanding as significance was detected in the Far East case. The impact was not observed in the Voyager case. The lack of significance may have to do with the instrument used to measure PDK.

The results from ESL imply the precise semantics associated with ER modeling may be more difficult for individuals with less familiarity with the language. The ESL covariate shows a strong relationship with recall and transfer ratios. ESL significance reported by Table 8 indicates a possible effect of the experimental condition between ESL and non-ESL groups. Simple Analysis of Variance (ANOVA) was used to investigate the degree and direction of any differences. Table 9 displays ANOVA results for the ESL group and Table 10 displays analysis results for the non-ESL group. Results indicate the treatment condition had a higher positive impact on the non-ESL group for the transfer ratios.

The effects of ESL need to be interpreted cautiously. An alternative explanation for at least a portion of the results may be related to possible task bias. The yes/no type of answer in the recognition task requires less language skills than responding in point form or complete sentences which is the format for the recall and transfer tasks. The potential task bias might explain why recognition results differ less than recall and transfer results across Table 9 and Table 10. It may not be clear, for ESL participants, whether

comprehension and understanding was measured as opposed to written language skill.

Therefore, a portion of the ESL results may be the result of a task basis. The results for

non-ESL participants would more likely reflect the true effect of iconic graphics.

	Case: Far East			Case: Voyager		
	Graphic N=26 Mean (sd.)	Standard N=30 Mean (sd.)	ANOVA F (Sig.)	Graphic N=32 Mean (sd.)	Standard N=34 Mean (sd.)	ANOVA F (Sig.)
Recog.	6.65 (1.98)	7.00 (1.80)	0.47 (0.50)	6.97 (1.51)	7.24 (1.79)	0.42 (0.52)
Recall	5.92 (3.14)	5.77 (3.29)	0.03 (0.86)	7.38 (4.17)	9.03 (5.67)	1.81 (0.18)
Transfer:						
Accept.	7.77 (3.76)	6.37 (3.39)	2.16 (0.15)	8.66 (3.71)	8.65 (3.95)	0.00 (0.99)
All	12.08 (4.03)	12.00 (4.28)	0.01 (0.95)	13.31 (4.41)	15.06 (5.27)	2.12 (0.15)
Ratio	0.63 (0.26)	0.51 (0.18)	4.24 (0.04)	0.65 (0.25)	0.58 (0.18)	1.90 (0.17)

Table 9: ANOVA analysis for participants with English as a second language (ESL)

	Case: Far East			Case: Voyager		
	Graphic N=26 Mean (sd.)	Standard N=21 Mean (sd.)	ANOVA F (Sig.)	Graphic N=19 Mean (sd.)	Standard N=18 Mean (sd.)	ANOVA F (Sig.)
Recog.	7.50 (1.50)	7.10 (1.95)	0.65 (0.43)	7.26 (1.24)	7.33 (1.50)	0.02 (0.88)
Recall	7.92 (3.22)	6.81 (2.98)	1.48 (0.23)	11.26 (4.99)	10.44 (6.23)	0.20 (0.66)
Transfer:						
Accept.	12.23 (3.85)	10.10 (4.07)	3.39 (0.07)	14.21 (3.57)	10.72 (4.10)	7.65 (0.01)
All	17.65 (5.61)	16.67 (4.37)	0.44 (0.51)	18.16 (4.83)	17.22 (5.25)	0.32 (0.58)
Ratio	0.71 (0.19)	0.61 (0.18)	3.69 (0.06)	0.79 (0.09)	0.61 (0.17)	15.28 (0.00)

Table 10: ANOVA analysis for participants with English as native language (non-ESL)

2.7.2   Treatment Effects

Having established the significance of the covariates, we turn our attention to the

treatment variable. The results provide support for hypothesis H2 only (Table 8). H2, the

hypothesis that embedded graphics will improve understanding, is confirmed for both

cases. Both cases showed significant transfer ratio score differences between treatment

and non-treatment conditions after accounting for influence of the covariates (F=11.16

and F=8.73 for the Far East and Voyager cases respectively).

The results in Table 8 show no evidence of significant differences across treatment groups for recognition or recall. Lack of significant differences between the treatment groups for recognition and recall across the two cases may imply that treatment and control groups received informationally equivalent experimental material.

In summary, the results of the MANCOVA support hypothesis H2 that suggests the use of iconic graphics generates a significant increase in the level of understanding when compared with participants viewing standard ER models. In addition, two covariates were shown to be significantly related to levels of understanding: PDK and ESL. The effect of the treatment condition was strongest for participants with English as their native language.

2.8   Discussion and Research implications

This study presented experimental findings on the use of embedded graphics in ER diagrams. The motivations for the study were based on an objective to improve overall effectiveness of ER diagramming for model viewers. Standard ER diagrams were adapted to include entities represented as iconic images and text titles. ER diagrams were chosen for their continued popularity in systems analysis and the ease of representing entities with embedded graphics. An experiment was conducted with two cases used in previous research (Batra, et al., 1990; Bodart, et al., 2001). The cognitive load theory and the cognitive theory of multimedia learning provided the theoretical foundation to generate hypotheses predicting the impact of embedded graphics on retention and understanding.

Results provide support for our primary hypotheses generated from the CTML and CLT. Iconic graphics did not have any significant impact on retention as measured by recognition and recall tasks; however, in both cases, graphic icons did support significantly higher levels of understanding as measured by the transfer task. These results suggest iconic graphics can positively impact the level of understanding gained by persons viewing ER diagrams. These results should encourage further research into the use of graphics and other enhancements in standard ER diagrams.

In addition to the effect of iconic graphics, the study also indicated that previous domain knowledge (PDK) and English as a second language (ESL) are two important variables to consider in any measurement of understanding. PDK was investigated as an element in explaining higher levels of understanding based on assumptions from the CLT (Sweller & Chandler, 1994), CTML (Mayer, 2001), and findings from Khatri et al (2006) that previous domain knowledge may play an important role in IS analysis and design. PDK findings did not provide robust results. We believe this may in large part be due to the measurement instrument for PDK. Pretest results for the Far East case indicated a low self reported prior case knowledge of 1.7 (1 is no knowledge). Only 9 (of 33) participants who reported a score greater than one also answered positively to two or more of the PDK related pretest questions (Questions 6 to 10 in Table 4). We believe this may have caused a statistical anomaly leading to a significant result. PDK is likely an important factor that impacts understanding, but this experiment may not have a robust enough data set to provide valid inferences.

ESL was introduced to isolate possible effects due to language processing. Our results indicate that embedding graphics in ER diagrams provided a larger effect on

understanding for non-ESL participants. As noted earlier, comparison of the ESL and non-ESL group is preliminary and may be affected by a task bias. The initial ESL result may seem counterintuitive because the use of representative images would typically be expected to allow users to relate textual description to graphical elements perhaps surpassing the limitations of written language. However, working with a foreign language can lead to additional sources of intrinsic cognitive load. Since the effects of cognitive load are cumulative, the CLT would suggest that ESL users would be subject to higher overall cognitive load compared to those working in their native language. Any positive effect of using graphics on reducing extraneous cognitive load would not necessarily compensate for the increase in intrinsic load required to process language (See Figure 9).
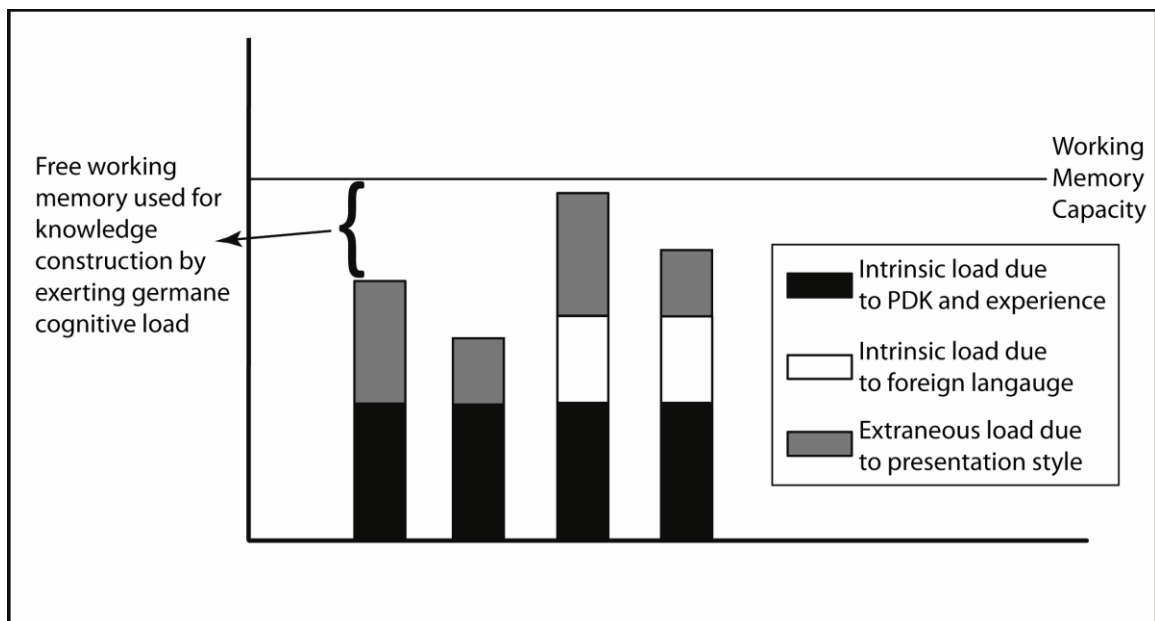
Figure 9: Cognitive Loads on working memory of ESL vs. non-ESL groups

This result should not be surprising as ER diagrams often pose a significant challenge for users even when presented in their native language. The results perhaps suggest that increased precision of semantics in ER diagrams requires a high familiarity

with the language. As 'offshoring' and multilingual communication requirements become more the norm, this finding could prove more important in considering methods to support effective communication.

An alternative explanation may provide some additional insight into the ESL results. The comprehension task required only yes/no type answers whereas retention and transfer tasks required written answers. It is possible the written tasks may have been more difficult for ESL participants to complete which introduces a task bias accounting for some of the measured variance.

It is clear that more work needs to be done to fully uncover the impact of presentation on model viewer understanding. We expect model viewer characteristics such as language, domain experience, and modeling experience to be important considerations in multilingual contexts.

2.9   Conclusions, Limitations, and Future Research

This study provides evidence that iconic graphics embedded in ER diagrams can have positive effect on domain understanding for viewers with relatively low levels of familiarity with ER diagrams. The importance of this work for practicing Systems Analysts and designers comes from two key elements of their job. First, modern IS projects are complex. The ability to understand large, complex projects requires tools that break these projects into meaningful, manageable components. The use of iconic graphics seems to reduce the extraneous cognitive load associated with these complex systems and deserve further attention. Secondly, systems analysis documents, like ER diagrams, are used as communication tools among systems experts, such as analysts and designers, and

among project stakeholders, such as end users and managers. A tool that more efficiently and effectively presents the modeled system can facilitate better understanding of the current and proposed Information System.

A limitation of these findings is using students as participants to review the two cases. While using student subjects does not represent experienced system analysts, students are a good sample for the general population of system users to which these conceptual models are often addressed (Gemino and Wand, 2004). We also found some effect differences across cases which may suggest the potential for additional work in indentifying when case differences impact measures of recognition, recall and transfer.

Another limitation is the size and complexity of the ER diagrams selected for the cases. Although the ER diagrams used in this study are significantly smaller than the average model used in practice, it was an important consideration to control the effects of other variables not considered in this study. For example, the CTML's spatial and temporal contiguity principles suggest that splitting a diagram onto multiple sheets of paper (or computer screens) will not be as effective as having the diagram presented in one location. Previous research (J. Kim, et al., 2000) has considered this issue and future research could more carefully consider the effects in combination with graphical representations. There is also a need for more thorough discussion and development of cases that can be used for this type of experimental research. It is difficult to establish external validity but use of widely accepted cases would improve the impact of results from experiments.

One important consideration is the choice of icons to be used. It seems natural to expect the use of icons to be more effective as graphics would more closely represent the

domain experience of the viewer. We, therefore, suggest that embedding icons using actual domain relevant images captured with digital cameras to enhance entities would more likely provide a better opportunity to promote understanding of conceptual models. Further research into the effect of icons with differing levels of domain relevance can address this issue.

Another interesting consideration is the impact of using icons on task efficiency. It is possible that icons could have an impact on understanding or recall efficiency. The research was designed to control for time used during each experimental task which limited the ability to measure task efficiency in conjunction with performance levels. Further research without a time restriction may be able to uncover the impact on task efficiency.

Results from this experiment suggest improvements can be made in presenting information in a way that is more effective than standard text based diagrams. This study focused on a single CTML principle. Further improvements are likely when more of the principles are considered. For example, including graphical elements combined with narration and user interactivity (such as computer aided navigation of the conceptual model) may lead to better understanding than standard techniques. We therefore suggest that further efforts should be made in developing conceptual models with a lower cognitive burden for systems analysis and design. Developing these methods will lead to improved communication of system requirements and, consequently, increased rates of success in information systems development projects.

The issues raised by results involving ESL in this study suggest new directions for future research. Possibility of interaction between writing skills and measurement of

understanding suggests that researchers should measure ESL (or language) when studying conceptual models' impact on understanding.

Further research will be required to extend the findings to other diagramming techniques. Class diagrams under the UML represent a strong candidate for embedding graphics to improve understanding. Class diagrams consist of class objects associated with attributes and operations. The potentially large number of attributes and operational elements per class requires an inexperienced user to spend valuable cognitive resources to manipulate these elements in preparation for knowledge construction. This can lead to an increase in extraneous cognitive load. It is predicted by the CLT and the CTML that a reduction of this load with help from multimedia elements will improve the process of knowledge construction and overall understanding.

2.10   References

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CHAPTER 3
MODULAR UML FOR BETTER UNDERSTANDING

A condensed version of this paper was presented at the 15th Americas Conference in Information Systems (AMCIS), 2009.

3.1   Abstract

Models created using the unified modelling language (UML) have become the standard in object oriented systems analysis and design. This article introduces 'Modular UML' to more effectively address quality of understanding of multiple UML diagrams. Cognitive theories are used to demonstrate a step-by-step process for creating the Modular UML approach.

3.2   Introduction

Conceptual models created using the unified modeling language (UML) have become the standard in object oriented systems analysis and design (Podeswa, 2005). The complexities of the language and its many diagrams have sparked discussion about UML's usability and overall effectiveness (Dobing & Parsons, 2008; Dori, 2002; Erickson, 2008; Glezer, Last, Nachmany, & Shoval, 2005; Grossman, Aronson, & McCarthy, 2005; Siau & Cao, 2001). This article introduces the idea of Modular UML, a unique approach to presenting conceptual models created using UML. The focus is placed on the pragmatic dimension of model quality as defined by Lindland, Sindre and Solvberg (1994).

The UML is designed to create abstract representations of objects and their interaction. This activity can be defined as a type of descriptive conceptual modeling (Schichl, 2004). Conceptual models in information systems development have two important objectives: to communicate system specifications, and to facilitate the systems analysis and design process (Wand & Weber, 2002). One measure of the quality of the model is the pragmatic understanding developed as a result of communication through the model.

The article presents an argument for combining structural and functional elements of UML models into a single diagram. No change to the UML's current constructs is necessary. The modularization is accomplished by decomposing selected UML diagrams into component modules followed by combining related modules from various diagrams together onto the same diagram. An example is shown in Figure 10. We refer to this approach as 'Modular UML'. The objectives of modular UML are twofold: to improve stakeholder (user or model viewer) understanding of UML diagrams during model reviews, and to improve communication between model developers and model viewers during model walkthroughs. The cognitive theory of multimedia learning (CTML) (Mayer, 2001) provides theoretical support for the argument that combination diagrams can enhance the quality of user understanding.
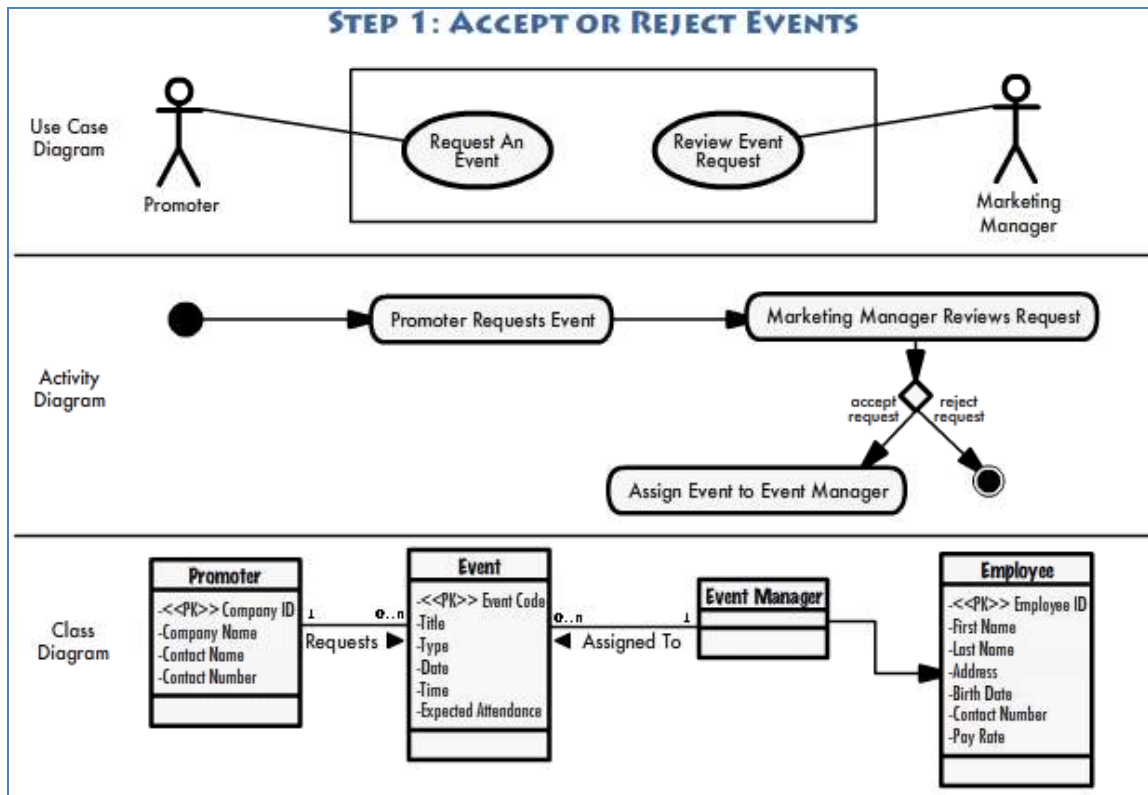
Figure 10: Combined UML diagram

In addition to introducing a modular approach to UML, we present a description of the Modular UML Interaction (MUI) system. The MUI system is a custom application designed to present combined diagrams and to test the effectiveness of these and other UML diagrams. A method for creating modular diagrams based on the foundation of use case narratives is also provided.

The paper is organized as follows. The next section provides a brief overview of conceptual modeling and UML. This is followed by a discussion of the complexities of UML. Next, empirical evidence to support the premise behind modular UML is presented. Then, a description of the cognitive theory of multimedia learning (Mayer, 2001) which forms the theoretical basis for modular UML is provided. An illustrative example and a description of an application used to demonstrate modular UML is

presented before we conclude the paper with a discussion of modular UML's limitations and future research.

3.3 Background

The use of descriptive models to communicate accurate specifications during systems development can be traced back to the early 1970s (Parnas, 1972). In 1976, Peter Chen introduced the Entity Relationship Diagram (Chen, 1976) heralding a new era of research into systems design and conceptual modeling techniques. Entity relationship and data flow diagrams were the main conceptual modeling components of the structured approach (DeMarco, 1978; Yourdon & Constantine, 1979). The search for an improved systems modeling technique led to the introduction of object-oriented methodology (Booch, 1994; Coad & Yourdon, 1990, 1991; Jacobson, 1991; Rumbaugh, et al., 1991). The collaboration of Grady Booch, Ivar Jacobson, and James Rumbaugh resulted in the formalization of the Unified Modeling Language as UML 1.0 in 1997 (www.uml.org).

UML quickly became the standard modeling language for design and development of object oriented software systems. Its adoption by the software development community encouraged its acceptance as the standard modeling language for systems analysis and design (Grossman, et al., 2005). UML diagrams, combined with other tools, are used by systems analysts during requirements gathering [see (Podeswa, 2005)]. However, the complexities of the language and its many diagrams have sparked debate about UML's usability and overall effectiveness. For example, Hugos (2007, p. 23) described UML and its diagrams as filled with words "*designed to confuse and disengage the typical business user*". This describes a general sentiment about the complexity of UML as summarized by Erickson (2008). Erickson suggests that UML's

continued dominance will depend, in part, on making it more comprehensible by

"*...finding ways to allow UML to appear less complex, if not actually be less complex*" (Erickson, 2008, p. v) to users and developers.

Research into the effectiveness and complexities of UML began soon after its formalization in 1997. Studies comparing UML with other object oriented methodologies, such as ORM (Object-Role Modeling) (Halpin & Bloesch, 1998) and OML (OPEN Modeling Language) (Henderson-Sellers & Firesmith, 1999), suggested the existence of some structural deficiencies in UML. More recent comparative research concluded that UML is more difficult to comprehend than OML (Otero & Dolado, 2005). Other research reviewed UML's complexities to discover that UML is two to eleven times more complex than similar object-oriented methodologies (Siau & Cao, 2001).

3.3.1   Complexity of UML

A significant source of complexity attributed to UML is the number of diagrams and a lack of apparent connectedness of these diagrams. UML 2.0 has 13 diagrams divided into three classifications: structure, behavior, and interaction. It is argued there is a large number of constructs and symbols associated with these diagrams that lead to difficulties in learning and using UML (Dori, 2002; Siau & Loo, 2006). In addition, the lack of an apparent strong relation among the multiple diagrams can lead to difficulty of learning UML (Siau & Loo, 2006) and continues to be a major concern of using UML despite the limited research in this area (Batra, 2008).

The different diagrams are not considered rigid or central for compliance to the UML structure. Analysts are empowered to select diagrams they believe are appropriate

to communicate with stakeholders (Fowler, 2004). In a survey conducted by Dobing and Parsons (2006), analysts reported a tendency not to use certain diagrams either because the diagrams are not well understood by analysts or the diagrams do not add sufficient value to justify the cost. The same survey revealed only 55% of analysts feel that UML was moderately successful, at best, in facilitating communication while 25% of analysts felt that UML was not successful at all (Dobing & Parsons, 2008). Dobing & Parsons concluded that *"the complexity of UML is a concern, suggesting more programs are needed to help IS professionals and their clients learn the language and how to use it more effectively"* (Dobing & Parsons, 2006, p. 113).

Perceived complexity of UML along with the research findings by Dobing and Parsons (2006, 2008) lend support to the suggestion that model complexity results in comprehension difficulties which, in turn, leads users to misunderstand information represented in the models (Gemino & Wand, 2003). Therefore, reducing the complexity of UML models is required to increase the effectiveness, usability, and to maintain or increase the dominance of UML.

Reducing the semantic and structural complexity of UML is difficult to accomplish. Kobryn (1999) suggests standardization is achieved through consensus which often leads to bloated specifications. The need for consensus to implement significant changes to reduce UML's complexity requires stakeholders who have invested heavily into the current UML (such as tool-vendors and users' installed base) to support large-scale changes. This is considered "*highly unlikely, if not impossible*" (Dori, 2002, p. 85). The increase to 13 diagrams in UML 2.0 from the original nine diagrams adds credence to Dori's statement. So, short term practical changes to UML must shift away

from semantics and structure towards a behavioral perspective to achieve the necessary

reduction of UML's overall complexity (Erickson, 2008).

Suggestions to reduce the complexity of UML models include combining

structure and behavior elements to reduce complexity and increase usability of these

models (Dori, 2002). Research in this area considered the use of Object Process

Methodology (OPM) (Dori, 2001) as a feasible representation of combining structure and

behavior. Other studies introduced the Functional and Object-Oriented analysis

Methodology (FOOM) to combine structural elements from class diagrams with data

flow diagrams (Shoval & Kabeli, 2001). FOOM studies yielded a partial advantage when

compared with OPM (Kabeli & Shoval, 2005). However, both of these approaches

suggest replacing UML altogether or, at the very least, amending the UML to include the

described modeling techniques. Adoption of such techniques implies a fundamental

change to UML which is unlikely to happen due to reasons highlighted by Dori (2002).

3.3.2 Empirical Support: Multiple Models and Cognitive Attention

The use of multiple models is intended to facilitate understanding by presenting

relevant constructs from multiple perspectives (J. Kim, et al., 2000). On the other hand,

having multiple models implies the model viewer must search and locate task specific

information across the diagrams available for review (Woods & Watts, 1997). Kim et al.

(2000) suggest models contain more information than is necessary to address the model

viewer's current hypothesis. This relevant information constitutes just a subset of the full

information presented by all the models. Therefore, the model viewer must actively

review, process, and eliminate information not relevant to the task at hand. From a

cognitive perspective, it can be theorized that information processing occurs in working

memory, which has a limited capacity (Baddeley, 1992; Miller, 1956). Overburdening working memory negatively impacts individual's performance on a range of tasks including comprehension and reasoning (Baddeley, 1992).

This view of limited cognitive resources is supported by results from an eye-tracking experiment (Yusuf, Kagdi, & Maletic, 2007). Eye movement methods to investigate cognitive processes can be traced back to the mid 1970s (Rayner, 1998). Eye-tracking uses an electronic device to capture eye movements and record fixations. Fixations are stabilizations of the eyes on an object. Processing of visualized information occurs during fixations. Yusuf et al. (2007) attempted to answer several questions about how users see and understand UML models including "*how do people navigate through the diagrams?*" (Yusuf, et al., 2007, p. 1). The experimental task required users to find answers to several model based questions. The findings discovered that users explored only the part of the model that contained information related to the question (Yusuf, et al., 2007). This finding supports the notion that for a specific task, users are interested in reviewing only relevant components of the model. Other findings noted that users explored the model from either the center and moved to the peripherals or from top-to-bottom and left-to-right (Yusuf, et al., 2007). This finding supports the idea that users must search and filter unnecessary information before fixating on and processing the relevant information.

Kim et al. (2000) evaluated the use of UML context diagrams with visual cues and contextual information to aid the user in determining which models are related. Results implied the treatment group used more diagrams and made more transitions between the diagrams compared with the control group. This was interpreted as a

confirmation that visual cues and contextual information given to the treatment group were successful in directing the users to the relevant diagrams. The higher number of transitions implied better integration of information. We argue the higher number of transitions may have been the result of increased burden on working memory forcing users to go back and forth repeatedly to fully understand the information. This result is supported by principles of the cognitive theory of multimedia learning (Mayer, 2001) discussed later in this paper.

It is important to also consider cognitive search processes using multiple diagrams (Hungerford, Hevner, & Collins, 2004). Search patterns of users reviewing a software system represented by entity-relationship and data flow diagrams were investigated. Two categories of cognitive techniques were identified. The "*concurrent across diagrams*" technique involves users conducting repeated, quick switches between the two diagrams. Subjects using the "*non-concurrent*" strategy chose to review one diagram at length before switching to the other diagram. The researchers concluded the concurrent across diagrams strategy to be the most effective cognitive search strategy (Hungerford, et al., 2004).

These empirical results can be used to suggest three important cognitive issues relating to viewing multiple models. First, the eye-tracking experiment from Yusuf et al. (2007) suggests that model viewers do not "take in" entire diagrams but instead focus on relevant areas within diagrams. This is consistent with findings from Gemino and Wand (2005). Second, the results from Hungerford et al. (2004) suggest that visual information from multiple diagrams are best understood if the models are viewed using repeated, quick switches rather than studying one diagram fully then moving to the next diagram.

This suggests there are temporal and spatial considerations present when viewing multiple models. Finally, results from Kim et al. (2000) suggest that frequent switches between models imply an increased level of integration of the information presented. In the next section, we present a cognitive theory that explains these results and provides insights into how to more effectively present models.

3.4 Theoretical Background: The Cognitive Theory of Multimedia Learning (CTML)

3.4.1 Overview

The formalization of the cognitive theory of multimedia learning (CTML) capped more than a decade of research into multimedia use to facilitate understanding and promote learning by students of scientific material (Mayer, 1989, 2001). The theory seeks to reduce the cognitive burden on working memory by taking advantage of humans' ability of dual mode information processing (Paivio, 1986, 1991). The CTML suggests understanding can be facilitated by presenting information to take advantage of how the human mind works. This is achieved by incorporating multimedia into the presentation of the material to optimize the presentation format to reduce the cognitive burden on the learner.

Multimedia presentations, as defined by Mayer, involve the use of words and pictures (auditory and visual) to deliver the message (Mayer, 2001). The basic premise of the CTML is that information enters working memory through our two sensory channels: visual (eyes) and auditory (ears). Working memory has limited capacity such that only a small amount of information can be present at any given time. Both visual and auditory information in working memory is organized to develop a mental model that is integrated

with knowledge from long-term memory. Understanding occurs when information in working memory is successfully integrated with long term knowledge. The CTML suggests having visual and auditory information presented at the same time improves development of mental models needed for understanding. The CTML views these two types of information as complementary and encourages using both in presenting complicated information.

The CTML offers seven principles to assist the design of multimedia presentations. Our proposed designs of the Modular UML and prototype application extend the CTML to systems analysis and design by focusing on three specific design principles: Spatial contiguity principle, temporal contiguity principle, and multimedia principle. Principles of the CTML have been successfully used in previous information systems research to investigate the effect of animation and narration in requirements validation (Gemino, 2004) and to test the impact of adding iconic graphics to entity-relationship diagrams (Masri, Parker, & Gemino, 2008b).

3.4.2   Spatial Contiguity Principle

The spatial contiguity principle suggests corresponding words and pictures closer in space to each other will yield better understanding than the same words and pictures placed farther apart on a page or screen. The principle is based on the split-attention effect indicating more cognitive resources will be used to visually search for corresponding information as they are placed farther apart (Chandler & Sweller, 1991). The limited working memory capacity assumption (Baddeley, 1986) suggests the use of cognitive resources to search for information results in a reduced likelihood for learners to simultaneously process both sets of information.

The distance of corresponding information may appear to be trivial to the casual observer but has been shown to have an effect on learning and understanding (Moreno & Mayer, 1999). The study, one of three used to verify the spatial contiguity principle, used a computer animation showing causes of lightning storms. The experiment was presented in two formats: one with a caption directly under an animation showing the causes of lightning (the separated presentation), and the other with the text embedded within the animation (the integrated presentation). Results show improved understanding with the integrated presentation despite the caption being on the same screen and appearing at the same time in both experiments. In other words, the cognitive process of searching for complementary information reduced users' ability to fully comprehend the message.

We extend this principle to reviewing multiple diagrams by suggesting that distance of related information affects understanding. Modular UML continues to separate the modules of various diagrams but the distance between the modules is significantly reduced by placing the information on the same viewing page. We propose that the cognitive effort required to review the modules decreases as the distance between them is reduced.

3.4.3   Temporal Contiguity Principle

The main premise of the temporal contiguity principle is that our ability to process information presented simultaneously is better than our ability to process information presented successively. Simultaneous presentation, according to the CTML, implies having information delivered using visual and auditory means at the same time. For example, showing a narrated video of how car brakes work. Successive presentation implies delivering information using one medium followed by the other medium. For

example, narrating in full how a car's braking system works followed by a video of the same topic. Extending the temporal contiguity principle to systems analysis diagram supports the idea of combining two models into one as proposed by the FOOM method (Kabeli & Shoval, 2005; Shoval & Kabeli, 2001) described earlier.

Mayer and colleagues proposed and tested extensions of the temporal contiguity principle suggesting that successive small-segment presentations are equally effective as simultaneous presentations (Mayer, 2001; Mayer, et al., 1999; Moreno & Mayer, 1999). Successive small-segments involve delivering a short presentation of a major step using one medium followed by a presentation using the other medium of the same step. The process is repeated until the complete presentation is delivered. The successive small-segment information delivery facilitates understanding because the relatively small amount of information delivered in each step does not exceed working memory capacity.

The extension of the temporal contiguity principle supports our proposition of decomposing UML diagrams into small, cognitively manageable modules. Having related modules from various diagrams on the same page is similar to successive small-segment presentations. Users will have to review several combined diagrams (small-segments) successively to fully review and understand the system. The process of delivering small-segments of the system is cognitively favorable since working memory would not be overburdened.

3.4.4 Multimedia Principle

The multimedia principle suggests that learners will develop more complete mental models from printed words and pictures to promote better understanding than

using words or pictures alone (Mayer, 2001). Words and pictures do not compete for sensory cognitive resources (Paivio, 1986) allowing the multi-modal information to be processed into a comprehensive mental model for integration with long term memory. This, according to the CTML, will lead to better knowledge construction and understanding.

The multimedia principle is not solely based on the interaction of words and pictures. The Multimedia principle suggests any two types of media using the two complementary channels (auditory and visual) will lead to better understanding than using one medium only. For example, animation and narration take advantage of the visual and auditory channels similar to pictures and words. Mayer provided support of this principle by successfully conducting experiments to measure an improved effect on understanding using presentations with pictures and words (Mayer, 1989a), and with animation and narration (Mayer & Anderson, 1991).

The multimedia principle is important to this study because the prototype application developed to test modular UML integrated concepts of the multimedia principles by making all elements (e.g., classes, relationships, and use cases) within all models interactive. Users can select an element to reveal a brief description displayed either as a tooltip (near the object) or as an audio recording that narrates the tooltip description. This interactive interface is discussed in detail later in the paper.

In summary, the CTML offers guidance with respect to how to effectively present information to utilize an individual's learning ability when examining new constructs. Improving this ability is exactly what the UML seeks to do, namely to provide an understandable overview of a complex system. The Spatial Contiguity principle suggests

that related exhibits should be placed close together to enhance understanding. The Temporal Contiguity principle suggests that learning in more linear 'chunks' also enhances understanding. Finally, the multimedia principle suggests that understanding would be further enhanced by combining words and pictures to explain a system. The UML structure is capable of incorporating all of these presentation principles. However, we suggest this requires integrating elements of current diagrams into a more modular format.

3.5   Modular UML

Modular UML is a presentation technique intended to facilitate understanding by reducing presentation complexity of multiple UML diagrams. The objective of using Modular UML is to improve communication and facilitate understanding of the domain as a whole. Working with modular UML does not require analysts to learn yet another modeling technique. Instead, it uses knowledge about the system and business process to decompose the models into a set of steps. Users receive the full set of diagrams plus the set of combined models for review. The availability of the full models is important since users may want to review the complete diagram or to confirm linkages between steps.

We suggest that the Modular UML development process can be thought of as comprising four distinct stages:

Stage 1: Create UML diagrams

Stage 2: Determine decomposition steps

Stage 3: Decompose models

Stage 4: Combine diagrams

At stage 1, the model developer (analyst) creates UML diagrams considered appropriate to model the system and used for communication with users. The diagrams are created according to UML specifications using standard UML constructs, notation, and procedures. Stage 2 requires the analyst to consider representing the system in chunks. Each chunk should represent a major step (function or process) of the system. We suggest that a summary (white level) use case narrative is a natural starting point that provides a general overview of the system to assist in defining the major steps.

The analyst decomposes each UML diagram into modules in stage 3. Each major step identified during stage 2 must be represented by a module from each diagram to be used in the final exhibits. For example, if a system represented by three UML diagrams was decomposed into four distinct steps, then there would be twelve diagram modules, one for each step and for each diagram.

Stage 4 involves the analyst combining the diagram modules for each step onto one combined diagram. Here, the intention is to place the related diagram modules on the same display area. No visual connection such as boxes, lines, or arrows between modules is necessary in the combined diagrams.

3.5.1 An Illustrative Example: Human Resource Scheduling

In this section, we use an illustrative model to demonstrate the process of creating combined diagrams. The system used in this example is a functioning human resource scheduling system designed and developed by the authors. The system continues to be used by an event hosting organization that owns and operates a large complex for hosting various events including professional sporting events. The system schedules over 500

part-time employees to host events over a two-week period. The analysis in this example generated business (high) level documentation. These include: a summary use case (Figure 11), a use case diagram (Figure 12), an activity diagram (Figure 13), and a class diagram (Figure 14).

Stage 1: Create UML Diagrams. The choice of which of the 13 possible UML diagrams to use depends on the usefulness of the diagrams as perceived by the analyst (Dobing & Parsons, 2008; Grossman, et al., 2005). Analysts therefore should choose the models they feel best communicate system information to users. Modular UML does not have any restrictions on which model to use although some diagrams are easier to decompose than others. For example, use case diagrams are easier to decompose than class diagrams.

The UML models selected for this example consisted of four of the top five most "popular" UML modeling techniques as noted in Dobing and Parsons (2008). Analysts rated, on a five point scale, use case narrative (4.00/5.00), activity (3.50/5.00), use case diagram (3.36/3.50), sequence (2.91/5.00), and class (2.90/5.00) as the top five diagrams used for verifying and validating requirements with client representatives (Dobing & Parsons, 2008, p. 10). The four diagrams for this example were intentionally selected from the top five listed to demonstrate use of modular UML with analyst-preferred diagrams.

Summary (White level) Use Case

Use Case Name: Event Employee Scheduling
Business Actor: Promoter – wants to host an event at EntertainCo. facilities
Stakeholders: Marketing Manager, Event Manager, HR Department Scheduler, Event Employee, Accounting Department.
Trigger: Promoter contacts EntertainCo to host an event

Normal flow of Events at EntertainCo.:

1. Promoter contacts EntertainCo. regarding hosting an event
2. Promoter provides Event type, requested date, anticipated attendance, and desired venue setup
3. Marketing Manager reviews the request. The process for this event ends if the event is rejected.
4. If the request is approved, then the event is assigned to an Event Manager
5. The Event Manager is responsible for generating a seating plan based on expected attendance and venue setup.
6. Event Manager creates staff deployment for the event. The deployment provides a list of positions available that includes start and end times, employee classification, and employee skill.
7. The deployment is passed on to the Human Resource Department Scheduler who is responsible for producing a completed schedule.
8. The HR Scheduler generates an empty biweekly schedule from all the events to be held during the scheduling period. At the same time, Event employees are required to submit their bi-weekly availability for the scheduling period one week before the schedule is produced.
9. The HR Scheduler produces a two week schedule for all events to be held during the upcoming two week period using the following scheduling constraints
   a. No employee can be assigned work exceeding 30 hours per week
   b. Each employee must receive a minimum 12 hours break between shifts
10. The HR Scheduler posts the schedule on the company website and in the employee dressing room
11. During the scheduling period the HR Scheduler manages the schedule according to the "Manage Schedule Subflow".
12. The HR Scheduler forwards the final worked schedule which lists employees with actual worked hours to the accounting department following the conclusion of the event.
13. The accounting department updates the bi-weekly payroll.

Manage Schedule Subflow:

Event Manager Cancels Shift:-

1. Event Manager notifies the HR Scheduler regarding update to the original deployment
2. HR Scheduler removes the employees from the schedule and notifies the employees

Event Employee Cancels shift:-

1. Event employee contacts HR Scheduler to be removed from schedule
2. HR Scheduler removes employee
3. HR Scheduler adds a replacement employee
4. HR Scheduler notifies employee added to the schedule

Figure 11: Summary Use case narrative

Stage 2: Determine Steps. We use the business level use case narrative as our starting point to identify major segments of the business process. While we recognize there are issues with using use cases to model business processes (Odeh & Kamm, 2003), the use case narrative provides a linear, temporal description of the process under investigation. In this example, the process can be summarized at a high level in a series of four steps: "a request is made, the event is scheduled, the employees are scheduled, and the employees get paid." Of course, the previous simple description ignores all the details uncovered and documented in the use case and supporting models, but the brief description provides the major processes for decomposing the system. For example, workflow statements 1 through 4 in the use case narrative are noted as "step 1: accept or reject events." The rest of the steps are shown in Figure 15.

It is important to note that the concept of "step" is not well defined. In general, a step should constitute a complete concept or function in the system. The number of work flow statements comprising the step should not be a factor in deciding the number of steps. For example, step 4 in Figure 15 represents the complete workflow to update payroll consisting of only two statements. This is significantly different from number of use case statements covered in step 3 detailing how to create and update a schedule.

Stage 3: Decompose diagrams. Another aspect of Modular UML is the decomposition of the diagrams into modules for each step. A central condition at this stage is that each diagram must be decomposed into the same number of steps identified in stage 2 to maintain visual consistency and familiarity. Users will expect to see chunks of each model in every combination diagram or they may be distracted by searching for the "missing" components.

In our example, the first step describes the process of requesting and deciding whether to host an event. The two actors are the promoter and the marketing manager. Consequently, the diagrams are decomposed based on workflow processes involving the two principle actors along with activities and structure associated with them. Figure 16 shows the combined diagram for step 1.

To be more specific, the decomposition of the use case diagram includes the principle actors involved in step 1 only. The activity diagram is decomposed based on the activities associated with these principle actors. The activities are "promoter requests event" performed by the promoter and the "marketing manager reviews request", "accept or reject" decision node, and the "assign event to event manager" activities performed by the Marketing Manager. The class diagram is decomposed based on classes associated with step 1. The class module for step 1 includes the "promoter", "event", "event manager", and "employee" classes. The modules for the remaining steps are derived using the same process. Figure 17 to Figure 19 show the combined diagrams for steps 2, 3, and 4 respectively.

Stage 4: Combine Diagrams. The final stage places the decomposed modules together on a page or screen. We suggest the following guidelines be used to create the combination diagrams: 1) identify the parent diagram of each module on every combination diagram, 2) use the same orientation and layout style for the modules as used on the parent diagram, and 3) clearly separate the modules.

Identifying the parent diagram provides users with a reference to quickly relate the module to the initial diagram. This becomes increasingly important when the diagrams are used with the MUI system described in the next section. Using the same

orientation and layout style provides consistency and necessary visual cues to the user to easily relate the module to the parent diagram. This is consistent with results from Kim et al. (2000). For example, objects in the activity diagram module of step 2 (Figure 17) may have been rearranged horizontally from left to right; however, the vertical presentation matches the layout and orientation of these activities on the parent activity diagram (Figure 13). Finally, separating the modules by using a divider eliminates a possible additional source of complexity. For example, a user may mistakenly assume that the last activity in step 2 leads to the "shifts" class if a divider is not used to separate the activity module from the class module.

Figure 12: Use case diagram

ACTIVITY DIAGRAM

Figure 13: Activity diagram

CLASS DIAGRAM

Figure 14: Class diagram

Summary (White level) Use Case

Use Case Name: Event Employee Scheduling
Business Actor: Promoter – wants to host an event at EntertainCo. facilities
Stakeholders: Marketing Manager, Event Manager, HR Department Scheduler, Event Employee,
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Normal flow of Events at EntertainCo.:

1. Promoter contacts EntertainCo. regarding hosting an event
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3. Marketing Manager reviews the request. The process for this event ends if the event is rejected.
4. If the request is approved, then the event is assigned to an Event Manager

        Step 1: Accept or Reject Events

5. The Event Manager is responsible for generating a seating plan based on expected attendance and venue setup.
6. Event Manager creates staff deployment for the event. The deployment provides a list of positions available that includes start and end times, employee classification, and employee skill.
7. The deployment is passed on to the Human Resource Department Scheduler who is responsible for producing a completed schedule.

        Step 2: Creating Deployment Sheets

8. The HR Scheduler generates an empty biweekly schedule from all the events to be held during the scheduling period. At the same time, Event employees are required to submit their bi-weekly availability for the scheduling period one week before the schedule is produced.
9. The HR Scheduler produces a two week schedule for all events to be held during the upcoming two week period using the following scheduling constraints
    a. No employee can be assigned work exceeding 30 hours per week
    b. Each employee must receive a minimum 12 hours break between shifts
10. The HR Scheduler posts the schedule on the company website and in the employee dressing room
11. During the scheduling period the HR Scheduler manages the schedule according to the "Manage Schedule Subflow".

        Step 3: Creating the Schedule

12. The HR Scheduler forwards the final worked schedule which lists employees with actual worked hours to the accounting department following the conclusion of the event.
13. The accounting department updates the bi-weekly payroll.

        Step 4: Update Payroll

Manage Schedule Subflow:

Event Manager Cancels Shift:-

1. Event Manager notifies the HR Scheduler regarding update to the original deployment
2. HR Scheduler removes the employees from the schedule and notifies the employees

Event Employee Cancels shift:-

1. Event employee contacts HR Scheduler to be removed from schedule
2. HR Scheduler removes employee
3. HR Scheduler adds a replacement employee
4. HR Scheduler notifies employee added to the schedule

Figure 15: System decomposition into the 4 steps

Figure 16: Combination diagram for step 1

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Figure 17: Combination diagram for step 2

Figure 18: Combination diagram for step 3

Figure 19: Combination diagram for step 4

3.6   Modular UML Interaction (MUI) System

The Modular UML Interaction (MUI) system is a software application specifically designed for presenting modular UML. The objectives of the MUI application are to demonstrate the power and ease of use of Modular UML, and to use it as an interface for conducting controlled experiments to test the effectiveness of modular UML. A professional developer was contracted to create the software under the direction of the authors. The next section provides a brief description of two features of the MUI interface.

3.6.1   MUI Interface.

MUI is designed as a potential communication tool between system analysts and users. System analysts would populate MUI with the diagrams and information explaining the system under investigation. Two major components are included in MUI: a video presentation, and a model navigation tool.

The video component of MUI is a guided animated description that provides an overview of the system under investigation and directions on how to read the diagrams. The video is a complementary tool to direct communication between analysts and users. During development projects, analysts would typically meet users to discuss analysts' perceptions and understandings of the system as well as any documentation created by the analysts. The documentation remains with the users for full review at a future time and date. It is suggested that the animated video provides a review of the information discussed during the meeting and directions explaining how to read the diagrams to facilitate interaction with the interface. The video may be more helpful for novice users. More research is necessary to fully understand benefits the video may provide.

For the scheduling example, the video briefly explained the scheduling process by closely describing the workflows presented in the use case narrative followed by review of the parent UML diagrams included in MUI. An animated screen capture application with voice-over was used to create the video.

The navigation tool designed for quick access to all diagrams is displayed in Figure 20. The interface is divided into two sections. The workspace section displays the diagram currently being viewed. The navigation section displays icons representing additional available diagrams. Each icon is clearly identified by the diagram name and by

a vector representation of the actual diagram. It is assumed that the vector representation increases familiarity and reduces the time required by users to locate a specific diagram.

The multimedia principle of the cognitive theory of multimedia learning suggests that presenting information using two sensory modes increases understanding (Mayer, 2001). We added an interactivity feature to the interface to take advantage of this principle. Every object on every diagram (including combination diagrams) was made interactive. We refer to interactivity as the ability of the user to select an object to obtain additional explanatory information. The user is provided with a choice of having the information presented orally or in written format. The option appears on the interface as a "sound disabled/sound enabled" toggle (see Figure 20).

With sound enabled, the user selects an object via a mouse click to hear a description of the object. The CTML suggests that hearing the information and seeing a related graphical display of the same information allows users to form more complete mental models of the information presented. The CTML equates the effectiveness of text messages to narrated messages as auditory inputs. The CTML suggests that individual differences play an important role in the effectiveness of the medium used to present the message (Mayer, 2001). Therefore, the sound toggle was implemented to give users the option to select their personal preference. The sound disabled option displays a tooltip message to replace the narrated explanation as shown in Figure 21.

.

STEP 2: CREATING DEPLOYMENT SHEETS

Use Case Diagram

Event Manager

Generate Seating Plan

Create Deployment

Produce Schedule

HR Department Scheduler

Activity Diagram

Create Seating Plan

Develop Deployment Sheet

Assign Event to Event Manager

Forward to HR Department

Icons for easy selection of available diagrams

Shifts
<<PK>>Shift ID
Date
Start Time
End Time
Classification
-Task
-Location
-Skill Code

1..n ◄ Generates 1

Seating Plan
-Venue Setup Type
-# of supervisors
-# of ushers
-# of cleaners
-# of security
-# of service reps

Event Deployment
-Employee ID

Quick option to toggle between sound and tooltip display features

Use Case | Use Case Diagram | Class Diagram | Activity Diagram | Step 1 | Step 3 | Step 4 | Sound Disabled

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Figure 20: Diagram navigation interface
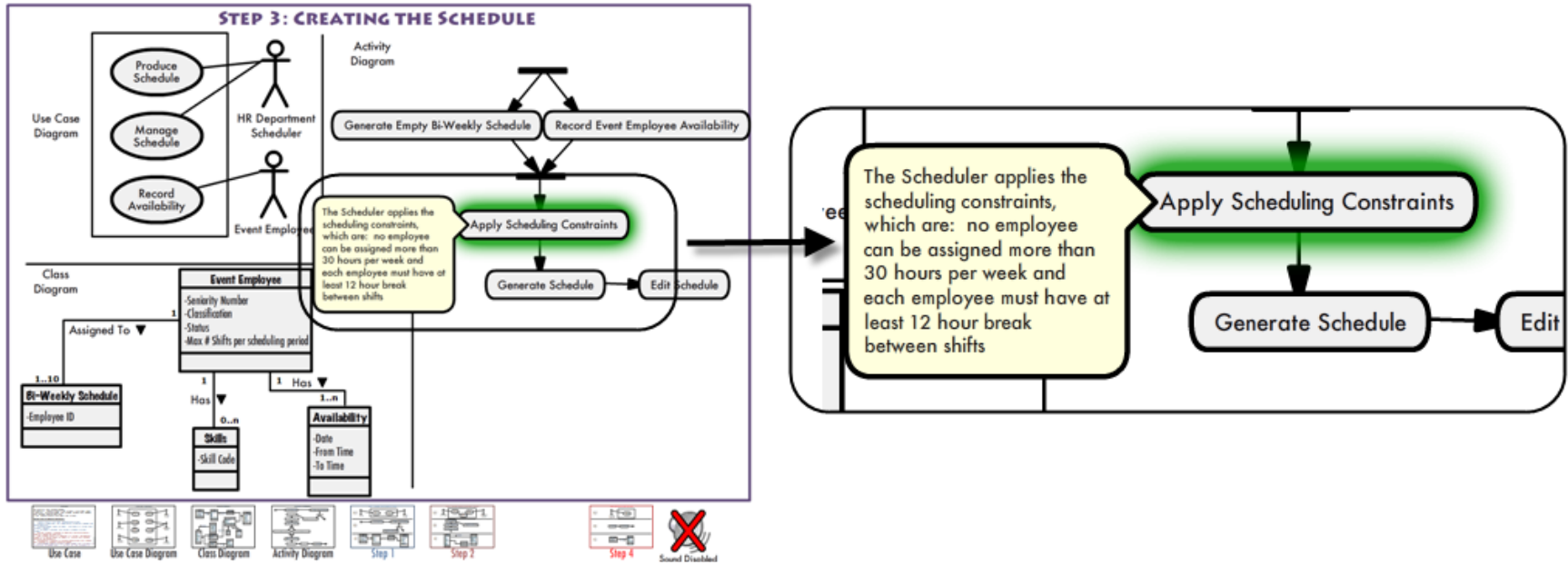
Figure 21: Text message using tooltips

3.7 Future Research and Limitations

3.7.1 Future Research

Modular UML presents an alternative technique for systems analysts to use UML diagrams. The purpose of modular UML is to reduce the complexity of working with multiple models. We relied on empirical evidence (Hungerford, et al., 2004; J. Kim, et al., 2000; Yusuf, et al., 2007) as well as cognitive theory (Mayer, 2001) to suggest a method of decomposing and combining portions of multiple UML diagrams to facilitate communication and user understanding. Preliminary experimental testing the effectiveness of modular UML on user understanding through a series of controlled trials provides support for the propositions presented in this paper (Masri, Parker, & Gemino, 2008a).

Future research must investigate effectiveness of presentation methods on user understanding. The presentations methods involving modular UML and additional principles from the CTML are numerous. These include simplistic comparisons such as standard UML diagrams versus the inclusion of combination diagrams as suggested by modular UML. Additional treatments may include the effect of narration on presentation techniques and the effect of text tooltips without having an option to switch between them.

MUI, which was designed to present modular UML to study participants, will be central to any future research. MUI has the ability to include varying treatment conditions using the same interface to minimize confounding results due to presentation bias. For

example, we can easily exclude combination diagrams from the interface allowing direct performance comparisons between standard UML diagrams and modular UML.

Defining and measuring the pragmatic quality of UML models, which includes the quality of understanding, presents the largest challenge to future research related to Modular UML. Fortunately, we can extend Mayer's research (Mayer, 2001) methodology and definitions to test the effects of modular UML on understanding and learning. Mayer defines two aspects of learning. *Retention* refers to a person's ability to remember what was presented (Mayer, 2001, p. 26). Retention can be measured using comprehension and recall exercises where experimental subjects are expected to recount information presented. *Transfer* is an individual's ability to apply what was presented to solve problems in new situations (Mayer, 2001, p. 29). Mayer uses transfer exercises as a measure for understanding by asking experimental subjects to solve a set of problems related to information presented earlier. Future research to test effectiveness of modular UML or other presentation techniques can mimic Mayer's experimental procedures to measure transfer (and understanding). The technique has been successfully used in previous Information Systems research (Gemino, 2004; Gemino, Parker, & Kutzschan, 2005; Gemino & Wand, 2005; Masri, et al., 2008b).

3.7.2   Limitations of the Research

The largest limitation of the research is the lack of a formal technique for developing combined diagrams. We have suggested beginning with use case narratives as they provide a natural process view. However, it is clear that this need not be the only or the best method to decompose the system into modules. Theoretical guidance for the modularization process might be provided through consideration of ontology or meta

modeling (Burton-Jones & Meso, 2006). We recognize that this lack of formalization is a limitation on the technique. However, the lack of formalized processes does not obfuscate the potential benefits of pursuing a modular approach. More work is necessary to establish foundations for the modular approach.

This paper proposes an experimental design. The empirical results from that design will serve to strengthen the argument posed from research to date and theoretical guidance. The lack of a formal development technique could confound the experimental results if significance is not found. A future challenge will be to formulate differing experimental designs to test the robustness of the approach. The example presented in this discussion decomposes neatly into four modules. Another challenge will be to test the ability of other systems analysis projects to be decomposed similarly.

3.8   Conclusions

Like the successes of structured modeling, the ability to decompose UML exhibits into more manageable 'chunks' offers a novel way to perhaps improve the quality of understanding of complex information systems. As the UML continues to become the *de facto* standard for systems analysts to describe systems under study, refinement will inevitably continue. This paper brings a suggested refinement based on tested theory, and proposes a novel format for presentation of UML exhibits. Rather than proposing a new methodology, we propose a format that does not require changes to the UML specification to formally adopt our proposition.

This paper introduced the ideas of a modular approach to UML modeling. We have provided an illustrative example of a modular UML process, showed the resulting

combined diagrams that emerge from the modular approach and provided a description of the interface for presenting the resulting models to users. We believe that a modular approach to UML can effectively address the issues of complexity associated with multiple diagrams in UML. While we see potential in a modular approach to UML, we also recognize the need to more formally develop a process for creating modules. We therefore look forward to future work in developing and extending these ideas.

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CHAPTER 4
COMBINING UML DIAGRAMS TO ENHANCE UNDERSTANDING OF CONCEPTUAL MODELS

The following chapter was presented at the Administrative Association Council of Canada (ASAC) conference, 2008. The paper received the "Best Paper" award at the conference.

4.1 Abstract

System analysts often use UML models to validate requirements. This paper presents an experiment to test theories of information presentation. The experiment offers a novel combination of UML exhibits to reduce complexity of interpretation. Results suggest that better understanding could be facilitated by combining elements of UML models in a single diagram.

4.2 Introduction

The Unified Modeling Language (UML) is widely considered the standard in software development modeling languages. Part of UML's success can be attributed to the characteristics of being methodology independent and having the ability to model aspects of systems at different levels of abstraction (www.uml.org). These characteristics empower system analysts to employ UML exhibits as part of requirements determination. Several studies have evaluated the effectiveness and complexity of UML diagrams (Burton-Jones & Meso, 2002, 2006; Kobryn, 1999; Siau & Cao, 2002). However, research has been lacking with respect to end-user's (stakeholders) ability to understand and accurately interpret these models. UML models must not only be accurately

developed, but also understood, to be effective. Lack of understanding during requirements determination can lead to developed systems missing important functionality.

UML 2.0 has defined many different diagramming/modeling techniques for describing systems. Analysts experienced with UML tend to use a combination of diagrams to model their projects (Dobing & Parsons, 2006). Cognitive theories such as the Cognitive Load Theory (Sweller & Chandler, 1994; Sweller, et al., 1998) and the Cognitive Theory of Multimedia Learning (Mayer, 2001) suggest viewing several diagrams successively can exert significant cognitive load on those viewing the models. Increased cognitive load reduces the ability to fully process the information presented which can result in a loss of cognitive resources needed to integrate the information about the modeled domain. This, in turn, can lead to a lack of understanding. The same theories suggest that reducing temporal and spatial complexity by reducing the space and time needed to search for relevant information might lead to improved understanding.

This study details an experiment conducted to evaluate the effectiveness of combining elements of UML diagrams when presenting information. The combination of appropriate pieces of diagrams can act to remove unnecessary cognitive load with the effect of increasing understanding. A custom built software application was used to develop the test. We make use of Cognitive Load Theory and the Cognitive Theory of Multimedia Learning to hypothesize that combining UML diagrams increases temporal and spatial contiguity of presented information leading to higher transfer. Improved transfer ultimately leads to higher levels of understanding (Mayer, 1989, 2001).

4.3 Conceptual Modeling during Requirements Validation

Requirements determination is a four phase process (Y.-G. Kim & March, 1995) that involves stakeholders' perceptions of a real world problem, analysts' interaction with stakeholders to discover these perceptions, formal representation of these perceptions using conceptual models, and validating the representations. Stakeholders in this example are classified as managers and users of the eventual system. Figure 22 - adapted from (Y.-G. Kim & March, 1995) and (Juhn & Naumann, 1985) - is a high level overview of the requirements determination cycle. Stakeholders are expected to convey their perceptions of the domain reality to the analysts. Analysts are then expected to document this information. Analysts typically create conceptual models using diagramming techniques from formal methods or languages such as the UML. Analysts represent the domain based on how the analyst interprets the information from stakeholders. Finally, stakeholders validate the conceptual models to verify that the analysts accurately interpreted their views of the domain. Approving inaccurate requirements is a risk if stakeholders do not fully understand the information presented by analysts during the validation phase.
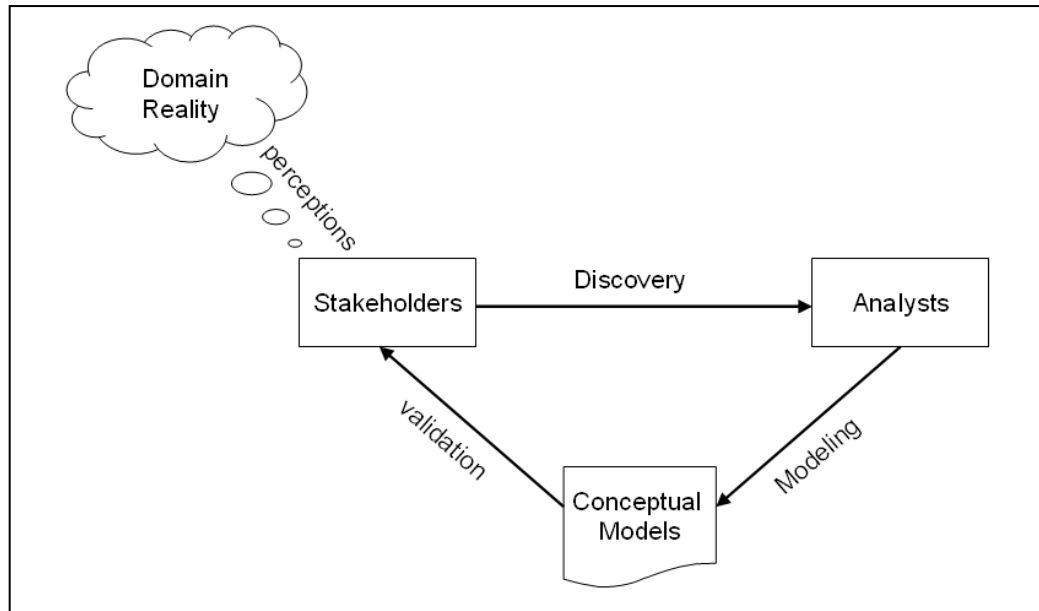
Figure 22: The Requirements Determination Cycle (Adapted from Kim & March, 1995)

UML 2.0 offers a set of 13 diagrams grouped in two major categories: structure diagrams and behavior diagrams (Fowler, 2004; Object Management Group, 2003). Structure diagrams model the static structure of objects in the system while behavior diagrams model the dynamic behavior of the objects (Object Management Group, 2003). The different diagrams are not considered rigid or central for compliance to the UML structure. Analysts are empowered to select diagrams they believe are appropriate to communicate with stakeholders (Fowler, 2004). In a survey conducted by Dobing & Parsons (2006), it was reported that analysts tend not to use certain diagrams because these diagrams are not well understood by the analysts or the diagrams do not add sufficient value to justify the cost. The same survey revealed that only 55% of analysts feel that UML was moderately successful, at best, in facilitating communication with users while 25% of analysts felt that UML was not successful (Dobing & Parsons, 2008). Dobing & Parsons concluded that "*the complexity of UML is a concern, suggesting more*

programs are needed to help IS professionals and their clients learn the language and how to use it more effectively" (Dobing & Parsons, 2006, p. 113). This study is directed towards this objective.

4.4 Cognitive Theory to Improve Understanding of Multiple Diagrams

Users exert cognitive effort while reviewing UML diagrams and interpreting analysts' instructions during requirements validation. It is likely that these users will not necessarily understand complex or substantial information as represented if the cognitive effort required is significant (Gemino & Wand, 2003). The cognitive load theory provides theoretical foundation for this argument (Sweller, 1988; Sweller & Chandler, 1994; Sweller, Chandler, Tierney, & Cooper, 1990; van Merriënboer & Sweller, 2005). In addition, the cognitive theory of multimedia learning provides a set of principles that can be used to effectively apply foundations of the cognitive load theory (Mayer, 2001).

4.4.1 Cognitive Load Theory

The cognitive load theory (CLT) originated more than two decades ago and is considered a major theory of cognitive architecture and learning (Paas & van Gog, 2006). The CLT started as a theory addressing cognitive constraints to improve learning for science and mathematics students but its application has extended to other domains such as music instruction (Owens & Sweller, 2008), enabling the elderly to acquire new complex skills (Van Gerven, Paas, Van Merriënboer, & Schmidt, 2000), and for evaluating conceptual models in information systems (Gemino & Wand, 2005; Masri, et al., 2008b). The theory provides some insight from a cognitive perspective to address

UML's limited success in facilitating communication with users as reported by Dobing and Parsons (2006, 2008).

The CLT is based on the assumption that working memory has a limited capacity (Miller, 1956) which interacts with long term memory to form the basis of intellectual skill (Sweller & Chandler, 1994). It further suggests that human ability to learn is determined by our ability to reduce the burden (load) on working memory by acquiring and using schema which aids in automatic processing of information. Schema is a cognitive construct that defines how working memory organizes related elements of information as one chunk for processing with long term memory to, in essence, circumvent the limitations of working memory. Working memory has a capacity to process approximately 7 chunks of information at any given time (Miller, 1956), so schema allows more elements to be processed by combining multiple elements as one chunk.

Schema acquisition is based on prior experiences and knowledge that allows individuals to create and store schema in long term memory. For example, the schema "American Black Bear" can be processed as one chunk of information by individuals familiar with bears. Individuals reviewing the same material but not familiar with bears will need to decompose 'American Black Bear' into its various elements, such as a large dark furry mammal quadruped with sharp claws who is omnivorous favoring berries and fish, looks cumbersome but can run very quickly, can be aggressive or predatory toward humans if challenged, but will usually avoid contact and is a forest dweller. The decomposition is necessary to adequately process the term. The decomposition of American Black Bear and separately processing its various elements increases the

cognitive burden on the individual. This increased burden leads to more difficulty in processing and understanding the material under review compared to the individual who is familiar with bears.

The CLT suggests that minimizing cognitive load when processing information provides more cognitive resources to process, learn, and understand presented information. Additional cognitive resource can be used to develop more complex schema. The theory identifies three types of cognitive load affecting learning and understanding: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load.

4.4.1.1 Intrinsic cognitive load.

Combining and processing elements into a to-be-learned schema in working memory is referred to as intrinsic cognitive load (Gerjets, et al., 2004). Our ability to fully comprehend the presented material and integrate it with long term memory may be reduced as the intrinsic cognitive load increases. The load depends on the number of elements to be processed simultaneously, the relational complexity of the content, and the individual's prior knowledge or experience (Sweller & Chandler, 1994).

The number of elements increases intrinsic cognitive load since more cognitive resources are needed to process the individual elements with schema stored in long term memory. The interactivity (or relational complexity) of these elements consumes additional cognitive resources as schema is developed using the related elements. However, prior experiences and knowledge reduce intrinsic cognitive load. Experts familiar with the material may be able to group informational units into one element whereas novices not familiar with the information will need to process the informational units as several independent elements to consume more cognitive resources. For example,

experts may process a class along with its attributes and relationships as one element when viewing a class diagram but novices may process the class, attributes, and relationships as individual elements. The same information will impose a higher intrinsic cognitive load on the novice viewer.

Conceptual models present elements of the system and their associated interactivity to describe the problem domain. The use of multiple related UML diagrams increases the complexity of element interactivity. So, the intrinsic cognitive load is expected to increase as more models are used and as the number of elements in each model increases.

4.4.1.2   Extraneous cognitive load.

Cognitive processes associated with locating and processing related pieces of information but not related to schema acquisition or knowledge construction constitute extraneous cognitive load (Sweller & Chandler, 1994). Extraneous cognitive load is directly related to the amount of mental effort the viewer is required to expend to locate related information on a page or screen. The process of locating information is considered an irrelevant cognitive task for knowledge construction but tends to consume valuable cognitive resources that otherwise could be directed towards learning and understanding. The CLT suggests that extraneous cognitive load can be reduced by carefully presenting the information to facilitate learning (Sweller & Chandler, 1994).

We argue that extraneous cognitive load is imposed on users reviewing multiple standard UML diagrams as users need to review a combination of diagrams to find and mentally integrate related information. For example, reviewing business level (high level) documentation may require the user to review an activity diagram to uncover the flow of

activities and the class diagram to confirm attributes to be collected. The process of flipping back and forth between the two diagrams imposes extraneous cognitive load that consumes valuable working memory resources potentially hindering users' abilities to understand the information presented.

4.4.1.3   Germane cognitive load.

Cognitive effort devoted to learning and schema construction is defined as the germane cognitive load. Unlike intrinsic and extraneous cognitive loads which impede learning, germane load contributes to learning and understanding (Paas, Renkl, et al., 2003). The total amount of the three cognitive loads cannot exceed the total available cognitive resources of working memory. Germane cognitive load can only be exerted if intrinsic and extraneous cognitive loads do not exceed the total capacity of working memory. Germane cognitive load is dependent on the message viewer's motivational prerequisites (Seufert, Jänen, & Brünken, 2007). That is, the individual must be willing to exert the additional load for understanding and learning to occur.

Intrinsic cognitive load cannot be manipulated or reduced except by experience and learning (Paas, Renkl, et al., 2003). Remaining cognitive capacity can be allocated to handle extraneous and germane cognitive loads. These two loads are inversely proportional in that a reduction of extraneous cognitive load will allow the allocation of more cognitive capacity to deal with germane cognitive load to enhance learning. Again, the potential for germane load should be separated from the actual germane load exerted. The individual must apply the cognitive resources that are available to develop understanding. Therefore, to develop understanding it is essential to reduce extraneous

cognitive load while reviewing UML diagrams to provide the potential for germane load to be exerted.

4.4.2 Cognitive Theory of Multimedia Learning

Richard Mayer formalized the cognitive theory of multimedia learning –CTML- (Mayer, 2001) to suggest several message design principles to promote learning and understanding by reducing extraneous cognitive load. The CTML is founded on the dual-coding (Baddeley, 1992; Paivio, 1986, 1991) and active processing assumptions (Wittrock, 1990). Dual coding suggests that humans possess two independent but complementary channels for processing information. One channel is responsible for introducing verbal information into working memory while the other introduces visual information. The term "multimedia" implies introducing verbal and visual information simultaneously. The active processing assumption suggests that humans are actively involved in learning by selecting and organizing relevant information to develop coherent mental representations for processing.

The theory presented in Figure 23 suggests that three cognitive processes are involved to fully process a message to promote understanding. Information viewed by the learner will enter sensory memory by either of the two sensory channels. The first cognitive process involves selecting relevant words or images to enter working memory by paying attention to elements of the message of interest. The second cognitive process occurs in working memory as verbal and visual information is actively processed to develop verbal and pictorial representations. Finally, the mental representations are integrated with long term memory to develop schema and to promote understanding. Taking full advantage of these cognitive processes requires the multimedia information to

be processed in working memory simultaneously. The foundations of the CTML led

Mayer to introduce a set of principles to assist designers to create effective multimedia

messages. Two principles of interest in this paper are the spatial and temporal contiguity

principles. These principles suggest that having related information presented in close

proximity in space (i.e., on the same page or screen) and time reduces the extraneous

cognitive load imposed by searching for the information.
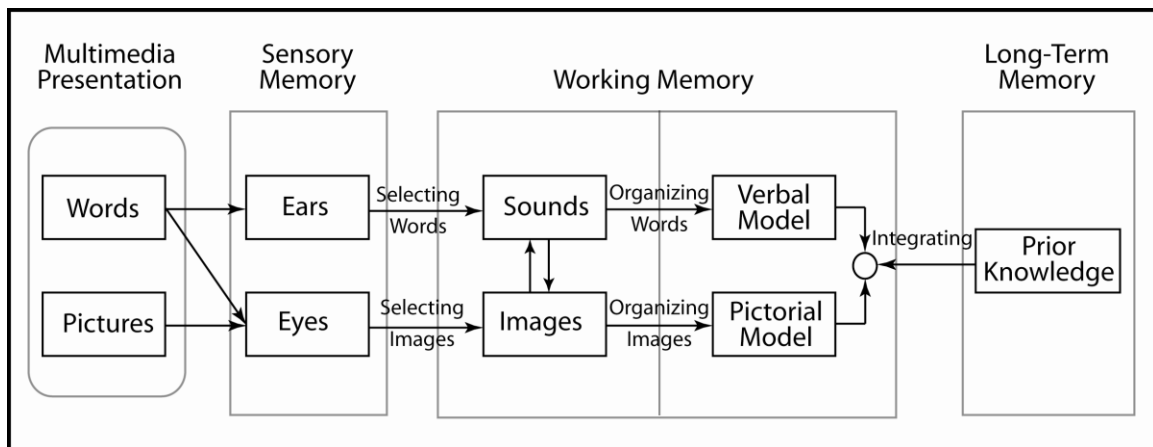
Figure 23: The Cognitive Theory of Multimedia Learning (Mayer, 2001, p. 44)

4.5   An Experiment to Test Theory

UML diagrams are multimedia presentations as defined by Mayer (2001). They

are multimedia because they use both textual and graphical elements. Textual information

includes descriptions in use case narratives, attribute names in class diagrams, and

activities in activity diagrams. Visual elements include actors in use case diagrams,

relationships in class diagrams and workflows in activity diagrams. In addition, the

different diagrams are complementary in the sense that they present different structure of

the same system. Therefore, information from all diagrams needs to be related and

integrated by viewers for full comprehension and understanding. We can therefore apply

the foundations of the CLT and CTML theories to investigate different presentation

techniques to promote understanding. An experiment is proposed to test these different techniques.

The experimental focus is on reducing extraneous cognitive load while increasing germane cognitive load to promote knowledge construction and understanding. The domain of interest used in the experiment was a human resource scheduling system, designed and developed by the authors, which has been used since 1996 by a large entertainment organization. An actual system was used to improve external validity of the work. Experimental results are often called into question because they are focused on "toy" problems. A successful functional system likely provides results that are of more interest to readers. The system was presented at a business level using four documents: use case narrative, use case diagram, activity diagram, and class diagram. The documents were selected based on research indicating these models were four of the top five documents used by analysts for requirements verification (Dobing & Parsons, 2006). Figure 24 shows some of the diagrams used during the experiment.

Reducing extraneous cognitive load was investigated by applying the spatial and temporal contiguity principles to the presentation of the UML diagrams. Spatial and temporal contiguity factors were reduced by combining elements from different diagrams onto the same page. The combination diagrams were created by displaying related portions of the use case, activity, and class diagrams on the same screen.

An effort was made to also investigate increasing germane cognitive load by encouraging users to actively engage with the diagrams. This was done by making elements on each diagram interactive. For example, users viewing class diagrams were able to mouse click on classes or relationships to see (or hear) a description of the

element. All diagrams, including combination diagrams, were interactive for the relevant treatment groups.

Understanding was assessed using procedures devised by Mayer (1989) and used successfully in previous research (Bodart, et al., 2001; Gemino, 2004; Gemino, et al., 2005; Gemino & Wand, 2005; Masri, et al., 2008b; Mayer, 1989, 2001; Moreno, 2007; Moreno & Mayer, 1999). Mayer (2001) suggests two levels of learning outcome may result from viewing information: retention and understanding. Retention is the ability to remember and reproduce or recognize presented material. Retention is measured using recognition and recall tasks. Understanding is the ability to develop a coherent mental representation of the material to use in new situations or for problem solving. Understanding is measured using transfer (also referred to as problem solving) exercises. The main objective of this research is to propose and evaluate presentation techniques which can increase understanding; however, our experiment was designed to measure both learning outcomes to remain consistent with Mayer's experimental procedures.
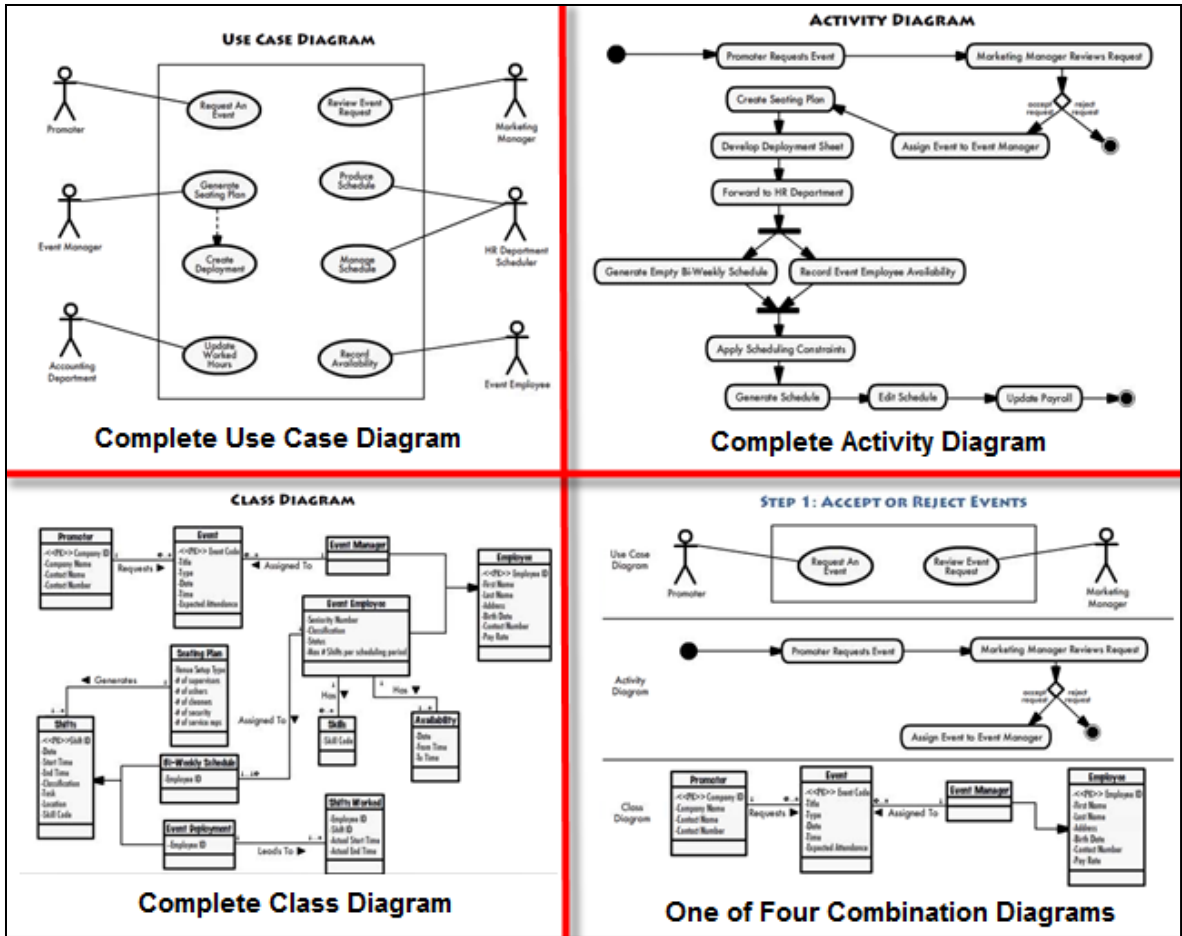
Figure 24: Some of the diagrams used to represent the system

4.6   Hypotheses

The primary proposition considered in this paper is that a viewer's understanding

of a set of UML models can be improved by combining related elements from different

models into a single combined diagram. Note that more than one combined diagram will

be necessary to create a full representation of the system. The argument we are making is

that combining appropriate elements from separate models reduces search and integration

processes (extraneous load) and provides the potential to apply a higher level of germane

load to the process of understanding the information being presented. We also argue that

the ability to interact with the models provides increased levels of engagement to enable

viewers to better utilize the potential germane load created by the combined diagrams.

The specific research hypotheses are as follows:

> **H1a:** Participants provided with combination diagrams (with no interaction) will show higher levels of *retention* than participants provided with standard diagrams only (no interaction).
>
> **H1b:** Participants provided with combination diagrams (no interaction) will show higher levels of *understanding* than participants provided with standard diagrams only (no interaction).
>
> **H2a:** Participants provided with ability to interact with the diagrams (without combination diagrams) will show higher levels of *retention* than participants unable to interact with the diagrams (no combination).
>
> **H2b:** Participants provided with ability to interact with the diagrams (without combination diagrams) will show higher levels of *understanding* than participants unable to interact with the diagrams (no combination).

Hypotheses H1:a,b and H2:a,b measure the effects of manipulating extraneous

and germane cognitive load separately. This is necessary for validating the experimental

results; however, the cognitive load theory suggests that germane cognitive load is

important for knowledge construction. The effects of reducing extraneous cognitive load

may make available more cognitive resources for understanding but understanding may

not necessarily be enhanced unless more germane cognitive load is actually applied

toward knowledge and schema construction. Therefore, it is necessary to measure the

total impact of combination diagrams and interactivity. This suggests hypotheses H3:a,b

and H4:a,b as follows:

> **H3a:** Participants provided with combination diagrams with interaction will show higher levels of *retention* than participants provided with combination diagrams without interaction.
>
> **H3b:** Participants provided with combination diagrams with interaction will show higher levels of *understanding* than participants provided with combination diagrams without interaction.

H4a: Participants provided with combination diagrams with interaction will show higher levels of *retention* than participants provided with standard diagrams with interaction.

H4b: Participants provided with combination diagrams with interaction will show higher levels of *understanding* than participants provided with standard diagrams with interaction.

4.7   Experimental Method

An experimental procedure adapted from Mayer (2001) was designed to evaluate the research hypotheses by measuring three dependant variables: recognition, recall, and transfer. Recognition and recall provide measures to compare retention across treatment groups whereas transfer is a measure for understanding.

4.7.1   Participants

193 undergraduate students participated in the experiment. Participation was voluntary with participants offered $10 and entry to a draw for an iPod. Most participants actively engaged in the exercise; however, a minority were less engaged. Since germane load was of interest in the study, a minimum transfer score was established to eliminate participants who were not actively engaged. The minimum level of 6 (or 1.5 acceptable solutions per transfer question) was chosen. This removed a total of 51 participants with a range of 11 to 15 per treatment group and leaving a sample size of 142. Table 11 lists participant demographics.

| | *Treatment* | | | |
	Interactive Combo (IC)	Interactive No Combo (IN)	Non-Interactive Combo (NC)	Non-Interactive No Combo (NN)
N	28	40	38	36
Age (mean)	19.9	19.7	20.4	19.0
Gender (% Male)	46.4%	57.5%	43.6%	44.4%

Table 11: Participant demographics

The design of the experiment was a standard two-by-two. Participants were randomly assigned to four treatment groups summarized in Figure 25. The groups established were: IC group which interacted with combination diagrams (in addition to the standard diagrams), IS group which interacted with standard diagrams only, NC viewed all diagrams without the ability to interact with any of them, and the NS group viewed standard diagrams only.

Treatment	Interactive (I)	Non-Interactive (N)
Combination Diagrams (C)	Interactive Combo (IC)	Non-Interactive Combo (NC)
Standard Diagrams only (S)	Interactive Standard (IS)	Non-Interactive Standard (NS)

Figure 25: Experimental Treatment Groups

4.7.2 Materials

The case presented was a system used by a large sports and entertainment company to schedule over 500 part time employees to host events at its complex. The diagrams used in the experiment modelled the complete business process starting from promoters requesting an event from management to payroll processing paycheques to the part time employees.

The combination diagrams were created by displaying related portions of the use case, activity, and class diagrams on the same screen. The use case narrative listed four distinct business processes. These processes provided a direct demarcation for the combined portions. Four combined diagrams were available along with the four standard documents.

4.7.3 Procedures

The experiment took place in a controlled computer laboratory. A programmer created a custom application allowing participants to engage with the experimental materials and to complete a series of tasks measuring recognition, recall, and transfer scores. The software was refined after a pilot study with over 130 participants to test for bugs or deficiencies. The same facilitators conducted all sessions to control for facilitator bias.

The experiment started with a brief training video to explain the four types of documents. Another video describing the business case was shown immediately following the training video. The case video described each of the actual documents given to participants in detail. The combination diagrams were used during the video to explain the business processes for all treatment groups to control for information bias.

The experimental tasks were administered immediately after the two videos. The first task was recognition where participants had access to the documents based on the treatment group. Participants had 18 minutes to review the documents using the computer application. Each participant had the ability to choose which diagram to review, for how long, and to interact with its elements if possible. Part of the recognition task required participants to answer 12 Yes/No/Unknown questions. The number of correct answers was recorded as the recognition score. Participants were informed that the diagrams would not be available after this task. The purpose of making the diagrams unavailable was to test the knowledge acquired while reviewing the documents.

The next task was the recall task. Participants were required to spend at least 3 minutes but no more than 5 minutes to answer the question "Using what you have learned

about Entertainco, please write down an explanation of how the company operates". The number of correct idea units represented the recall score.

The final task was the transfer task. It involved asking the participants to answer four problem-solving questions. Participants had to respond to four business problems with as many possible solutions as they could think of. Each question was given two minutes. The number of acceptable solutions for all four questions was labelled the "acceptable transfer score." The total number of answers given was recorded as the "total transfer score." Finally, the ratio of the acceptable score to total score was noted as the "Ratio transfer score." The pressure of having two minutes to respond to each question may have encouraged participants to note down possible solutions from prior experiences but not directly inferred from the case. This may confound the results if we rely on the acceptable transfer score only. The ratio score provides a more accurate indication of understanding as higher ratios compared to raw score imply more mental engagement with the material to answer the questions (Masri, et al., 2008b).

4.8   Results

One rater familiar with the system scored the recall and transfer tasks to increase rater reliability. Rater bias was controlled by removing the treatment types during the rating process. This proved to be sufficient as responses did not in any way reveal the treatment since questions dealt only with the case.

Descriptive statistics for all variables of interest are shown in Table 12. The results for all transfer measures are reported but we focus on the transfer ratio only. Directional comparison of the means was generally consistent with predictions from the

hypotheses. The only exception was the prediction for H2a and H2b. Mean results indicated the NS group outscored the IS group in both retention and understanding.

Dependent Variable	Treatment			
	IC n=28	IS n=40	NC n=38	NS n=36
Recognition	7.64 (1.59)	6.72 (1.32)	7.39 (1.24)	7.08 (1.46)
Recall	7.21 (3.16)	6.48 (3.26)	6.63 (3.34)	6.67 (3.54)
Transfer (Acceptable)	10.21 (3.34)	9.00 (2.57)	9.42 (3.07)	9.14 (2.27)
Transfer (All Responses)	13.29 (3.72)	13.68 (0.67)	13.58 (4.04)	14.28 (4.37)
Transfer Ratio: *Acceptable/All Responses*	0.77 (0.14)	0.67 (0.14)	0.71 (0.15)	0.67 (0.14)

Table 12: Means and standard deviations for experimental tasks

Statistical significance was tested using the multiple analysis of variance (MANOVA) statistical technique with results listed in Table 13. Results show that H4a was partially supported along with H4b at the 0.05 significance level and H3b at the 0.1 significance level.

	H1 (NC - NS)		H2 (IS – NS)		H3 (IC – NC)		H4 (IC – IS)	
	F	Sig.	F	sig.	F	Sig.	F	Sig.
Recog.	1.41	0.24	1.26	0.27	0.26	0.61	6.71	0.01
Recall	0.00	0.95	0.06	0.81	0.38	0.54	0.87	0.35
Transfer Ratio	1.57	0.21	0.06	0.80	3.25	0.08	8.02	0.01

Table 13: MANOVA results

4.8.1 Retention

The recognition task had participants search for answers to 12 case related questions while viewing the material. The main objective of the task was to get

participants to study the diagrams by looking up responses to questions such as "Is the operations department responsible for creating the employee schedule?"

The results for retention are not inconsistent with the theoretical foundations of the research despite lack of significance. The adaptation of the experimental procedures to information systems research explain the differences between our results and Mayer's (2001) contentions with respect to retention. We had participants actively engage the material during the recognition task whereas participants in Mayer's experiments do not have access to the material while responding to the recognition questions. This may have accounted for the lack of significance in our results as the task was transformed from a recall exercise to an engagement process. However, the significance of H4a with respect to recognition is interesting. This result may indicate that searching for information while fully engaged with material presented in a format to reduce extraneous cognitive load facilitated the review process.

Another discrepancy between our experimental procedures and Mayer's procedures may account for the lack of significance of the recall score. All participants received the same video describing the case irrespective of treatment group whereas Mayer integrates lesson description with the treatment. It was noticed that responses to the recall questions were derived primarily from the video description rather than from the supplied diagrams.

4.8.2 Understanding

The results for the transfer task were mixed for supporting H1 through H4. The IC treatment group (H4b) significantly outperformed the IS group implying that using

combination diagrams with interaction promoted better understanding of the case than interacting with standard diagrams. The IC group outperformed, but to a lesser statistical degree (F=3.25, sig.=0.08), the NC treatment group (H3b) as well indicating that interacting with combination diagrams led to better understanding than not interacting with combination diagrams. H1b and H2b did not yield any statistical significance.

While the results initially show a lack of significance, the combined results of all four hypotheses provide strong support for the theoretical foundations of the research. This is outlined in the following discussion.

4.9   Discussion and Conclusions

This paper presented findings of an experimental study to measure effectiveness of combining and interacting with UML diagrams on end user understanding. The cognitive load theory provided the theoretical underpinnings for the research while principles of the cognitive theory of multimedia learning were applied to formulate new UML diagrams presentation techniques to promote understanding. Research methods developed for the CTML were adapted to test hypotheses developed for this research.

Results generally support the cognitive foundations of the research. It is important to explain the results in context of the CLT to fully appreciate the contribution of cognition on presentation techniques of conceptual models. Since the level of understanding developed is the focus of this study, our evaluation of this contribution focuses on the discussion of results from the transfer task.

Intrinsic, extraneous, and germane cognitive loads are cumulative according to the CLT. The total load cannot exceed the capacity of working memory. In this study,

manipulating extraneous and germane loads is the only possibility to promote understanding since intrinsic cognitive load is dependent mainly on the learner's existing schema (prior knowledge) which we assume has been randomized across groups. The hypotheses predicted the impact on understanding by reducing extraneous, increasing germane, or simultaneously reducing extraneous while increasing germane cognitive loads.

The first hypothesis, H1 (NC – NS > 0), predicted that reducing extraneous load through combination diagrams would positively affect understanding. However, this hypothesis is based on the assumption that participants are willing or motivated to expend the extra effort needed to increase germane cognitive load. Reducing extraneous load is a necessary condition for developing understanding, but it is not sufficient. Increasing germane load is necessary to improve understanding since germane load is primarily responsible for learning and schema acquisition. Therefore, the lack of significant results for H1 may be explained by suggesting that participants in this treatment group did not fully utilize the potential germane load made available by the reduced extraneous load. Results (F= 1.57, sig. = 0.21) showed no significant difference between the treatment groups.

H2, (IS – NS > 0) suggested that increasing germane cognitive load while maintaining the same relative extraneous cognitive load was expected to increase understanding. Again, this prediction is based on the assumption that the total cognitive load is not already at its capacity. The germane cognitive load cannot increase if it is at capacity. If the standard diagrams required more extraneous load, then it is possible that germane cognitive load did not increase significantly because of the high extraneous load

resulting from the complexity of UML diagrams (Burton-Jones & Meso, 2002, 2006; Kobryn, 1999; Siau & Cao, 2002). Results (F= 0.06, sig. = 0.80) showed no significant difference between the treatment groups.

H3, (IC – NC > 0) suggested that the combined impact of reducing extraneous load with the combination diagrams and increasing germane load with interaction would lead to higher understanding. The use of combined diagrams was expected to reduce extraneous load such that cognitive resources would be available for germane activity. Interaction was expected to encourage participants to engage with the diagrams. This extra effort leads to increased germane activity. Results (F= 3.25, sig. = 0.08) provided a larger difference between means. This result can be explained by suggesting that the reduction of extraneous cognitive load in the NC group would have enabled participants in that group to increase their germane activity, but not at the level of the IC group. Interaction therefore seems to have some effect on levels of understanding when extraneous load is lowered.

H4, (IC-IS) provides the ultimate test. In this case, both groups could interact but one group had standard diagrams and the other used combined diagrams. Here we tested the combined impact of manipulating extraneous and germane cognitive loads. Results showed strong significance (F=8.02, sig. = 0.01,). In this case, the IC group had a reduced extraneous load (from combined diagrams) as well as the increased engagement provided by interaction. However, the comparison group (IS) did not benefit from a reduction of extraneous cognitive load; therefore, participants' ability to interact with the diagrams had little effect because increase in germane load may have overloaded working memory.

Two conclusions can be inferred from the detailed analysis of the results. Increased germane cognitive load must accompany a reduction of extraneous cognitive load for full impact on understanding. So, given limits on cognitive resources, one can argue that reducing extraneous load is a necessary condition for improving understanding,. However, increasing the actual germane load is necessary and sufficient for improving understanding.

The research provides a theoretical base to encourage researchers and practitioners to consider enhancing presentation techniques to take full advantage of the human cognitive processing capabilities. Information Systems research has mostly ignored investigating effects of manipulating conceptual modeling tools in favor of research investigating the accuracy and appropriateness of the modeling language. We contend that the latter research is very important to correctly model systems, but we hope to elevate the priority of research focusing on presentation techniques to improve the requirements determination cycle. Practitioners may consider using results of this research stream to improve communication between themselves and stakeholders for purposes of shortening the requirements gathering cycle while producing systems with more accurate functionality.

The UML has evolved into a standardized set of exhibits. The use of these exhibits, however, has been at the discretion, based on experience and heuristics, of the system developers. This paper has proposed a novel way of clustering UML exhibits around elements of work. This approach offers promise to increase understanding of the modeled system by end users, something that has been noted as lacking in the literature to

date. We believe that further work on this approach, and the cognitive theories underlying

it, offers promise for improving the presentation of UML models.

4.10   References

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CHAPTER 5
CONCLUSIONS

5.1   Overview

The main objective of this dissertation is to introduce a user-centric cognitive approach to the conceptual design and development of information systems. The approach aims to improve the effectiveness of communication between stakeholders and analysts during information systems requirements gathering. In this thesis, established analysis methods were used to demonstrate that improvements in communication can be achieved by a user-centric cognitive approach rather than to changes in the structure of modeling methods. The implication for this research is that improved communication will improve the common understanding of systems under development to reduce possibility of misinterpretation.

A user-centric approach can be viewed as a significant deviation from research that has dominated the field of systems analysis for the last 40 years; specifically, an approach focused on developing methods driven largely from the analyst/developer-perspective. Methods driven research has been successful in providing useful analytical and modeling tools for practitioners and researchers. It has resulted in evolutionary improvements of these ISD tools and techniques. There can be little question that the introduction of methods and their continued improvement has had positive effects on the success of ISD. It is also clear after 40 years of research that the consideration of methods alone cannot address the persistent difficulties in ISD (R. L. Glass, 1999). It may be

argued that continued introduction of competing techniques has made it difficult for the

analyst community to adopt some forms of standardized approach. In fact, this search for

common methodological ground provided much of the impetus for the collaboration of

researchers and practitioners on introducing modeling standards such as the Unified

Modeling Language and Business Process Modeling Notation (BPMN at

www.bpmi.org). Refer to Finkelstein (2005) for a brief overview of BPMN.

Problems related to the success of information systems development persist

despite the advances and eventual standardization of some methods. The rise of agile

development, being a radical departure from many standardized ISD methods, supports

the notion that standardized methods are not fully accepted by the analyst and

development communities. The user-centric perspective introduced in this dissertation

suggests that ISD researchers should consider cognition as well as methodologies. In the

end, it is the stakeholders' ability to fully understand requirements documentation that

increases the likelihood of success. As Frederick Brooks (1987, p. 11) notes:

> "I believe the hard part of building software to be the specification, design,
> and testing of this conceptual construct, not the labour of representing it
> and testing the fidelity of the representation. We still make syntax errors,
> to be sure; but they are fuzz compared with the conceptual errors in most
> systems."

This thesis argues that cognitive theories provide a foundation for advancing the

development of tools that improve our ability to effectively capture and communicate the

conceptual construct underlying ISD projects. In previous chapters, the cognitive load

theory and the cognitive theory of multimedia learning were introduced as important

theoretical tools to support a user-centric focus. The cognitive load theory (CLT) defines

the cognitive constraints imposed on users viewing complex information, whereas the

cognitive theory of multimedia learning (CTML) supplies guiding principles to effectively present information to circumvent some of these cognitive constraints. Exploratory research investigated these theories for applicability in ISD using entity relationship diagrams (Chapter 2). The theories were then extended to propose the modular UML presentation technique (chapter 3) followed by an empirical analysis to investigate the technique's performance with respect to quality of understanding (chapter 4).

The aim of the research articles was to investigate and measure the impact of some of the CTML principles. Table 2summarizes all the CTML principles and highlights the Chapter that investigated each principle, if applicable.

The next section summarizes and relates the results of the research to the principles of the CTML. The rest of this chapter details the implications and contributions of the research, its limitations, and proposed future work to advance the findings.

5.2   Design Principles for Improved communication

Mayer's latest revision of the Cognitive Theory of Multimedia Learning (2009) introduced 10 design principles to more effectively present information leading to deeper understanding. Mayer suggests the principles generally lead to a reduction of extraneous cognitive load, an increase in germane cognitive load, or a combination of the two. Extraneous cognitive load is the use of cognitive resources to organize information but is not directly attributable to learning and understanding (Sweller & Chandler, 1994). German cognitive load is the use of cognitive resources for knowledge construction that contributes to learning and understanding (Paas, Renkl, et al., 2003).

Design Principal	Description	Chapter Coverage
Multimedia Principle	Recipients learn better from words and pictures than from words alone.	Chapters 2
Spatial Contiguity Principle	Recipients learn better when corresponding words and pictures are presented near rather than far from each other on a page or screen.	Chapters 3, 4
Temporal Contiguity Principle	Recipients learn better when corresponding words and pictures are presented simultaneously rather than successively.	Chapters 3, 4
Coherence Principle	Recipients learn better when extraneous material is excluded rather than included in the presentation.	Not specifically considered
Signaling Principle	Recipients learn better when cues highlighting organization and importance of information are included	Considered but not directly evaluated in Chapter 4
Segmenting Principle	Recipients learn better when the message is divided into small user controlled segments	Chapters 3, 4
Modality Principle	Recipients learn better from animation and narration than from animation and on-screen text (spoken text rather than printed text).	Considered but not directly evaluated in Chapter 4
Redundancy Principle	Recipients learn better from animation and narration than from animation, narration, and text.	Not specifically considered
Individual Differences Principle	Design effects are stronger for low-knowledge learners than for high-knowledge learners, and for high-spatial learners rather than for low-spatial learners.	Considered in Chapter 2
Pre-training Principle	Recipients develop a deeper understanding when familiar with names and characteristics of main concepts	Considered but not directly evaluated Chapter 4

Table 14: The Principles of the Cognitive Theory of Multimedia Learning (First and Second revision)

The research extended the principles to two of the most traditional conceptual modeling techniques used during ISD; namely, structured and UML methodologies. However, the results of the research may be applicable to other methods and conceptual modeling techniques since the research did not introduce any new modeling constructs or grammar into the experimental instruments.

5.2.1 Design Principles and Iconic Graphics

The experiments on the use of iconic graphics considered the effects of the multimedia principle. Iconic graphics representing key objects in entity-relationship diagrams were embedded in the ERD diagrams. Analysis of the results suggests an improvement in understanding for participants in the iconic graphics treatment group. However, individual differences based on language skills contributed to mixed results. The research's conclusion is that extraneous cognitive load can be reduced by applying the multimedia principle to conceptual models. However, this reduction in extraneous cognitive load may not necessarily offset an increase in intrinsic cognitive load. In addition, a reduction in extraneous cognitive load does not automatically increase germane cognitive load necessary for understanding. Therefore, it is important to motivate the recipient of the conceptual model to increase germane cognitive effort. The ability for participants to interact with the material and control the pace of learning can contribute to increased germane cognitive load (Moreno & Mayer, 2007). The experimental procedure prohibited users from controlling the pace thereby possibly limiting the effects of the embedded iconic graphics.

These results highlight the complexity of extending the CTML principles and the CLT to conceptual modeling research. It is important to measure the impact of each principle in isolation to exclude the possibility of introducing external factors to the experiments; however, some CTML principles are complementary to each other in order to produce the maximum benefit. The remaining research (Chapters 3 and 4) addressed this issue by combining elements of multiple CTML principles into the development and testing of Modular UML.

5.2.2   Design Principles and Modular UML

The research revolving around Modular UML introduced elements of the spatial

contiguity, temporal contiguity, signalling, segmenting, and pre-training principles. It is

important to note that the research, including the experiments, were completed prior to

the release of the second edition of the CTML (Mayer, 2009). So, several of the

experimental techniques, such as the use of videos to guide participants and techniques

described to breakdown UML diagrams, were devised without taking full advantage of

the suggestions offered by the CTML or the opportunities to isolate the impact of each

principle.

The over arching objective of Modular UML is to reduce the extraneous load

users are subject to when viewing multiple diagrams. Systems analysts use multiple tools

at their disposal to prepare a conceptual description of the system under investigation

(Dobing & Parsons, 2006, 2008). Users reviewing these diagrams will be, in general,

more interested in reviewing certain characteristics of the design instead of the entire

system. Searching and locating the necessary information about the domain element in

question imposes an extraneous cognitive load that can interfere with understanding.

Modular UML segments each diagram into several modules that allows users to select the

module most relevant to them thereby reducing the cognitive resources allocated for

filtering through the unnecessary information. The segmenting principle suggests that

learners understand better when reviewing and analyzing small segments instead of the

full set of information.

Modular UML also combines related segments from several diagrams to reduce

cognitive effort required to flip back and forth between the diagrams to synthesize related

information. The temporal and spatial contiguity principles provided the foundation of this process. Having related segments on a single page or computer screen reduces the spatial and temporal distances between related information, which increases the likelihood of retaining related information in working memory to enable knowledge construction and integration with long-term memory.

The Modular UML Interaction system incorporates three additional principles: signalling, pre-training, and modality. All three of these principles were considered and used in the interface but no attempt to determine each of their effects on understanding was undertaken. The videos used to describe UML diagrams and the system fall within the pre-training principle. The videos used screen shots of the diagrams and highlighting effects to draw participants' attention to key objects. The use of highlights falls under the visual signalling category. According to the CTML, the use of videos and highlights lead to a reduction of extraneous cognitive load. The experimental results were not affected since videos were administered to all treatment groups. The use of videos was important to control for possible experience bias.

The use of textual tooltips and sound descriptions satisfies the modality principle as both features add a second complementary process to describe each object in the diagrams. The two features were administered to the "interactive" treatment groups only. There was no attempt to isolate the effects of the modality principle on understanding; however, the modality principle in combination with the segmenting principle revealed a significant impact.

The findings of the two studies should not be considered in isolation. It is believed the results can be extended and applied to each of the methodologies and related

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diagramming tools. The use of iconic graphics can be embedded in UML diagrams to represent objects in use case diagrams, class diagrams, activity diagrams and others. Consequently, Modular UML techniques can be applied to entity relationship (ERD) and data flow diagrams (DFD). Typically, ERD and DFD are used together to represent a system using the structured methodology. Segmenting the ERD and DFD and combining related modules should have a positive impact on cognitive load. The Modular UML Interaction interface can be easily adapted for use with the structured methodology. Again, the author anticipates that using the MUI interface with structured diagrams should lead to a positive impact on understanding.

5.3   Research Contributions

The answer to the general research question listed in Chapter 1 summarizes the major contributions of this thesis. The research question "How can accepted conceptual modeling techniques be adapted to provide better user/stakeholder understanding?" can be addressed as follows:

- Shift the focus of research from the process of building conceptual models by analysts to presenting the model to the user in the most cognitively efficient manner
- Rely on established cognitive research and theories to determine cognitively efficient presentation techniques for conceptual models and users
- Use these cognitively efficient presentation techniques during ISD processes

The following sections describe the contribution in more detail.

5.3.1   User-Centric Approach to Information Systems Design

The first major contribution of this research is shifting the focus from system analysts and the process of building models to a user-centric focus. The user-centric focus

involves the need to consider the user's ability to fully understand the model under consideration. Failure for users to understand system documentation during requirements verification has implications throughout the system development process as well as the functionality of the final product.

The user-centric approach presented in this thesis is not the same as user participation in information systems development. It is widely considered essential and critical to the success of ISD project to involve users during the development process (Ives & Olson, 1984). User participation is the assignment, activities, and behaviours that users perform during systems development (Barki & Hartwick, 1994). The user-centric approach elevates user participation by suggesting the need to develop and utilize tools that are less confusing and more functional for users to increase the benefits of user participation.

Current research on tool and technique development tends to address the accuracy of the model being developed, the ease of development by analysts, and understandability by analysts. How much the users understand of the model, from this perspective, has been largely ignored. A reason for this may have been a lack of a theoretical foundation to guide the research. It is hoped that the introduction of the two cognitive theories to ISD may spur additional research into cognition and user involvement.

5.3.2 Introducing and Applying Cognitive Theory foundations to Information Systems Design

The second major contribution is the introduction of cognitive theories to the early stages of information systems analysis to support the proposed user-centric approach to requirements validation. The cognitive load theory (Sweller & Chandler,

1994; Sweller, et al., 1998) provides the theoretical foundation necessary for a user-centric perspective. The cognitive theory of multimedia learning (Mayer, 2001, 2009) provides design principles to apply the cognitive load theory to understanding of conceptual models.

Experimental tasks to measure retention and understanding were introduced to support the use of cognitive theory. The tasks, based on Mayer's research methodology, were refined from earlier work by Gemino (1999). The experimental procedure used recognition and recall tasks to measure retention. Retention is defined by Mayer (2001) as surface level understanding or rote learning. Users with high retention are capable of reproducing information found in conceptual models and they are capable of answering descriptive questions about the system or process under investigation. Understanding is measured by the transfer experimental task. Mayer defines understanding as the ability to apply constructed knowledge for use in new situations (Mayer, 2001).

The introduction of cognitive theories and procedures to apply and test them to ISD creates a new research stream revolving around user understanding. The use of cognitive theories is method independent and may be expanded to other areas of ISD research. By being method independent, these cognitive theories may be applied to structured methodologies, any of the various object-oriented methodologies, and emerging methodologies such as agile development. The experimental procedures described in this thesis are not necessarily restricted to conceptual modeling in ISD but may be applied to text or computer based documentation, user interface design, or any area that relies on extensive use of diagramming such as the Business Process Modeling Notation.

5.3.3   Proposing updates to CASE tools

An important contribution is the possibility of incorporating some of the experimental techniques in existing or future Computer Aided Software Engineering (CASE) tools, particularly upper case tools focused on conceptual designs of the systems. Current case tools are packages designed to simplify the modeling tasks of system analysts. Some, such as the IBM Rational Rose data modeller, include validation routines to check associations and applicability of the UML grammar to model design. Microsoft Visio, the popular mass-market modeling tool, also contains features to simplify the modeling process of UML diagrams. Visio has the additional capability of including images and other multimedia elements. However, neither of these two example applications deliver an efficient process of embedding multimedia elements directly into the diagrams and they do not facilitate different views of the same diagram.

It is hoped that some features of the experimental design used in this research (specifically, Modular UML) will be of interest to CASE Tool developers. The Modula UML interaction system built for conducting the research is a self-contained and fully functional application. It is based on the Extensible Markup Language (XML) to enable quick diagram designs and to assist in segmenting and combining the various diagrams. The interface lacks the ability to verify models based on UML rules and techniques.

Adopting some of the features of the MUI system into a commercially supported application provides additional features for analysts to support users during the requirements validation phase of systems analysis.

5.4   Limitations

The research presented in this thesis relied solely on laboratory controlled experimentation. Experimental analysis is necessary to control for the numerous variables that could confound the results. High internal validity and ability to test theories provide an advantage for conducting cognitive based experiments. Consequently, first and second year university business students were the primary participants in this research. Use of students in a laboratory setting will naturally limit the generalizability, or external validity, of the study but should not restrict its internal validity. External validity is the degree to which we can extend research results to non-experimental situations such as practitioner based settings. Internal validity is the accuracy of the inferences of causal relationships in a study.

Difficulties in generalizing the findings lead to two main limitations of the research. The first limitation is the ability to extend the finding to industry settings. The second limitation is that the use of a fixed type of participants, such as business students, who do not represent a broad spectrum of individual differences of system users who may be expected to participate in systems analysis and design. Other limitations include lack of a formal process to decompose diagrams in Modular UML and the effect of applying multiple design principles which is unclear and requires further study.

5.4.1   Validity in Industry

The experimental material and cases used throughout the research (such as the adapted entity-relationship diagram and Modular UML diagrams) were restricted in scope and complexity and created in advance by the researchers. This provides an

important limitation as systems in industry tend to be complex and are created by analysts under time pressure.

The diagrams were purposely restricted in complexity in order to limit the intrinsic cognitive load on inexperienced participants and to allow a reasonable experiment procedure. A heavy intrinsic cognitive load would completely consume working memory capacity confounding the experimental results. Therefore, it was necessary to limit the complexity of the cases. However, real world systems will have more complex systems and more experienced users. It is not clear what this combination of complex systems and experienced users will have on the baseline intrinsic cognitive load of users. It is believed that the results of the study would mimic real world examples as the relative baseline intrinsic cognitive load would be at similar levels since experience tends to reduce intrinsic load of the complex information. Further research is necessary to test this hypothesis.

The diagrams and presentation techniques were prepared carefully in an unrestricted environment. The Modular UML Interactive application was created over several months and tested repeatedly before use during the experiments. Systems analysts work under time pressure to prepare system documentation. Complex systems usually lead to a generous number of diagrams and other documents. System Analysts may not have the freedom to engage in creating additional diagrams or adding multimedia cues to existing diagrams. Therefore, it is not clear if analysts will be willing to apply results from the research into the real world. The research stream is at its infancy and it is recommended that future research considers the practicality of using multimedia design principles in more complex situations.

It is believed that this limitation can be transcended if CASE tools are available that take advantage of suggested design principles. An example would be a feature that allows automatic voice recording of a description of an object while automatically tagging the recording to that object. The technology already exists and is used in many consumer applications but is not available in any CASE tools today. Others examples would be the ability of analysts to highlight portions of diagrams in order for the system to automatically generate combination diagrams based on the selections. It is understood that it becomes a circular cause and consequence argument. CASE tool developers will not automatically add functionality not demanded (or considered standard) by analysts. Analysts will not necessarily demand such features if they have not been exposed to them. Therefore, it becomes important for the academic research community to raise the profile and benefits of such research by conducting more research that encourages CASE tool developers to consider adopting extraneous cognitive load reducing presentation design features.

5.4.2   Individual Differences

Different individuals prefer different formats based on experience and visual perceptual abilities. The individual differences principle as suggested by Mayer (2001) implied that prior experiences could compensate for poor message design. This may imply that users with high experience are less likely to benefit from suggestions listed in this thesis. Mayer's individual differences principle was formed based on research with high school students learning scientific content. This perspective suggests that high experience learners (those with scientific background) will have significantly lower intrinsic cognitive load than their inexperienced counterparts such that they may not be

sufficiently cognitively overburdened to benefit from a reduction in extraneous cognitive load. Users reviewing documentation during ISD projects are faced with two distinct experience measures: experience with the domain being modelled, and experience with the modeling tools and diagrams. It is not clear if experience in one or the other, but not both, will reduce the effectiveness of the design principles. Participants involved in the study were selected to have low experience in both aspects the tools and the domain.

Users involved in ISD projects are typically selected based on their high experience with the business domain but not necessarily with the modeling. The question that remains unanswered is whether these users will benefit from diagrams adapted to reduce extraneous cognitive load.

The study also did not address individual differences based on spatial or other visual perceptual abilities. *"Spatial and other visual perceptual abilities have to do with the individual's abilities in searching the visual field, apprehending the forms, shapes, and positions of objects as visually perceived, forming mental representations"* (Carroll, 1993, p. 304). Mayer suggests that high spatial individuals would benefit from design principles that make extensive use of graphics and animation. However, considering that conceptual models are graphical in general, further study needs to examine the effects the research findings on low versus high spatial individuals.

5.4.3   Other limitations

The process of decomposing UML models was presented in Chapter 3 to create Modular UML diagrams and facilitate understanding is in the early stages of formalization. The process was formulated for the example Human Resources Scheduling

system described in the research. It is not clear how effective this process can be with other, specifically larger, system analysis tasks.

The example system was decomposed following a functional decomposition approach based on a high level Use Case. Users' specific review needs were not considered for the decomposition process. Taking into consideration how users view the diagrams and the information they are seeking may reveal more effective decomposition methods such as based on specific work process (rather than Use Case steps) or a group of related work processes.

Another limitation is the inability to fully isolate the impact of each of the CTML design principles for effective model presentation. Multiple design principles were necessarily included during the experiments as attempts to isolate them was very challenging. Specifically, the impact of individual differences principle combined with the impact of other principles. Attempts to measure the impact of narration using verbal cues and text cues were confounded by the individual differences principle. Isolating experimental results of narration versus text cues was difficult since the experiments lacked an effective method to measure individual differences based on auditory preferences. In addition, a larger sample would have been required for statistical accuracy.

A more interesting limitation partially uncovered in the experiments described in Chapter 5 is the impact of combining multiple design principles for maximum impact. Although it is important to isolate the impact of each principle, combining these principles may lead to a more pronounced effect. For example, in Chapter 4, it was suggested that reducing extraneous load was in itself not sufficient to improve

understanding. An increase in germane cognitive activity is a necessary condition to fully utilize

5.5   Future research

Future research should address the limitations discussed in the previous section. Specifically, future research should address the external validity of the findings, to determine the impact of individual differences, to formalize the decomposition process, and to investigate the compounded effect of combining multiple design principles on cognitive processes.

External Validity: The CTML design principles were introduced to improve learning and understanding of complex scientific and mathematical lessons of high school students. The research demonstrated the CTML's applicability to conceptual modeling by University students in a controlled setting. However, it is not yet verified that the process is effective in a real world systems analysis environment. It is also challenging to conduct effective quantitative experimental research in an industry setting considering the large sample size necessary for valuable analysis. A suggestion for future research may include action research whereas the researcher can work with an organization as an analyst (or guides analysts) to create and introduce some of the design principles to their requirements gathering process. Qualitative and observational analysis may produce results that address the applicability of some of the recommendation in an external setting.

Individual Differences: The participants used in this research were not evaluated nor separated based on spatial and other perceptual or cognitive abilities. The next step to

enhance the findings would be use measures that can evaluate the participants' individual differences. Research from the field of psychology may provide some tests or other means to group individuals based certain cognitive capabilities. The tests may be conducted prior to completing some of the experiments discussed in this thesis. Results would address some of the individual differences limitations.

Formalized decomposition process: A valid criticism of modular UML is the lack of a formal decomposition process that can be applied to wide variety of systems. Also, the number of possible modular diagrams that can be created for large systems may be overwhelming to analysts particularly if more than five or six different types of UML diagrams is used to represent the system. Future research could extend the action research suggested earlier to include investigating general rules to represent modular UML. Understanding how module UML may be used in the field should contribute significantly to a formalized decomposition process.

Combining multiple design principles: The impact on understanding of the effects of combining multiple design principle may be more than the sum of individual principles. This premise guides future research to investigate the consequences of combining different principles. Controlled experiments similar to those documented in this work may provide the best mechanism for future research. Again, the challenge of this future research would be to generalize any findings and to suggest methods to apply the results to real world examples.

5.6   Final Comments

The research program discussed in this thesis embarked on an unconventional journey to investigate users' understanding and improve communication between users and analysts solely by altering the presentation format of accepted conceptual models. This is unconventional since most research involving conceptual modeling tends to revolve around introducing new modeling methodologies based on various theoretical and conceptual foundations.

It is hoped that the findings presented here introduce another research stream that can work in conjunction with methodological based research to significantly improve the early stages of systems analysis leading to overall improvements in ISD success rates. It is also hoped that results in this thesis invigorates conceptual modeling studies and expands the field to include cognitive based research.

Like all things, even the most unconventional of journeys must end!

Thank you for reading my work.

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APPENDIX 1: INSTRUMENTS FOR ERD STUDY

Appendix 1-A: Experimental material for "Far Eastern Repair Facility" Case

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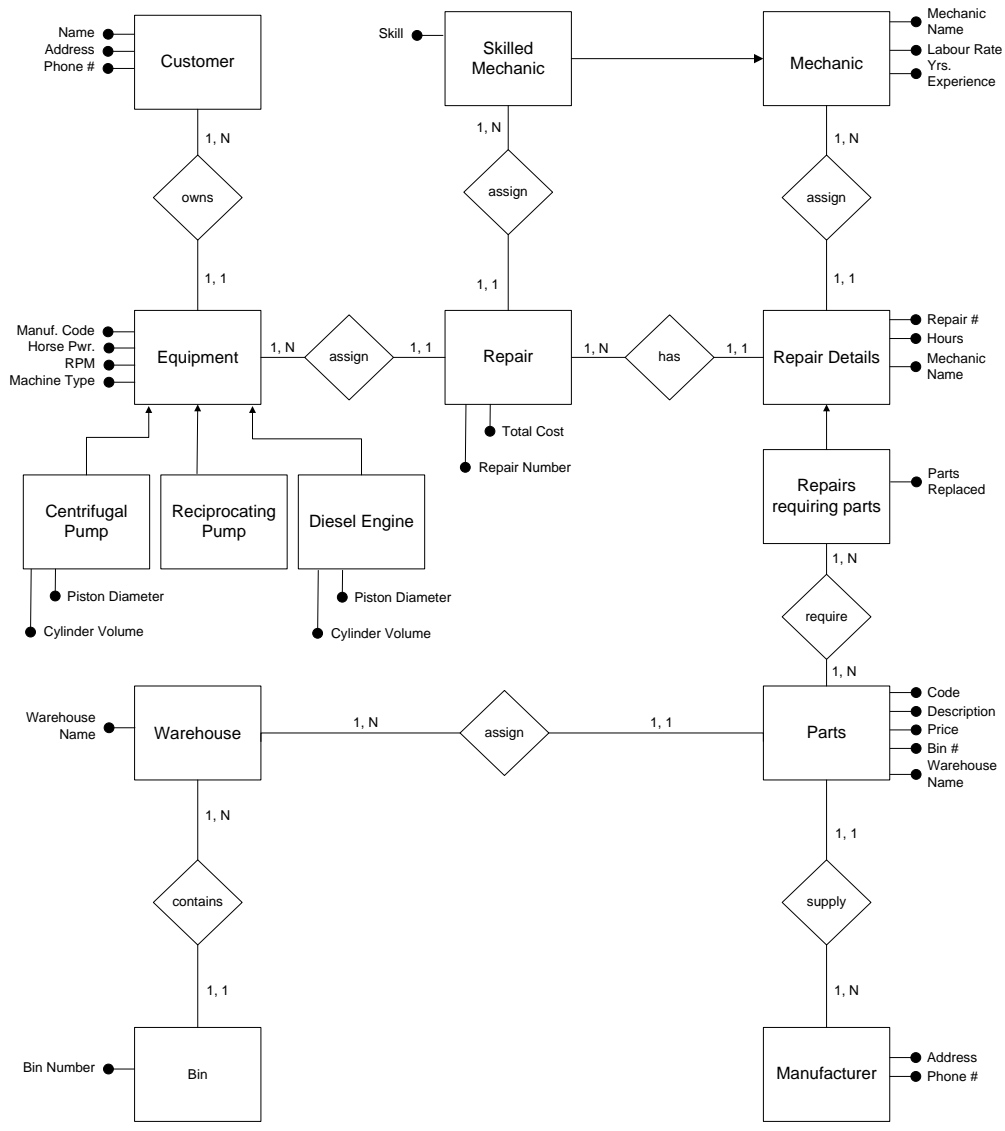
Far Eastern Repair Facility

The Far-Eastern Repair Facility carries out repairs of manufactured equipment for clients. The objectives of the Far Eastern Repair Facility (Far Eastern) are to run an efficient repair facility that provides high quality repair service in the shortest possible time. The repair facility has provided Far Eastern with the capability to repair three general types of manufactured equipment: centrifugal pumps, reciprocating pumps, and diesel engines.

When Far Eastern receives a piece of equipment in need of repair, the company assigns a repair number and records the original equipment manufacturer's code along with the horsepower and speed (RPM) at which the machine will run. For centrifugal pumps and diesel engines, Far Eastern also records both the piston diameter and cylinder volume associated with each piece of equipment. Every piece of equipment brought to Far-Eastern Repair is owned by a customer. Far Eastern maintains the current address, and phone number of the customers for billing purposes.
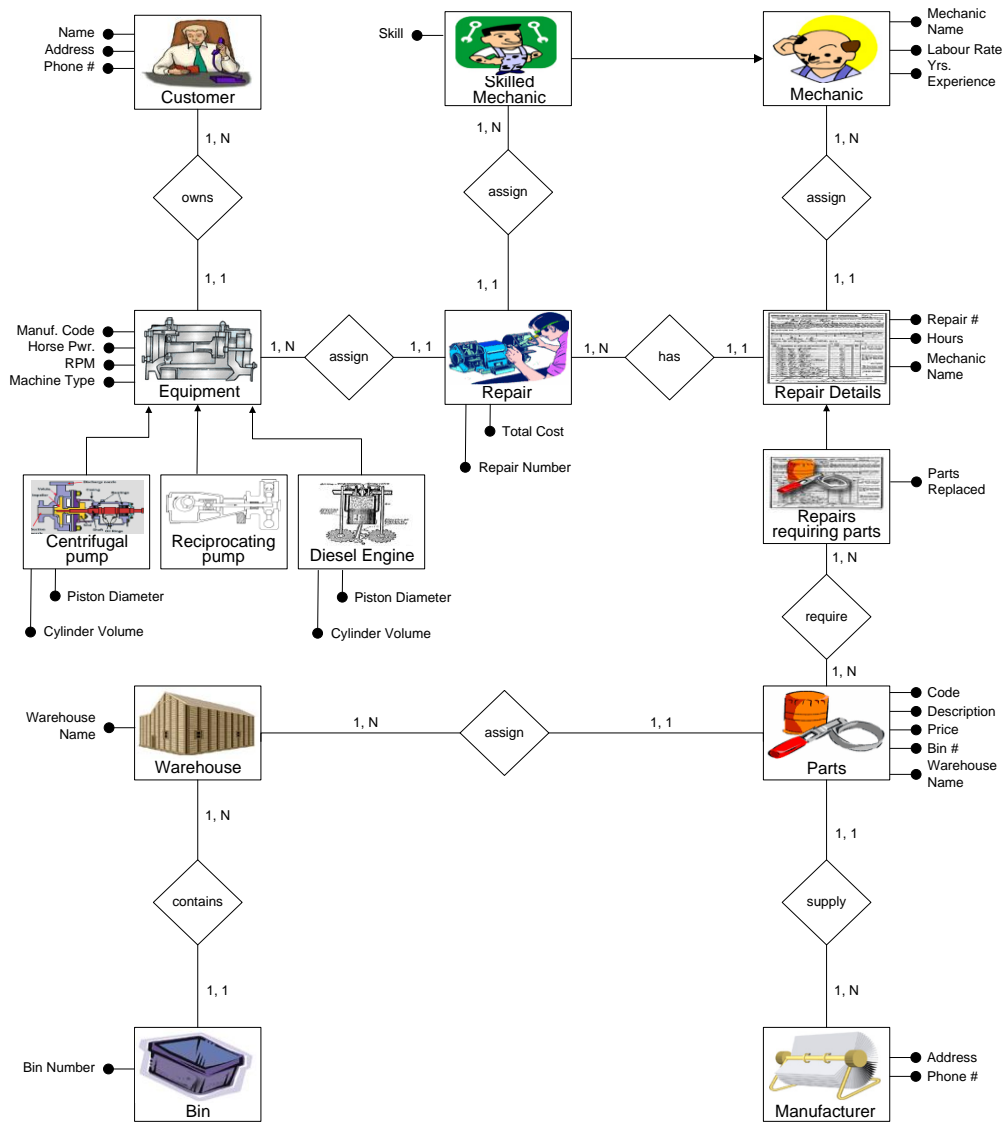
Far Eastern maintains an inventory of spare parts. The repair facility collects the address and phone number of each part manufacturer so that they can order spare parts for machines they repair. The parts inventory is warehoused in three different buildings labelled warehouse 1, 2, and 3. Parts are stored in numbered bins within each warehouse. Each part is identified by a part code along with the description, list price, bin number, and weight for each part.

There are several mechanics at the facility. Since each mechanic differs in skill and experience, each mechanic has a different labor rate. If a mechanic has a special skill; that skill is recorded by Far Eastern. Years of experience is also recorded. When equipment arrives for repair, one of the skilled mechanics is assigned to the repair task. The skilled mechanic then can assign other mechanics to details associated with the repair. When the repair is completed, each mechanic working on the repair task enters the number of hours they spent on repair, parts replaced (if any), and a description of the repair. The total cost associated with the repair task is then calculated and recorded.

Far Eastern Repair Facility

Customer
- Name
- Address
- Phone #

1, N
owns
1, 1

Skilled Mechanic
- Skill

1, N
assign
1, 1

Mechanic
- Mechanic Name
- Labour Rate
- Yrs. Experience

1, N
assign
1, 1

Equipment
- Manuf. Code
- Horse Pwr.
- RPM
- Machine Type

1, N   assign   1, 1

Repair
- Total Cost
- Repair Number

1, N   has   1, 1

Repair Details
- Repair #
- Hours
- Mechanic Name

Centrifugal Pump
- Piston Diameter
- Cylinder Volume

Reciprocating Pump

Diesel Engine
- Piston Diameter
- Cylinder Volume

Repairs requiring parts
- Parts Replaced

1, N
require
1, N

Warehouse
- Warehouse Name

1, N   assign   1, 1

Parts
- Code
- Description
- Price
- Bin #
- Warehouse Name

1, N
contains
1, 1

1, 1
supply
1, N

Bin
- Bin Number

Manufacturer
- Address
- Phone #

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Far Eastern Repair Facility

Recognition Task Questions - Far-Eastern Repair Facility

	Question	Answer
1.	Do all repairs require parts?	N
2.	Can a repair be worked on by more than one mechanic?	Y
3.	Are all repairs assigned to at least one mechanic	Y
4.	Are there parts stored in the warehouse that are not used for repairs?	U
5.	Does Far Eastern collect different information for different machine types?	Y
6.	Does Far Eastern differentiate their local customers in any way?	U
7.	Can a mechanic who does not have a special skill be assigned to more than one repair?	Y
8.	Do all the mechanics related to the same repair, pool their hours to create a single entry for hours worked?	N
9.	Can a piece of equipment undergo more than one repair?	Y
10.	Can more than one part be listed in a single repair detail?	Y
11.	Is the cylinder volume recorded for all pumps that are repaired?	N
12.	Can a part be supplied by more than one manufacturer?	Y

Transfer Task Questions and Answers: Far-Eastern Repair Facility
(note: answers are sample answers only. The lists are not intended to be comprehensive)

Question 1:
A customer of Far Eastern has called to complain that the machine they sent for repair has not been repaired yet. What possible reasons can you provide for what might have gone wrong. (Provide as many solutions as you can think of.)

Answers
1. No parts available (not yet available).
2. No mechanics available or assigned to repair.
3. No mechanic with skill available or assigned.
4. Part warehouse remote and difficult to access.
5. Machine already repaired but customer not contacted.
6. Machine already repaired but paperwork not complete or wrong.
7. May not be a machine type that Far East can repair.
8. Mechanics not able to solve problem.
9. No method for tracking machine in repair.
10. Duplicate value in repair number.
11. More repairs discovered.
12. Mechanics behind schedule.

Question 2:
Far Eastern is experiencing a very large increase in the number of machines that they should repair. What problems might Far Eastern experience because of this increase in repairs? (Provide as many solutions as you can think of.)

Answers
1. Not enough parts in inventory.
2. Not enough skilled mechanics.
3. Not enough mechanics.
4. Too many repairs assigned to mechanic.
5. More people to handle paperwork.
6. Need to efficiently schedule repairs.
7. Difficult to track machine being repaired.
8. Not enough space in shop or warehouse (backlog).
9. Backlog and delays of repairs.
10. Increased customer dissatisfaction.
11. Labor costs increase as mechanics may work more hours.
12. Not able to fix all machines.

Question 3:
Customers of Far Eastern are not happy when the actual repair price is higher than the estimated repair price. The sales person says that it is not his fault because the estimation is so difficult. Provide as many possibilities as you can think of that make the accurate estimation of the total repair price difficult. (Provide as many solutions as you can think of.)

Answers
1. Price of parts change (number of parts required).
2. Estimate of hours required by mechanics difficult.
3. Not sure who will do the repair.
4. Problems may be discovered after the repair begins.
5. Sales person not experienced with repair details.
6. State of equipment (age, disrepair) without taking apart (not sure what is wrong).
7. Availability of necessary equipment to complete the repair.

Question 4:
Far Eastern is considering investing in a machine that can be used to repair large turbine engines. How would the current data structure be affected by the purchase of the new machine? Try to think of as many affects as possible. (Provide as many solutions as you can think of.)

Answers
1. Nothing - any repair would still need a mechanic (update only).
2. Add a new classification for equipment that can be repaired.
3. Who will operate the machine? Need new mechanics, new skills.
4. Machine may not require mechanic to make repair. Add attributes to describe machine.
5. New warehouse for parts.
6. New attributes for equipment.
7. More data to be stored.
8. New suppliers and new parts added (attributes - part codes and bin number).
9. Repair details needs new attribute (machine used in repair).
10. Add entity called machine.
11. Include cost and cost estimates.
12. Cardinalities in some jobs may change.
13. Need to categorize size of engine for repair.

Appendix 1-B: Experimental material for "Voyager Bus, Inc." Case

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Voyager Bus Inc.

Voyager Bus Inc. (Voyager) is a company specializing in bus trips to places of interest or special events. The objectives of Voyager are to provide high quality and safe travelling experiences for tourists.
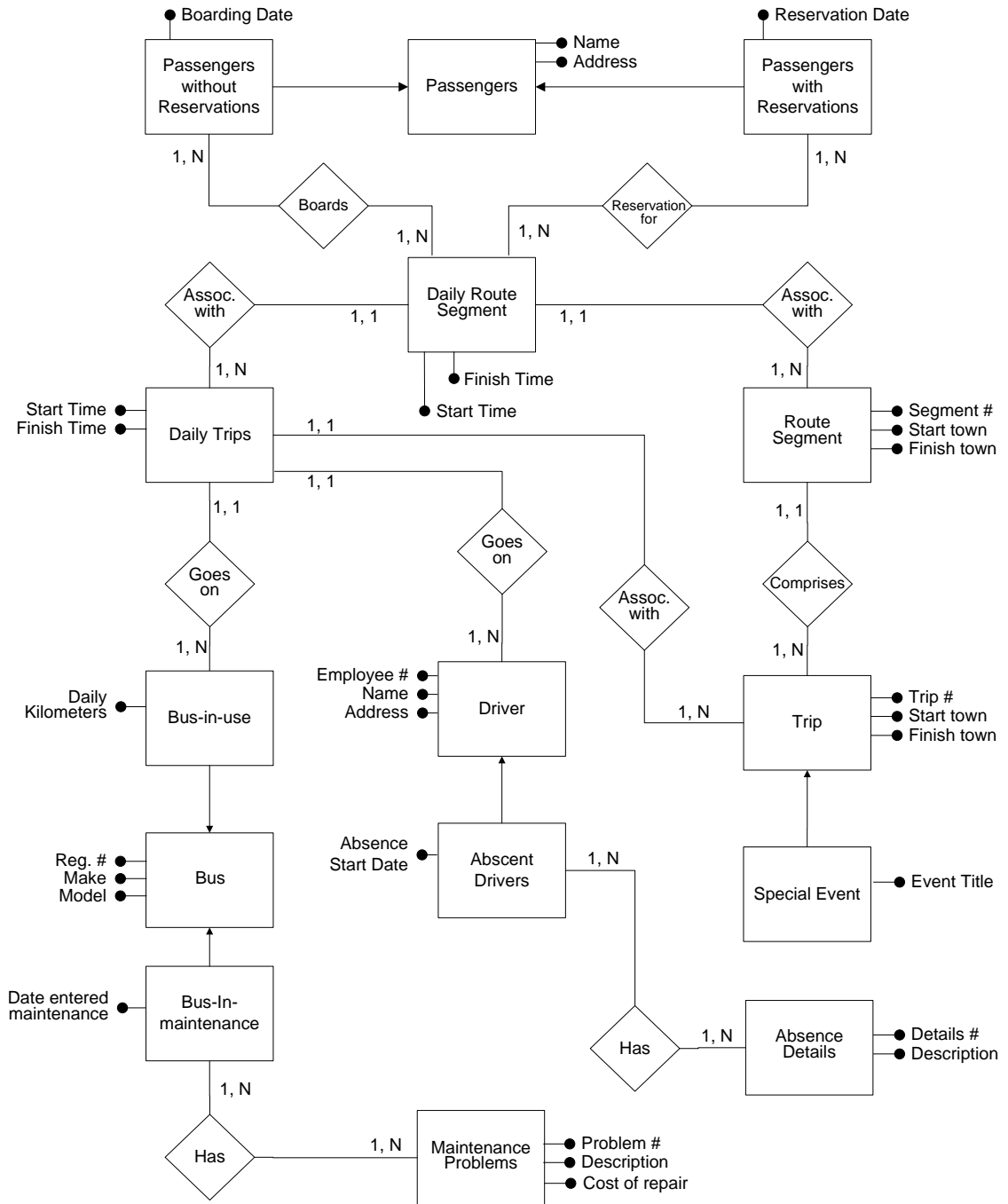
There are two ways for people to travel with Voyager. Passengers can either make a reservation on a trip, or passengers can show up at the boarding gate without a reservation and purchase a ticket for an unreserved seat. Passengers with a reservation are assigned a reservation date, whereas, passengers without reservations are assigned a boarding date. The name and addresses of all passengers are collected. Telephone numbers are collected where possible.

All bus trips are organized into daily route segments. All daily route segments have both a start time and an end time. Each daily route segment Voyager organizes is classified as a route segment with a segment number, start town, and finish town. Voyager offers a range of trips, and each trip is made up of one or more route segments. For every trip there is a trip number, start town, and finish town. If the trip is organized around a special event, the event name is also associated with the trip.
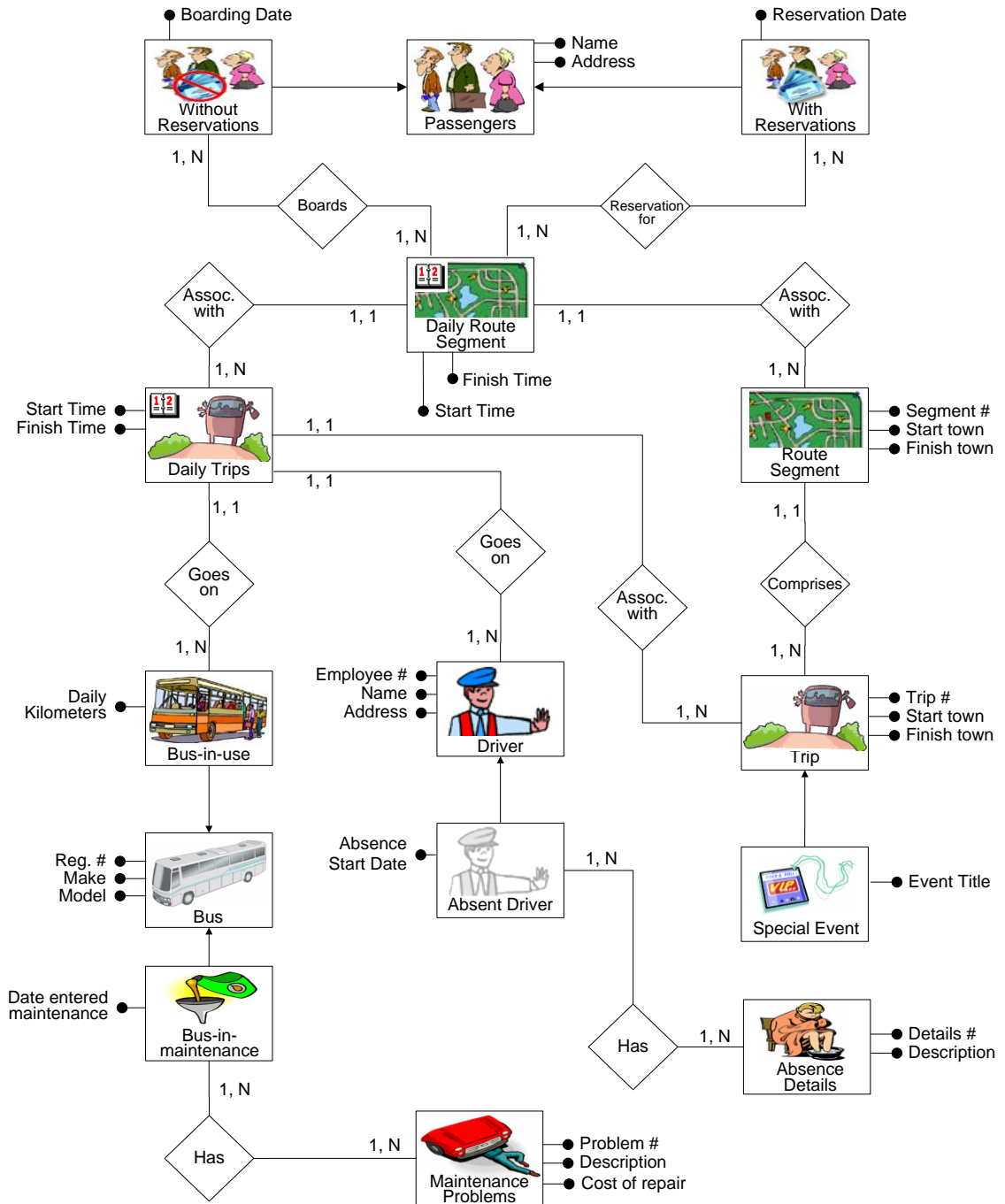
Each daily route segment that Voyager offers is part of a daily trip. A daily trip is undertaken by one or more bus drivers. The name, address, and employee number of all drivers is collected. Voyager also records information about absent drivers. When a driver is absent, Voyager records the absence start date and the details about the absence. The absent driver provides one or more reasons for being absent and each reason is assigned a detail number and a short description.

Voyager also collects information about the buses used for daily trips. Buses have a make, model, and registration number. For buses in use, the average daily kilometers is collected. If a bus requires maintenance, Voyager notes the date on which the bus entered maintenance and records the one or more problems with the bus. Voyager assigns a problem number and a short description for every maintenance problem. Finally, the average cost to repair all problems with a bus in maintenance is also recorded.

Voyager Bus Inc.

Entity-Relationship diagram for Voyager Bus Inc.

- Boarding Date

Passengers without Reservations

Passengers
- Name
- Address

- Reservation Date

Passengers with Reservations

1, N

1, N

Boards

1, N

1, N

Reservation for

Assoc. with

1, 1 **Daily Route Segment** 1, 1 **Assoc. with**

1, N

1, N

- Finish Time

- Start Time

- Start Time
- Finish Time

Daily Trips 1, 1

1, 1

Route Segment
- Segment #
- Start town
- Finish town

1, 1

1, N

Goes on

Goes on

Assoc. with

Comprises

1, 1

- Daily Kilometers

Bus-in-use

1, N

- Employee #
- Name
- Address

Driver

1, N

1, N

Trip
- Trip #
- Start town
- Finish town

- Reg. #
- Make
- Model

Bus

- Absence Start Date

Abscent Drivers

1, N

Special Event - Event Title

- Date entered maintenance

Bus-In-maintenance

Has 1, N **Absence Details**
- Details #
- Description

1, N

Has 1, N **Maintenance Problems**
- Problem #
- Description
- Cost of repair

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Voyager Bus Inc.

Entity-Relationship diagram for Voyager Bus Inc.

- Boarding Date — **Without Reservations**
- **Passengers** — Name, Address
- Reservation Date — **With Reservations**

Without Reservations → **Passengers** ← **With Reservations**

- Without Reservations — 1, N — **Boards**
- With Reservations — 1, N — **Reservation for**

Boards 1, N — **Daily Route Segment**
Reservation for 1, N — **Daily Route Segment**

- **Assoc. with** — 1, 1 — **Daily Route Segment** — 1, 1 — **Assoc. with**
- Daily Route Segment — Finish Time, Start Time

- Assoc. with — 1, N — **Daily Trips**
- Assoc. with — 1, N — **Route Segment**

- **Daily Trips** — Start Time, Finish Time
- **Route Segment** — Segment #, Start town, Finish town

- Daily Trips — 1, 1 — **Goes on** (Driver)
- Daily Trips — 1, 1
- Daily Trips — 1, 1 — **Goes on** (Bus-in-use)
- Route Segment — 1, 1 — **Comprises**

- **Goes on** — 1, N — **Bus-in-use** — Daily Kilometers
- **Goes on** — 1, N — **Driver** — Employee #, Name, Address
- **Assoc. with** — 1, N — **Trip**
- **Comprises** — 1, N — **Trip** — Trip #, Start town, Finish town

- **Bus-in-use** → **Bus** — Reg. #, Make, Model
- **Driver** ← **Absent Driver** — Absence Start Date
- **Trip** — **Special Event** — Event Title

- Absent Driver — 1, N — **Has** — 1, N — **Absence Details** — Details #, Description

- **Bus** — **Bus-in-maintenance** — Date entered maintenance

- Bus-in-maintenance — 1, N — **Has** — 1, N — **Maintenance Problems** — Problem #, Description, Cost of repair

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Recognition Task Questions - Voyager Bus Inc.

Question		Answer
1.	Can a trip be made up of more than one route segment?	Y
2.	Does a person have to make a reservation to go on a trip?	N
3.	Can a daily trip be assigned to more than one bus?	Y
4.	Does Voyager Bus Inc. collect the same set of information for all of the passengers?	N
5.	Can the same daily route segment be associated with two different trip numbers?	Y
6.	Can Voyager Bus Inc. record a maintenance problem that has not yet been experienced by any of their buses?	U
7.	Is the daily route segment modeled as an entity?	Y
8.	Can a bus driver be assigned to more than one daily trip?	Y
9.	Are all buses that are available for use assigned to a daily route segment?	U
10.	Is model an attribute of bus?	Y
11.	Is the cost of repair recorded for all buses in maintenance?	Y
12.	Can the end town assigned to a route segment be different from the end town associated with a trip that uses the route segment?	Y

Transfer Task Questions and Answers: Voyager Bus, Inc.
(note: answers are sample answers only. The lists are not intended to be comprehensive)

Question 1:
An employee at Voyager Bus Inc. has come up with an idea for a new trip, and has assigned the trip with a trip number, start town, and end town. The employee showed the newly planned trip to his manager and she said that the trip, although exciting, was not possible. What reasons can you provide for the trip not being possible? (Provide as many solutions as you can think of.)

Answers
1. Not able to fit trip to daily route segments.
2. Not enough buses.
3. Not enough drivers.
4. Not enough passengers to pay for trip.
5. Overlapping start and end times.
6. Not a profitable route.
7. Bus not able to make trip (too many kilometers, too rugged).
8. Trip number is not unique.
9. Route segment already served by another bus.

Question 2:
A bus driver for Voyager Bus Inc. has a problem. All seats on the bus have been taken, yet there is a passenger waiting to board the bus. What could have happened to cause this

problem? (Provide as many solutions as you can think of.)

Answers
1. Passenger without reservation boarded the bus.
2. Head office does not keep track of how many passengers are assigned for each bus (overbooking).
3. Driver not aware of how many reserved seats are required.
4. Wrong bus was assigned to route.
5. Waiting passenger does not have reservation.
6. Some passenger boarded the wrong bus.
7. Waiting passenger has right route but wrong day (or wrong bus).
8. Bus has faulty seat.

Question 3:
A person wants to go to a special event that is part of a trip offered by Voyager Bus Inc., yet the employee at Voyager Bus Inc states that, given the current situation, the person cannot go on the special trip. What could be stopping the person from going on the trip? (Provide as many solutions as you can think of.)

Answers
1. No more seats left on bus.
2. No buses are available (broken down).
3. Shortage of drivers (absent).
4. Passenger did not have reservation.
5. Voyager does not service the route segment.
6. Passenger has special needs that cannot be handled by Voyager (handicapped).
7. Trip requires special legal paper (Visa) or age restriction.
8. Employee is not correctly informed.
9. Event has been cancelled.
10. Part of the routes have been cancelled (bad weather, etc.).
11. Not enough demand for the trip.
12. Bus has already left.

Question 4:
Voyager Bus is considering the purchase of several new medium sized buses. What might be the effects of this purchase on Voyager Bus Inc. as it currently stands. (Provide as many solutions as you can think of.)

Answers
1. They can provide more trips.
2. Need to hire more drivers.
3. More maintenance problems.
4. Provide medium sized trips.
5. Serve more route segments (more new trips).
6. Decrease number of cancelled trips (more flexibility in schedule).
7. Where will the buses be stored?
8. Additional slack resources during off-peak season.

9. Retire older buses.
10. Less passengers need to reserve seats.
11. Drivers need different skills or licenses.
12. No attribute for bus size.
13. Record purchase of new bus.
14. Average number of customers per trip may be affected.
15. Lower maintenance since buses are new.
16. Record maintenance problems associated with new bus.

Appendix 1-C: Explanation of ERD grammar (pre-training)

Student	**The rectangular symbol refers to an entity. The name of the entity is provided inside the box.**
Advise (diamond)	The diamond shaped symbol refers to a relationship. The name of the relationship is inside the diamond.
———	A line with no arrows is used simply to connect the relationships
←———	A line with an arrow used to point from an entity subtype to a more general entity. In the example below, the line with the arrow indicates that a graduate student is a subtype of the more general entity called student. Note that lines with arrows are only used to point from one entity to another more general entity.
●——	The solid knob indicates a mandatory attribute of an entity. In other words, the entity must have a valid value for this attribute.
1, N	The (1,1), and (1,N) symbols indicate cardinalities associated with connections between entities. The first number represents the minimum number of connections between two entities; the second number represents the maximum number of connections. In the example below, a graduate student has a minimum of 1 advisor and a maximum of 1 advisor. However, a graduate advisor has a minimum of 1 student and a maximum of N students to advise.

Example:
The example below shows the relationship between students and advisors. All faculty members have a name and an office number. Some of the faculty members are also graduate advisors (as shown by the "graduate advisor" subtype and its relationship to the "Faculty Member" entity). All students have names and student numbers. Graduate advisors can have more than one graduate student as an advisee. However, a graduate student can only have one graduate advisor. Faculty members are not advisors for undergraduate students.
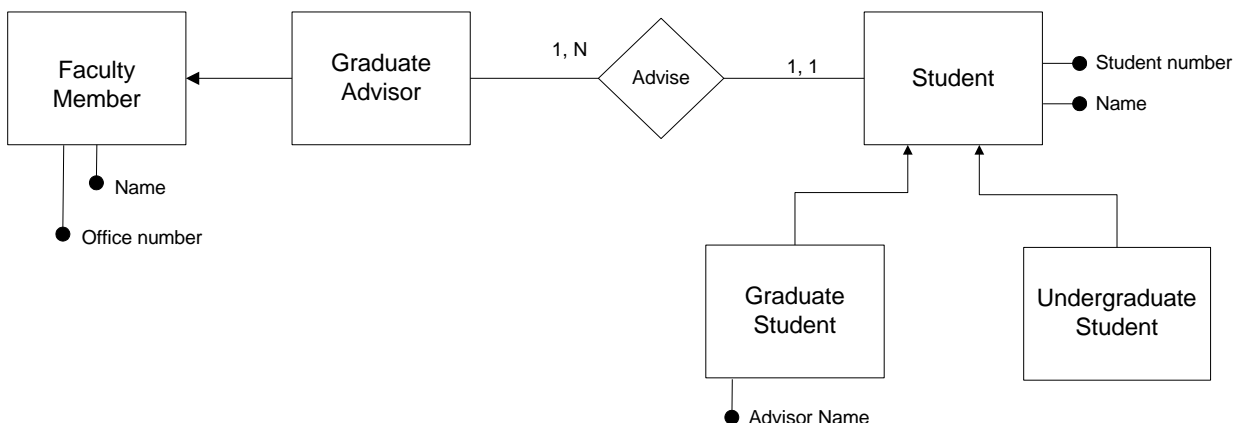
Appendix 1-D: Sample screen captures of software developed for the experiments

Welcome to the Faculty of Business, MIS Research Facility.
Please follow the instructions presented in the next few screens AND your research facilitator.

Please type the code on the front of your document Package then hit enter to continue   vg-01

Please enter your age [ ] and your gender [▾]

Q1. How many courses have you taken that have covered some aspects of Systems Analysis and Design diagramming techniques/models?   [ ] (enter a number between 0 and 99)

Q2. Please indicate your level of knowledge of "Entity Relationship Diagrams":   ○ ○ ○ ○ ○ ○ ○ (1 for no knowledge and 7 for expert knowledge)
   1 2 3 4 5 6 7

Q3. Have you ever used Entity Relationship Diagrams to model a business organization?   ☐ Yes   ☐ No

Q4. Do you consider English to be your first language?   ☐ Yes   ☐ No

Please indicate your level of knowledge of the following business:

Q5. Organizing a bus tour company: ○ ○ ○ ○ ○ ○ ○ (1 for no knowledge and 7 for expert knowledge)
   1 2 3 4 5 6 7

Please indicate which of the activities listed below you have done:

Q6.	Taken a Bus tour	☐ Yes	☐ No
Q7.	Worked as a bus driver	☐ Yes	☐ No
Q8.	Made a reservation for a bus trip	☐ Yes	☐ No
Q9.	Traveled by bus to a special event	☐ Yes	☐ No
Q10.	Organized a set of short bus trips	☐ Yes	☐ No

Step 1 of 5   **Next**

Pretest Task

This step requires you to become familiar with the operations of the business provided. You should have three documents:
- A description of the business
- A conceptual model (an entity relationship diagram) representing the operations of the business; and,
- A document explaining the symbols used on the diagram.
You may use any or all three to answer the following 12 questions. You have 15 minutes to review all the documentation and respond to the questions. Please click "Start" when asked by the facilitator to do so.

Q1.	Can a trip be made up of more than one route segment?	☐ Yes	☐ No	☐ Unknown
Q2.	Does a person have to make a reservation to go on a trip?	☐ Yes	☐ No	☐ Unknown
Q3.	Can a daily trip be assigned to more than one bus?	☐ Yes	☐ No	☐ Unknown
Q4.	Does Voyager Bus Inc. collect the same set of information for all of the passengers?	☐ Yes	☐ No	☐ Unknown
Q5.	Can the same daily route segment be associated with two different trip numbers?	☐ Yes	☐ No	☐ Unknown
Q6.	Can Voyager Bus Inc. record a maintenance problem that has not yet been experienced by any of their buses?	☐ Yes	☐ No	☐ Unknown
Q7.	Is the daily route segment modeled as an entity?	☐ Yes	☐ No	☐ Unknown
Q8.	Can a bus driver be assigned to more than one daily trip?	☐ Yes	☐ No	☐ Unknown
Q9.	Are all buses that are available for use assigned to a daily route segment?	☐ Yes	☐ No	☐ Unknown
Q10.	Is model an attribute of bus?	☐ Yes	☐ No	☐ Unknown
Q11.	Is the cost of repair recorded for all buses in maintenance?	☐ Yes	☐ No	☐ Unknown
Q12.	Can the end town assigned to a route segment be different from the end town associated with a trip that uses the route segment?	☐ Yes	☐ No	☐ Unknown

Step 2 of 5   **Next**

Recognition Task

190

Please put the documents away for this step. Simply put them out of view or hand them back to you TA if asked to do so. Click start when asked by the facilitator. You will have 6 minutes to complete this section.

Using what you have learned about this company, please write down an explanation of how the company operates.

Step 3 of 5

Next

Recall Task

This section has four questions. You will have 2 minutes to answer each question. Each question has many possible solutions. Please write down ONE answer per box AND write down as many answers as you can think of.

Question 1 of 4:

An employee at Voyager Bus Inc. has come up with an idea for a new trip, and has assigned the trip with a trip number, start town, and end town. The employee showed the newly planned trip to his manager and she said that the trip, although exciting, was not possible. What reasons can you provide for the trip not being possible? (Provide as many solutions as you can think of.)

Solution 1:

Solution 2:

Solution 3:

Solution 4:

Solution 5:

Solution 6:

Solution 7:

Solution 8:

Solution 9:

Solution 10:

Step 4 of 5

Next

Problem Solving (Transfer) Task

APPENDIX 2: INSTRUMENTS FOR UML STUDY

Appendix 2-A: Experimental Material for EntertainCo. Case

General Case Overview

{Every treatment received the following general description as part of the video introducing the case and diagrams for the case}

EntertainCo is a company that owns a large sports and entertainment complex which holds a variety of events including professional sports, concerts, and conventions. The program of events is planned several months in advance. While no more than one event can take place at any given time, it is possible for more than one event to occur on the same day. The company employs several part time Event Employees to work these events. Each employee can have one classification designation such as security, customer service representative, etc. Since EntertainCo's event program is not consistent, event employees are allowed to declare their own availability schedule for when they are able to work.

EntertainCo is interested in developing a system that facilitates the scheduling of these employees to work these events. Four documents were created to outline and help understand the complete business process necessary to scheduling employees and events. The documents are:

1. A Use Case Diagram: represents an overview of the functionality of EntertainCo's scheduling process by showing the major business functions along with the stakeholders involved with these functions.
2. Use Case Description: expands on the use case diagram by providing a detailed listing of EntertainCo's business tasks associated with the scheduling process.
3. An Activity Diagram: This Activity Diagram shows the workflow of EntertainCo from business process initiation to process completion.
4. A Class Diagram: The class diagram shows the relationships between classes (persons, places, things, or concepts) associated with EntertainCo's employee scheduling process as well as the attributes of each of these classes

Recognition Task Question and Answers

Question/Answer

1. Is the Marketing Manager responsible for deciding when events are to be held at the complex?
   Y (from Use Case)

2. Does a promoter know that their event application has been accepted and placed into the program of events?
   Y (Indirectly from the Use Case)

3. Is the human resource scheduler responsible for creating the deployment sheets?
   N (from Use Case)

4. Can employees select which events they are scheduled for?
   N

5. Can employees decide which physical location they are assigned to during an event?
   U

6. Is the operations department responsible for creating the employee schedule?
   N

7. Can employees declare a maximum number of shifts they work per week?
   Y (from Class Diagram)

8. Can the schedule be generated before employees declare their availability for the scheduling period?
   N (from activity diagram)

9. Is it the responsibility of the Human Resources Department to generate empty bi-weekly schedule and the completed schedule?
   Y (from Activity Diagram)

10. Is there more than 5 different employee groups assigned to work an event?
    N (Class Diagram)

11. Can a schedule be modified after being generated?
    Y (Use Case, Use Case Diagram, Activity Diagram)

12. Do employees required specific skills?
    N (Class Diagram)

Transfer Task Questions and Answers: EntertainCo. Event Case.
(note: answers are sample answers only. The lists are not intended to be comprehensive)

Question 1:
Suppose that an employee was available to work on a Saturday but they were not scheduled to work. How could this have occurred? (Provide as many possible suggestions as you can think of).

Answers
1. The employee does not have the correct skills.
2. Staffing requirements did not need that many people (some left out).
3. Employee has worked too much this week.
4. There was no event on Saturday.
5. A mistake was made by human resources.
6. Employee data not up-to-date.
7. Employee did not submit in availability information.
8. Large number of staff available on Saturday.
9. Hours of availability restricted on Saturday.
10. Incorrect availability submission.
11. Event cancellation or change.
12. Has worked up to his limit in hours.
13. The start of the Saturday event was less than 12 hours from the end of the last shift.

Question 2:
Suppose that it is a very busy two weeks for the sport complex with events scheduled for every day of the week. What problems might be encountered due this busy schedule. (Provide as many possible suggestions as you can think of).

Answers
1. Scheduling conflicts.
2. Not enough employees for staffing.
3. Complex setup problems (ice to basketball).
4. Time needed to clean.
5. Might run out of supplies.
6. Crowding entertainers (not enough change rooms).
7. Time needed to create and adjust deployment sheets.
8. Impossible to extend events.
9. Hard to find employees at short notice in case of emergency.
10. Marketing manager may have trouble scheduling events.
11. Overtime for employees.
12. Audience may be too small or too big.
13. Weather causes delay.

Question 3:

Suppose that a promoter underestimated the number of people who wanted to attend a event. The promoter now wants to increase the number of seats available for an event which results in an updating seating plan. Given that there are some seats that could be opened, what problems would be created by this request? (Provide as many possible suggestions as you can think of).

Answers
1. Extra tickets must be sold.
2. Staffing requirements may have to change.
3. Informing operations manager and providing adequate time for changes.
4. Promoter must provide new seating plan.
5. Deployment sheets have to change.
6. Staff schedule has to change (more employees required).
7. Cost increase due to overtime.
8. Employees added to schedule need notification.
9. Not enough employees.
10. Need to provide extra supplies.
11. Conflict with following event.
12. Confusion during seating.

Question 4:
Assume that the marketing department, operations department (where the Event Manager works), and the human resources department act independently of each other. What problems might occur if the departments do not share their information quickly or work closely with the other departments? (Provide as many possible suggestions as you can think of).

Answers
1. Marketing schedules events that don't fit in complex.
2. Operations may under /overstaff an event.
3. HR department may not provide correct number of workers.
4. HR department may provide workers with the wrong skill.
5. HR department may hire the wrong skill type.
6. HR does not have deployment sheet to create staff schedule.
7. Departments may not be working with up-to-date information since they are unaware of
1. updating process.
8. More expenses may be incurred by lack of communication.
9. Operations may start working on staffing requirements, even if event is not yet accepted.
10. Employees may be scheduled for an event that has been cancelled.
11. An event that cannot be staffed may not be cancelled in time.
12. Staff schedule may not reflect last minute changes.
13. Marketing may not give information regarding events to operations, so no deployment sheet is created.

Appendix 2-C: Sample screen captures of software developed for the experiments

Login/Welcome Screen

Pre-test Task

Training Video
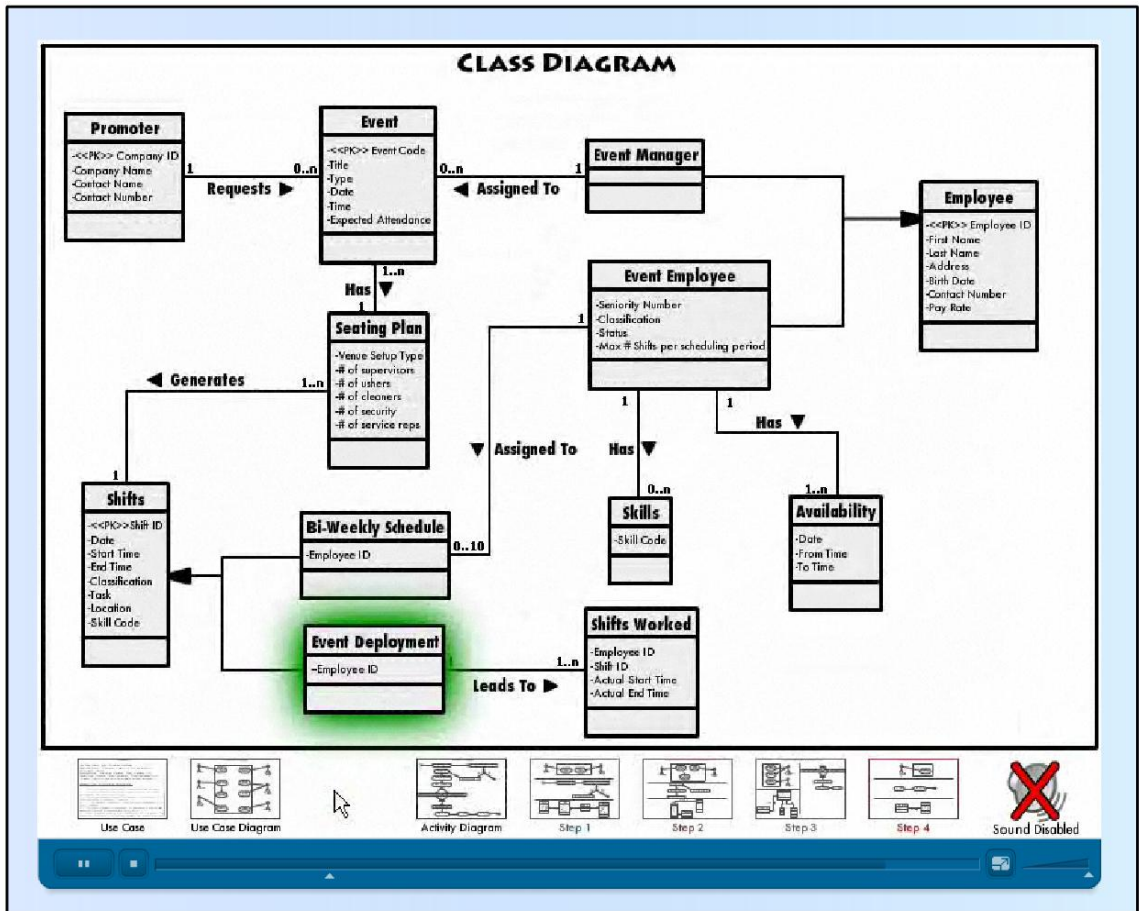
Video that describes the case and diagrams

Recognition Task User interface

RECALL

Using what you have learned about EntertainCo., please write down an explanation of how the company operates.

5 SECONDS LEFT

Next

Recall Task

Suppose that an employee was available to work on a Saturday but they were not scheduled to work. How could this have occurred? (Provide as many possible suggestions as you can think of).

Problem Solving (Transfer) Task