The Effects of Business Process Management Cognitive Resources and Individual Cognitive Differences on Outcomes of User Comprehension

by

Bret R. Swan

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
In partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Industrial and Systems Engineering

Dr. Eileen M. Van Aken (Chair)
Dr. Steven E. Markham (Co-Chair)
Dr. C. Patrick Koelling
Dr. Tonya Smith-Jackson
Dr. David P. Tegarden

March 26, 2007
Blacksburg, Virginia

Keywords: Business Process Management (BPM), BPM Systems, Business Process Modeling, Enterprise Modeling, Graphical Process Models, Tacit Knowledge, Explicit Knowledge, Metagraphs, UML, User Comprehension, Ontological Completeness

E x t e n d e d   A b s t r a c t

The Effects of Business Process Management Cognitive Resources and User Cognitive Differences on Outcomes of User Comprehension

by

Bret R. Swan

EXTENDED ABSTRACT

There is a growing need to study factors that affect user comprehension of Business Process Management (BPM) information portrayed by graphical process models (GPMs). For example, deployment of BPM Systems, unique types of enterprise-level information systems, has dramatically increased in recent years. This increase is primarily because BPM Systems give a variety of managers across an enterprise the ability to directly design, configure, enact, monitor, diagnose, and control business processes that other types of enterprise systems do not. This is possible because BPM Systems uniquely rely on GPMs derived from formal graph theory. Besides controlling the business processes, these GPMs, such as metagraphs and Unified Modeling Language (UML) diagrams, portray business process information (BPI) and prompt BPM managers to apply their training and expertise to deal with BPM situations. As a result, GPMs are the primary information artifacts for decision-making and communication among different, often geographically dispersed stakeholders.

Therefore, user comprehension of these unique GPMs is critical to the efficient and effective development, deployment, and utilization of BPM Systems. User comprehension outcomes are jointly affected by the (1) BPM cognitive resources available to each manager (including the type of GPM, BPI, and user educational training and experience), and (2) cognitive differences between individual BPM managers (such as their mental workload, cognitive styles and cognitive abilities). Although research has studied GPMs in various contexts, there is apparently no empirical research investigating GPM user comprehension in the context of BPM Systems. This research makes an important contribution by addressing this gap in the literature.

Statement of the Objective

The purpose of this research is to empirically study how BPM cognitive resources and cognitive differences between individuals affect outcomes of GPM user comprehension. This research centered on the following objectives:

A. Investigate whether more positive user comprehension outcomes are produced by novice users if a single GPM technique is used to portray different types of BPI (e.g., as with metagraphs) or if different GPM techniques are used to portray different types of BPI (e.g., as with UML diagrams).

B. Investigate whether one type of BPI is more easily comprehended and interpreted by novice users irrespective of the type of GPM or the type of educational training of the user.

C. Investigate whether users with a specific type of user educational training can more easily comprehend and interpret BPM information irrespective of the type of GPM or the type of BPI.

D. Evaluate influences of individual cognitive differences (i.e., mental workload, cognitive styles, and cognitive abilities) on outcomes of user comprehension.

In order to accomplish these objectives, this study: (a) defined a theoretical framework conceptualizing user comprehension outcomes in terms of the interaction between cognitive resources external to the user and individual differences affecting how users cognitively process BPI, (b) empirically tested an operational research model of GPM user comprehension that is based on the theoretical framework, and (c) interpreted the experimental results in the context of related literatures.

Description of Research Methods

This study empirically tested relationships between several variables representing BPM cognitive resources and individual cognitive differences hypothesized as influencing the outcomes of user comprehension. A laboratory experiment, involving 87 upper-level undergraduate students from two universities, analyzed relationships between participant comprehension of two types of GPMs (i.e., metagraphs and UML diagrams) used to portray three types of BPI (i.e., task-centric, resource-centric, and information-centric BPI) by novice GPM users possessing different educational training (i.e., industrial engineering, business management, and computer science training). Dependent variables included assessments of task accuracy, task timeliness, subjective mental workload, and self-efficacy. Covariate effects were also analyzed for two types of participant cognitive abilities (i.e., general cognitive ability (GCA) and attentional abilities) and two types of participant cognitive styles (extroversion-introversion and sensing-intuitive). Multivariate analysis techniques were used to analyze and interpret the data.

Discussion of Results

The type of GPM and participants' GCA produced significant effects on the dependent variables in this study. For example, metagraph users produced significantly more desirable results than UML users across all dependent variables, contrary to what was hypothesized. However, if only the BPM cognitive resources (i.e., GPM Type, BPM Type, and the Type of Participant Education) were studied in relation to user comprehension outcomes, spurious conclusions would have been reached. When individual cognitive differences were included in the research model and analyses, results showed participants with higher GCA produced significantly more positive user comprehension outcomes compared to participants with lower GCAs. Also, many of the impacts of differences in the types of BPI and the types of UET were moderated by the differences in participants' GCA and attentional abilities. In addition, the relationship between subjective mental workload and task performance (i.e., accuracy and timeliness) suggest a possible GPM cognitive 'profile' for user comprehension tasks in a BPM Systems context. These results have important implications for future research and practice in several bodies of knowledge, including GPM user comprehension in management systems engineering, BPM modeling, BPM Systems, HCI, and cognitive ergonomics literature.

ACKNOWLEDGEMENTS

Meaning no disrespect to the many people that have given me so much help in completing this dissertation, but the most important person that has made this dissertation possible is my wife Niki. She is the brightest light in my life and has sacrificed so much to make this possible. I can never repay her for her hard work, encouragement, and sacrifices.

Next, I want to acknowledge the sacrifices of my children, Trent, Tauna, and Kinley, who have given up so much of their time they wanted to spent with me. They have boosted my faith and encouraged me on numerous occasions when I wanted to quit, but the simple faith of my children has sustained me and Niki at times I didn't expect. I am also grateful to them for the times they tried to pick up the slack around the house to make life easier on their mom and I during times that I was away.

I want to specifically give a special and heart-felt thank you to Dr. Eileen M. Van Aken, the chair of my dissertation committee, for the years of friendship and support, especially because she has mentored, guided, and encouraged me in pursuing my research interests. She is an excellent example of dedication, hard work, perseverance, support, and, most importantly, my life-long friend.

In terms of life-long friends and mentors, there are none more important to me than my Dissertation Committee Co-Chair, Dr. Steven E. Markham. For a decade, he has encouraged me, taught me, and given me great consulting and research experiences that have determined the direction of my career. I cannot express how grateful I am to Dr Markham.

I also wish to express my gratitude for the support, encouragement, and friendship of my committee members: Dr Tonya Smith-Jackson, Dr. David Tegarden, and Dr. C. Patrick Koelling. I have learned so much from each of you, both professionally and personally, and look forward to our ongoing associations.

I also don't know how to express my love and gratitude to my sister, Shanae Dee Branham, for her years of believing in me, encouraging me, mentoring me in my writing, and editing this dissertation for me. She has helped open my eyes to my potential. She is a great example and is truly inspiring to me.

I would be amiss if I did not also acknowledge the support, love, and counsel of my father, Gary Swan, who has always been there for me to help me keep going when I was at the end of my energies and did not know how to proceed.

I also want to acknowledge and thank Dee and Marylou Whittier, James and Linda Evans, and Scott and Joyce Hendricks for taking me into their families and supporting me through my ups and downs during my years at Virginia Tech.

Additionally, I am grateful for Don Colton, Department Chair of Information Systems, and Bret Ellis, Dean of the School of Computing, at Brigham Young University in Hawaii for their continuous encouragement and support as I completed this dissertation.

Last, but not least, Clint and Lesley Arnoldus, my in-laws, have made great sacrifices, encouraged me, and supported my family in such tremendous ways that have made it possible for me to finally complete this dissertation.

I cannot express the gratitude I feel or repay the friendship and support for me and my family that all of you have given, both named and unnamed. Thank you.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

C h a p t e r   O n e

CHAPTER 1 - INTRODUCTION AND SCOPE OF THIS RESEARCH

This chapter introduces the topic of this research: the study of the extent to which graphical process models (GPMs) facilitate user comprehension of Business Process Management (BPM) cognitive resources despite cognitive differences between individuals. First, this chapter summarizes the context and need for GPM user comprehension research related to BPM and BPM Systems. Next, the research objectives, questions, and hypotheses are presented. Lastly, this chapter outlines the research model, research methodology, and contributions of this study to related literatures.

1.1 PROBLEM STATEMENT

Dynamic business environments and an increasing reliance on BPM Systems are driving the restructuring of enterprises around knowledge-intensive business processes. BPM Systems are unique types of enterprise-level information system that are based on and driven by GPMs derived from formal graph theory. These distinctive GPMs give users of BPM Systems the ability to cross-functionally understand, manage, control, and reconfigure business processes from across an enterprise without having to rely heavily on information technology (IT) personnel. There is apparently no research investigating whether BPM managers, with differing educational training and experience, can efficiently and effectively comprehend the business process information (BPI) portrayed by these types of GPMs. Without accurate and timely user comprehension of BPI portrayed by these GPMs, BPM decision-makers may not be able to properly manage and adapt the business processes that create and sustain a competitive advantage in today's dynamic organizations and markets. Therefore, empirical research is needed that takes into account key BPM cognitive resources and individual cognitive differences affecting GPM user comprehension in the context of BPM and BPM Systems.

1.1.1 Trends Have Changed the Focus of Enterprises to Business Processes

The term business process refers to the sets of value-adding tasks that convert specified inputs to outputs for an internal or external customer or market (Crowston, 1997; Davenport & Beers, 1995; Hammer

& Champy, 2003; Malone, Crowston, & Herman, 2003; Schael, 1998). BPM refers to the practices and technologies used to manage business processes (Smith & Fingar, 2003; Wolf & Harmon, 2006).

Recent market forces and organizational trends are shifting the focus of many business enterprises to reorganize themselves around their business processes, as opposed to hierarchal forms of organization (Crowston, 1997; Hammer, 1996; Smith & Fingar, 2003; Wensley, 2003; Weske, van der Aalst, & Verbeek, 2004). Examples of such trends include E-business (Lowry, Cherrington, & Watson, 2002), E-commerce (Turban, King, Lee, Warkentin, & Chung, 2002), fast-response micromarketing (Basu & Blanning, 2000), reengineering (Hammer & Champy, 2003), outsourcing (Marc, 2005), agile manufacturing (Basu & Blanning, 2000), knowledge management (KM) (Apostolou & Mentzas, 2003), supply chain management (SCM) (Serve, Yen, Wang, & Lin, 2002), customer relationship management (CRM) (Chen & Popvich, 2003), enterprise architectures (Vernadat, 2002), workflow management (zur Muehlen, 2004b), and virtual enterprises (Goranson, 1999). These trends make business processes, as well as the management of these processes, more dynamic and knowledge-intensive than in the past (Eppler, Seifried, & Ropnack, 1999; Markus, Majchrzak, & Gasser, 2002; Osborn, 1998; Weske et al., 2004). As a result, business processes have come to be characterized as more or less knowledge-intensive depending on the stable or dynamic natures of both the business processes and their associated knowledge resources (1998).

As a result of this recent shift in focus, new types of enterprise-level information systems have been developed to help organizations manage their knowledge-intensive business processes more efficiently and effectively. Examples of such enterprise systems include Enterprise Resource Planning (ERP) systems, Supply Chain Management (SCM) systems, workflow management systems, and BPM Systems (Vernadat, 2002; Weske et al., 2004; zur Muehlen, 2004b). This study centers on the comprehension of BPI portrayed in BPM Systems. BPM Systems are unique from other enterprise systems in that they allow "BPM process owners armed with business process management orchestration tools [the ability to] change process and information flows using graphically based tools with little or no involvement of the traditional IT department" (Light, 2005, p. 1).

1.1.2 Prevalence of BPM Systems

In recent years, the development and implementation of BPM Systems have become essential to keep organizations and enterprises competitive in current market environments (Light, 2005; Wensley, 2003; Weske et al., 2004). Miers, Harmon, and Hall (2006) in their 2006 "BPM Suites Report" described 19 difference BPM Systems currently used in industry:

- ACI Worldwide: WorkPoint (formerly Insession)
- Appian Corp.: Appian Enterprise
- Ascentn Corporation: AgilePoint
- B2Binternet: XicoBPM
- Chordiant: Chordiant Enterprise Platform
- Clear Technology Inc.: Tranzax
- CommerceQuest Inc.: TRAXION Enterprise Business Process Management Suite
- eg Solutions Ltd.: eg work manager
- FileNet Corp.: FileNet Business Process Manager
- Global 360 Inc.: Global 360 Enterprise BPM Suite
- Graham Technology: GT Product Suite
- HandySoft Global Corporation: BizFlow
- IBM: IBM WebSphere BPM Suite
- M1 Global Solutions Inc.: Business Convergence Suite
- Oracle Corporation: BPEL Process Manager
- PegaSystems Inc.: Pegasystems SmartBPM Suite
- Singularity: Singularity Process Platform
- TIBCO Software Inc.: TIBCO Staffware Process Suite
- Ultimus Inc.: Ultimus BPM Suite

Practitioner literature describes how the adoption of BPM Systems has increased substantially over the last several years. The Delphi Group found that early adopter deployments of these advanced BPM Systems more than doubled between 2001 and 2003 (indicated by 20% of respondents using BPM systems in 2003 compared to less than 10% in 2001) (Palmer, 2003). A 2004 Forrester Research study found that a third of U.S. companies were either using or piloting BPM Systems (Crosman, 2004). In 2006, Wolf and Harmon's (2006, p. 24) "State of BPM Report" surveyed 348 respondents that represented a broad cross-section of large, medium, and small companies of industries from around the world, and found:

> "Ninety percent (90%) of small companies are spending under $500,000 on BPM. Sixty percent (60%) medium sized companies are spending under $500,000, 23% are spending between $500,000 and $999,999, and 15% are spending between $1 and $5 million. Thirteen respondents described large companies that they said were spending over $10 million on [BPM Systems]."

The Gartner Group, a leading industry research organization, predicted that by the year 2015 (Light, 2005, p. 1):

> "A significant shift will occur to embrace process-focused mind-sets toward managing the business. There will be an explosion of interest in business process management suites and their integration with underlying software infrastructure."

These statistics reflect a growing industry recognition that competitive advantages can be achieved through an end-to-end, enterprise-level focus on BPM supported by BPM Systems (Basu & Kumar, 2002; van der Aalst, 2004; Weske et al., 2004). Trends promoting BPM and BPM Systems will continue as long as organizations attempt to respond to the increasingly dynamic natures of their business processes and environments in the new networked economy (Aguilar-Saven, 2004; Osborn, 1998; Sheth, van der Aalst, & Arpinar, 1999).

1.1.3 BPM Systems Facilitate Knowledge-Intensive BPM

BPM Systems help facilitate the management of knowledge-intensive business processes using GPMs. *BPM Systems* are "generic software systems driven by explicit process models [that] enact and manage operational business processes" (Weske et al., 2004, p. 1). The explicit process models (i.e., GPMs) that drive BPM Systems are unique because they are derived from graph theory formalisms. Because these GPMs are based on graph theory, they make BPM systems "process-aware," meaning they permit mathematical modeling that facilitates the management and control business processes in ways that other enterprise systems cannot (Basu & Blanning, 2000; Curtis, Kellner, & Over, 1992). Several formal GPM techniques have been developed or extended to be used in BPM Systems: for example, Petri nets (van der Aalst, 2000), and metagraphs (Basu & Blanning, 2000), and Unified Modeling Language (UML) diagrams (Vernadat, 2002).

According to BPM, knowledge management, and information systems (IS) literature, the management of knowledge-intensive business processes involve both tacit and explicit knowledge. *Explicit knowledge* is knowledge that can be codified and transmitted in a systematic and formal representation or language (such as GPMs) (Gronau & Weber, 2004; Ramesh & Tiwana, 1999). In contrast, *tacit knowledge* is knowledge that is difficult to formalize, record, articulate, or encode because it is developed through personal experimentation and experience (Gronau & Weber, 2004; Markus et al., 2002; Ramesh & Tiwana, 1999).

Both individuals and information artifacts possess or store tacit and explicit knowledge for future use (Amaravadi & Lee, 2005; Davenport & Beers, 1995; Eppler et al., 1999; Madhavan & Grover, 1998).

Individuals (e.g., process managers, executives, and IT managers) possess both tacit and explicit knowledge in their memories. *Information artifacts* (also referred to as IT artifacts) are "those bundles of material and cultural properties packaged in some socially recognizable form such as hardware and/or software" (Orlikowski & Iacono, 2001, p. 121) that store and portray explicit knowledge to users (e.g., email, databases, documents, information systems, and GPMs) (Basu & Blanning, 2000; Hollan, Hutchins, & Kirsh, 2000).

Therefore, in this study, the information artifact of interest is the type of GPM used to portray BPI in BPM Systems. BPM Systems facilitate knowledge-intensive BPM because they (1) provide access to required BPI, (2) facilitate the communication and transfer of BPM knowledge between managers across an enterprise, and (3) provide direct control and reconfiguration of BPM Systems[1]. For example, transformation of BPM knowledge from individuals and information artifacts into efficient and effective BPM decisions is accomplished through the user comprehension of two types of BPM knowledge. Managers comprehend the explicit BPM knowledge, e.g., the type of BPI needed for a specific task, portrayed by the information artifacts, i.e., the GPMs, using the BPM System. Managers use their tacit BPM knowledge, e.g., the educational training of the user, as they comprehend the GPMs (Gronau & Weber, 2004; Markus et al., 2002; Sampler & Short, 1998). The decisions made by BPM managers are then enacted and implemented, in part, using BPM Systems (Basu & Blanning, 2000; Basu & Kumar, 2002; van der Aalst, Desel, & Oberweis, 2000; Weske et al., 2004; zur Muehlen, 2004b).

1.2 GPM User Comprehension in the Context of BPM Systems

In this study, the term *cognition* refers to mental processes that involve perception, thinking, memory, and action (van Duijn, Keijzer, & Franken, 2006). User comprehension is one aspect of cognition (Just & Carpenter, 1992), and in this study, refers to the ability of an individual to grasp the meaning of something (Agarwal, De, & Sinha, 1999; Just & Carpenter, 1992; Kintsch, 2005). User comprehension outcomes are the result of the mental processes (e.g., reasoning, intuition, or perception) of cognitive resources (i.e., information, knowledge, and experience). User comprehension outcomes are assessed in several ways, including task performance indicators (e.g., accuracy and timeliness) and the mental workload individuals experience during task performance (cf. Kintsch, 1988; Nordbotten & Crosby, 1999; Shoval,

[1-1] See Section 2.1.2 for more information about BPM Systems.

Danoch, & Balabam, 2004). Self-efficacy refers to peoples' perceptions their own capabilities to organize and execute tasks up to the level of performance that is required of them (Bandura, 1986), and is considered an outcome of user comprehension, as well as an antecedent of task performance (Compeau, Higgins, & Huff, 1999; Staples, Hulland, & Higgins, 1999).

1.2.1 BPM Cognitive Resources Affecting User Comprehension

The above overview of BPM Systems-related literature identify three types of BPM cognitive resources: (1) the information artifact represented by the type of GPM, (2) explicit BPM knowledge represented by the type of BPI, and (2) tacit BPM knowledge represented in this study by the type of educational training of the user. For BPM to occur, managers cognitively process these three resources to produce user comprehension outcomes..

This study compares two types of GPMs proposed for use in BPM Systems: Unified Modeling Language (UML) diagrams (Eriksson & Penker, 2000; Marshall, 2000; Vernadat, 2002) and metagraphs (Basu & Blanning, 2000)[2]. These two GPM techniques were chosen for this study for several reasons. First, they have both been specifically developed or extended for use in BPM Systems. Second, UML diagrams are becoming the standard GPM technique for development of enterprise systems. Metagraphs have been developed to specifically counter the weaknesses of UML diagrams for user comprehension. Lastly, these techniques clearly match the criteria to test the principle of Ontological Completeness (see Sections 1.1.3, 2.3.1.1, and 2.3.1.4 for further discussions).

Three different types of BPI are of interest in this study: (1) task-centric BPI that documents the sequential flow of business process activities; (2) resource-centric BPI that depicts relationships between resources (i.e. physical, personnel, or information resources); and (3) information-centric BPI[3]. Prior research shows various views or perspectives are required to model all the real-world constructs needed for BPM (Basu & Blanning, 2000; Green & Rosemann, 2000; van der Aalst, 2004; Vernadat, 2002). Previous research agrees that the three BPI perspectives chosen for this study are required in all BPM systems. These three types of BPI exist in both metagraph and UML diagram formats, and are designed to define critical BPM information flows, data relationships, and aid in checking completeness and correctness of models of

[1-2] For examples of different Types of GPMs see section 2.3.1.

[1-3] For examples of different Types of BPI see section 2.3.2.

the business process (Basu & Blanning, 2000; Vernadat, 2002) (see Sections 1.1.3 and 2.3.2 for further discussions).

Lastly, this study operationalizes the tacit BPM knowledge of managers using participants with industrial engineering, computer science, and business management types of user educational training. As discussed above, BPM Systems are expected to support the BPM needs of a variety of managers across the enterprise, including executive managers, process managers, and IT managers. Participants with business management education are selected to approximate executive managers' tacit BPM knowledge. Participants with industrial engineering education are selected to approximate process managers' tacit BPM knowledge. Lastly, participants with computer science education are selected to approximate the education of IT managers' tacit BPM knowledge (see Section 1.1.3 and 2.3.3 for further discussions).

1.2.2 Individual Cognitive Differences Affecting User Comprehension

Literature related to user comprehension identify several individual differences that affect user cognition. Three of the most commonly-studied individual cognitive differences include mental workload, cognitive styles and cognitive abilities.

When the cognitive resources used as inputs to an individual's mind approaches or exceeds the limits of the individual's cognitive capacity, the *mental workload* the individual experiences is increased (cf. Baddeley, 2003; Braarud, 2001; Miyake, 2001; Paas, Tuovinen, Tabbers, & Van Gerven, 2003). Psychological and subjective assessments of mental workload are found in related literature. This study uses assessments of subjective mental workload as an indicator of how taxing the process of GPM user comprehension is on individuals as they mental process BPM cognitive resources.

Cognitive styles are often described as different genetically-based dimensions of human personality (Gardner & Martinko, 1996; Myers & Myers, 1995) as well as "consistent individual differences in preferred ways of organizing and processing information and experience" (Sadler-Smith, 2001, p. 610). Two cognitive styles are identified from related literature as important to in this study: (1) how users prefer to interact with the world around them (i.e., assessed using subjective reports of extroversion vs. introversion preferences) and (2) how users prefer to perceive information (i.e., assessed using subjective reports of sensing vs. intuition preferences) (Gardner & Martinko, 1996; Myers & Myers, 1995).

A *cognitive ability* refers to an individual's ability to learn (Schmidt, 2002) or what Woltz (2003) calls cognitive processes that represent an individual's aptitudes for learning. Cognitive abilities act as the set of mental tools an individual uses to control or manage their cognitive processing of information when performing a task (Goldstein, Yusko, & Nicolopoulos, 2001; Hartmann, Sunde, Kristensen, & Martinussen, 2003; Schmidt, 2002; Woodcock, 2002). An individual's cognitive abilities are much more effected by experience and practice than an individual's cognitive styles. Two evaluations of participants cognitive abilities are included in this study: (1) a broad measure of a participant's cognitive abilities evaluating their ability to learn (i.e., General Cognitive Abilities (GCA)) and (2) an assessment of how well a participant can focus their attention during GPM user comprehension tasks (i.e., their attentional abilities). General Cognitive Abilities (GCA) represent a survey of a range of narrow cognitive aptitudes (e.g., numerical aptitude, spatial aptitude, verbal aptitude, etc.) (Schmidt, 2002; Woodcock, 2002). Attentional abilities assess an individual's ability to focus their attention under different task conditions (Crawford, Brown, & Moon, 1993; Rose, Murphy, Byard, & Nikzad, 2002; Woltz, Gardner, & Gyll, 2001).

1.2.3 The Need for GPM User Comprehension Research in the Context of BPM Systems

GPMs are expected to facilitate user comprehension of different types of BPI irrespective of the background and expertise of the BPM managers using a BPM System (Basu & Blanning, 2000; Light, 2005; Weske et al., 2004; zur Muehlen, 2004a). Without accurate and timely comprehension of the BPI portrayed by GPMs, BPM managers may not be able to properly manage and adapt their business processes to create and sustain a competitive advantage in today's dynamic organizations and markets (Crosman, 2004; van der Aalst, ter Hofstede, & Weske, 2003; Weske et al., 2004).

Although research has studied GPMs in various contexts, there is apparently no research in BPM, BPM Systems, information systems, enterprise modeling, Human-Computer Interaction (HCI), cognitive ergonomics, and cognitive psychology literature that empirically investigates GPM user comprehension in the context of BPM Systems. While related literature contains some empirical GPM user comprehension in various contexts, such as requirements analysis and general information visualization, no empirical research was found on the topic of this study. Additionally, no user comprehension research was found that has been guided by a theoretically-based framework that integrates the cognitive resources and the individual cognitive differences of interest in this study. Therefore, this empirical study begins to address several needs in related literature by proposing a theoretical framework for GPM user comprehension and then testing this framework through the use of a experimental research methodology.

1.3 RESEARCH PURPOSE AND OBJECTIVES

The purpose of this research is to empirically study how BPM cognitive resources and cognitive differences between individuals affect outcomes of GPM user comprehension in the context of BPM Systems. Consequently, this study seeks to accomplish the following research objectives:

A. Investigate whether more positive user comprehension outcomes are produced by novice users if a single GPM technique is used to portray different types of BPI (e.g., as with metagraphs) or if different GPM techniques are used to portray different types of BPI (e.g., as with UML diagrams).

B. Investigate whether one type of BPI is more easily comprehended and interpreted by novice users irrespective of the type of GPM or the type of educational training of the user.

C. Investigate whether users with a specific type of user educational training can more easily comprehend and interpret BPM information irrespective of the type of GPM or the type of BPI.

D. Evaluate influences of individual cognitive differences (i.e., mental workload, cognitive styles, and cognitive abilities) on outcomes of user comprehension.

In order to accomplish these objectives, this study: (a) defined a theoretical framework conceptualizing user comprehension outcomes in terms of the interaction between BPM cognitive resources external to the user and individual differences affecting how users cognitively process BPI, (b) empirically tested an operational research model of GPM user comprehension that is based on the theoretical framework, and (c) interpreted the experimental results in the context of related literature.

1.4 RESEARCH QUESTIONS

This study addresses the following research questions (RQs):

RQ1: How do different types of GPM influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?

RQ2: How do different types of BPI influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?

RQ3: How do different types of user educational training influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?

RQ4: When interpreting graphical business process information, does the relationship between user subjective mental workload and task performance follow the Yerkes-Dodson Law (an inverted-U relationship)?

RQ5: When interpreting graphical business process information, how does user subjective mental workload relate to their self-efficacy after task completion?

RQ6: How do user cognitive styles affect the subjective mental workload they experience when interpreting graphical business process information?

RQ7: How do user general cognitive abilities affect the subjective mental workload they experience when interpreting graphical business process information?

RQ8: How do user attentional abilities affect the subjective mental workload they experience when interpreting graphical business process information?

1.5 OPERATIONAL RESEARCH MODEL

The research model shown in Figure 1-1 relates the variables of interest in this study based on related literature. Drawing on BPM, HCI, cognitive ergonomic, cognitive psychology, and user comprehension research, this study investigates the relationships between three BPM cognitive resources cognitive resources and individual cognitive differences that hypothetically affect GPM user comprehension task performance, mental workload, and self-efficacy outcomes. In this experiment, BPM Systems are conceptualized as portraying explicit BPM knowledge (operationalized as different types of BPI) using its primary information artifact, the GPM. Additionally, users also possess different types of tacit BPM knowledge (operationalized as the type of user educational training) that participants draw on during GPM user comprehension tasks. As participants mentally process BPM cognitive resources, their cognitive styles and cognitive abilities impact GPM comprehension; resulting in differences in the mental workload participants experience during GPM user comprehension. Task performance (i.e., accuracy and timeliness) and self-efficacy outcomes are also hypothesized to be affected by the mental workload participants experience during the GPM user comprehension.

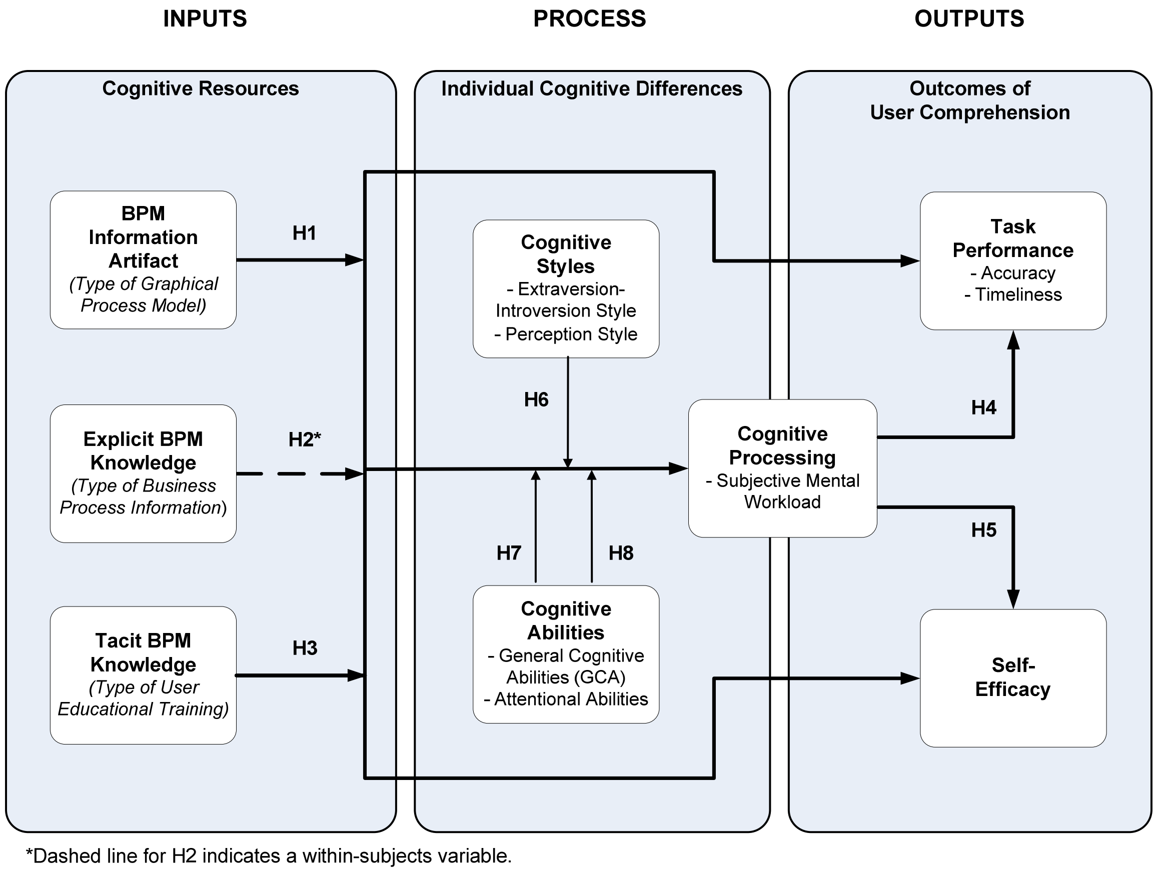


Figure 1-1. Operational Research Model for testing GPM user comprehension in the context of BPM and BPM Systems.

1.6 RESEARCH HYPOTHESES

These research questions and variables of interest were operationalized into the following hypotheses (illustrated in Figure 1-1):

Hypothesis 1: The type of graphical process model will significantly affect participants' task performance (i.e., accuracy and timeliness), subjective mental workload and self-efficacy.

Hypothesis 2: The type of business process information will significantly affect participants' task performance (i.e., accuracy and timeliness) and subjective mental workload[4].

[1-4] *Self-efficacy* was not measured within-subjects so it is not included in this hypothesis.

Hypothesis 3: The type of User Educational Training of participants will significantly affect participants' task performance (i.e., accuracy and timeliness), subjective mental workload, and self-efficacy.

Hypothesis 4. Participants' subjective mental workload will significantly affect task performance (i.e., task accuracy and timeliness) in inverted-U relationships (in accordance with the Yerkes-Dodson Law).

Hypothesis 5: Participants' subjective mental workload will significantly and negatively affect self-efficacy results.

Hypothesis 6: Participants' cognitive styles will significantly affect the subjective mental workload they experience during task performance.

Hypothesis 7: Participants with high general cognitive abilities will experience significantly lower subjective mental workload.

Hypothesis 8: Participants scoring high on attentional abilities will experience significantly lower subjective mental workload during task performance.

A detailed discussion of the rationale for the proposed theoretical framework and development of these hypotheses[5] is discussed in Chapter 2.

1.7 Overview of the Research Methodology

In this experiment, data were collected using a 2 (GPM) x 3 (UET) x 3 (BPI) factorial design, with repeated measures on the third variable, the type of BPI. These data were analyzed using three-way mixed MANOVAs that included two between-subjects variables (the type of GPM and the type of user educational training (UET)) and one within-subjects variable (the type of BPI). Dependent variables assessed included user comprehension accuracy, timeliness, subjective mental workload, and self-efficacy. Additionally, the effects of the following moderating variables were statistically controlled for: general cognitive abilities (GCA), attentional abilities, extroversion-introversion cognitive style, and perceptual cognitive style (i.e., sensing-intuition).

The total sample size was 87 participants. The participants were third and fourth year university students majoring in Industrial Engineering (IE), Business Management (MGT), and Computer Science (CS) at a large southeastern U.S. university and a small U.S. university in Hawaii. Each group of

[1-5] Several sub-hypotheses are discussed in Chapter 2.

participants, that possessed different types of educational training, were presented with different treatment combinations of the types of GPM and BPI manipulated according to the experimental treatment and assessment strategy (see Section 3.5). Assessments of participants' cognitive styles were made using the Myers-Briggs Type Indicator (MBTI) (Myers, McCaulley, & Most, 1985). Assessments of participants' cognitive abilities were made using the Wonderlic Personnel Test (WPT) (Dodrill, 1981) and the Differential Attentional Processes Instrument (DAPI) (Grumbles & Crawford, 1981). Experimental treatments, as well as assessments of participants' cognitive styles and cognitive abilities, were analyzed in relation to task accuracy (assessed as the percent of correct answers on a task questionnaire), task timeliness (assessed by a stopwatch as time on task), subjective mental workload (assessed using the NASA Task Load Index [TLX]) (Hart & Staveland, 1988a, 1988b), and self-efficacy (assessed by a questionnaire adapted from an existing computer self-efficacy instrument).

These data were, by definition, multivariate, because the same data set collected on three independent variables were used to analyze the results of four dependent variables. Cell sizes for the between-subject independent variables were unequal, but each contained a minimum treatment cell size of at least twelve participants. Preliminary analyses were conducted to help ensure these data were analyzed and interpreted appropriately (see Appendices M and N). Also, preliminary analyses were conducted to describe data representing each dependent and moderating variable while taking into account the unequal cell sizes and the multivariate nature of the data. Univariate and multivariate statistical techniques were used to analyze data testing the research hypotheses.

More detailed information about the research methodology used in this study is discussed in Chapter 3. The results are detailed in Chapter 4 (see also Appendices N and O). Discussions of the results and conclusions appear in Chapters 5 and 6, respectively.

1.8 CONTRIBUTIONS OF THIS RESEARCH

This study has implications for management systems engineering in BPM and BPM Systems contexts, as well as several related bodies of knowledge including HCI, cognitive ergonomics, and information systems. This study is targeted at the *information portrayal/information perception* interface between the BPM manager and the BPM System in the Management System Model (see Figure 1-2).

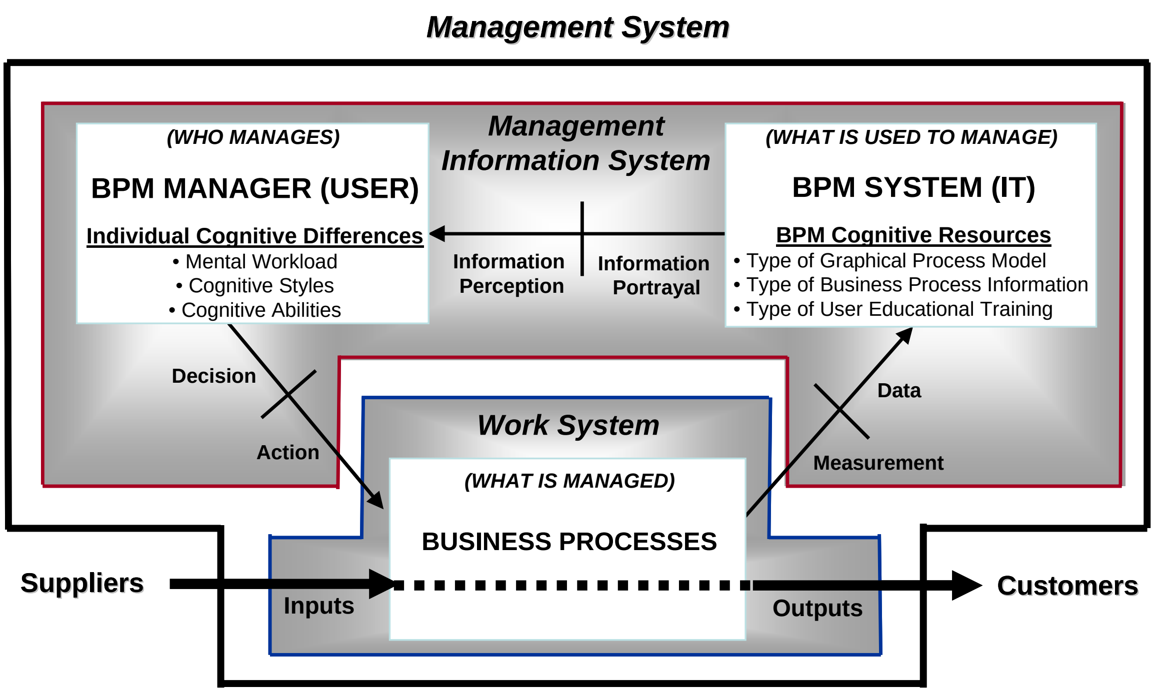


Figure 1-2. GPM user comprehension takes place at the information portrayal/information perception interface between the BPM cognitive resources and the BPM System user[6].

In general, the Management System Model illustrates the management information-flow relationships between the people, technology, and the work system being managed (Kurstedt, 2000). This study refers to a *system* as an assembly or combination of parts that form a complex unifying whole (Blanchard & Fabrycky, 2006) that maintains and functions as a whole through the interaction of its parts (O'Connor & McDermott, 1997). For the purposes of this study, the definition of a *management system* is

[1-6] Adapted from George W. L. Sousa's adaptation of Kurstedt's (2000) Management Systems Model.

adapted to include both a work system and a management information system. A *work system* includes aspects of the organization that actually does the work that produces value for the organization or enterprise, such as value-adding business processes. The *management information system* includes the individuals and IT that gathers, processes, analyzes, portrays, and controls the flow of information used to help managers make decisions and take actions that affect the work system.

The focus of this study is on the management information system that describes the interaction between BPM Systems (the IT) with BPM managers. As a result, this study takes into account the BPM cognitive resources facilitated by BPM systems as well as the individual cognitive differences between managers that affect BPM of an enterprise-level work system. Because GPMs facilitate the interactions between the manager and IT components of the management information system, GPM user comprehension is conceptualized as taking place within the management information system at the *information portrayal/information perception interface* (see Figure 1-2).

Therefore, this study specifically contributes to management systems engineering by adding needed empirical research to the areas of BPM and BPM Systems. Also, this study appears to be one of the first to theoretically integrate and empirically study the major BPM cognitive resources and individual cognitive differences affecting GPM user comprehension in the context of BPM and BPM Systems. This study contributes to the HCI, cognitive ergonomics, and information systems related research by extending empirical GPM user comprehension research to BPM Systems contexts. This study also provides practitioners guidance to aid in GPM design, manager training, and matching BPM user comprehension tasks to individual abilities. This research framework and these results can be used in future studies to compare and interpret past studies, as well as extend and refine future research and practice.

C h a p t e r   T w o

CHAPTER 2 – REVIEW OF LITERATURE

This study explores user comprehension of graphical process modeling (GPM) techniques that are required for the development and operation of business process management (BPM) systems. This research is unique from related literature in three specific ways. First, this research uses a laboratory experimental design to empirically study the effects of variations in three types of BPM cognitive resources (the type of GPM, the type of business process information [BPI], and the type of user educational training [UET]) on four user comprehension outcomes (task accuracy, task timeliness, subjective mental workload, and self-efficacy). Second, this study attempts to account for the moderating effects of cognitive differences between individuals (e.g., user cognitive styles and cognitive abilities) on GPM user comprehension outcomes. Lastly, this study integrates various individual hypotheses from related literatures into a theoretical framework and research model to guide the empirical tests of BPM cognitive resources and individual cognitive differences on GPM user comprehension outcomes.

Despite the fact that BPM Systems have received a large amount of attention in recent years, no theory-based research model was found that incorporated the key BPM cognitive resources and individual cognitive differences pertinent to GPM user comprehension in the context of BPM Systems. The lack of empirical research on GPM user comprehension requires development of a theoretical framework to study this topic. Therefore, using concepts found in Activity Theory and Distributed Cognition Theory as an organizing framework, an operational research model is developed that integrates various research constructs and theory-based relationships from related literature.

This chapter discusses relevant literature used to operationalize this study's eight research questions (RQs) and supports the derivation of the operational research model presented in Chapter 1. Consequently, this chapter serves several purposes:

- Reviews BPM Systems literature and related GPM techniques (Section 2.1).
- Reviews user comprehension research in related literature (Section 2.2).
- Reviews literature relating BPM cognitive resources to user comprehension (Sections 2.3).
- Reviews literature relating individual cognitive differences to user comprehension (Section 2.4).

- Reviews theory used as a framework for integrating impacts of BPM cognitive resources and individual cognitive differences on GPM user comprehension (Section 2.5).
- Summarizes the operational model and research hypotheses that relate the independent, dependent, and moderating variables of interest in this study (Section 2.6).

2.1 BPM SYSTEMS RESEARCH OVERVIEW

This section proceeds by defining knowledge-intensive business processes and their relationship to BPM Systems. Next, unique features of BPM Systems are discussed as well as the need for empirical research. Finally, prior GPM user comprehension research is described in relation to BPM and BPM Systems

2.1.1 Knowledge-Intensive BPM and BPM Systems

In this study. the term *business process* refers to a business process as "the combination of a set of activities within an enterprise with a structure describing their logical order and dependence whose objective is to produce a desired result" (Aguilar-Saven, 2004, p. 129). In other words, a business process is a "sequence of functions that are necessary to transform a business relevant object (e.g., purchase order, invoice)" (Green & Rosemann, 2000, p. 78). For the purposes of this study, business process are categorized as more or less knowledge-intensive depending on whether both the business process and associated knowledge resources are stable or dynamic (Osborn, 1998).

Researchers and practitioners have used the term BPM in different ways. Some authors use BPM to mean Business Process Management, and others prefer Business Performance Management (Wolf & Harmon, 2006). Some authors use the term in a broad way to refer to any business practice or technology used in the management of business processes (Smith & Fingar, 2003), while others use the term more narrowly to refer to the use of software techniques and technologies that manage the runtime execution of business processes (Weske, van der Aalst, & Verbeek, 2004; Wolf & Harmon, 2006). In this study, the term BPM is used broadly to refer to both the practices and technologies used to manage business processes. BPM Systems are an example of what is meant by the latter, more narrow use of the term BPM.

2.1.1.1 Knowledge-Intensity of Business Processes

The management of knowledge-intensive business processes has become a popular topic and an important area of research in recent years; primarily due to advances in information and communication technologies that provide managers with an abundance of BPI (Amaravadi & Lee, 2005; T. H. Davenport & Beers, 1995; Hlupic, 2003). For example, Sampler and Short (1998) review research strategies and laid out an agenda for the study of dynamic, knowledge-intense business environments. Hlupic, Pouloudi, and Rzevski (2002) describe three types of knowledge and business process management issues: hard, soft, and abstract. Markus et al. (2002) describe the management needs of highly dynamic, knowledge-intensive business processes. Eppler et al. (1999) classify business processes in terms of knowledge intensity vs. process complexity. They also categorize different types of BPM knowledge as (a) knowledge about the process, (b) knowledge within the process, and (c) knowledge from the process. Lastly, Gronau and Weber (2004, p. 165) define the knowledge-intensity of a business process by how much of the process value can only be produced by fulfillment of the knowledge requirements of the business process managers.

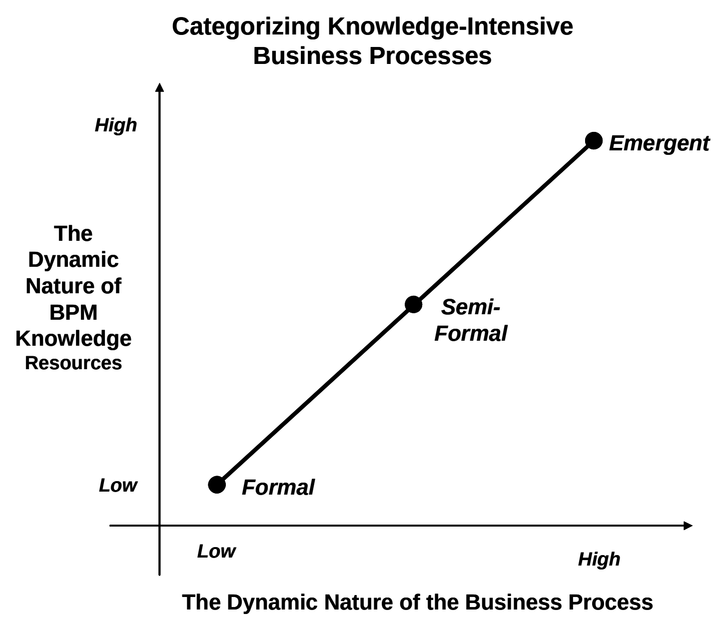


Figure 2-1. Category of knowledge intensity of a business process based on the dynamics of the processes and the knowledge resources.

These studies are based on the idea that business processes can be conceptualized as more or less knowledge-intensive. By integrating the concepts in these studies, the relationship between BPM knowledge resources and business processes result in the categorization of business processes as either formal, semi-formal, or emergent (see Figure 2-1) (Eppler et al., 1999; Gronau & Weber, 2004; Markus et al., 2002; Osborn, 1998):

- A <u>formal business process</u> is defined as relatively stable and explicitly definable (such as a manufacturing assembly process or a financial audit process). A formal business process does not change frequently. As a result, explicit BPM knowledge (such as BPI portrayed by GPMs) can be more easily automated and documented. Consequently, BPM of a formal business process relies heavily on explicit knowledge. BPM Systems allow the control of formal business processes through the executable GPMs that portray the BPI, which contains explicit knowledge of the business process.
- A <u>semi-formal business process</u> is described as more dynamic than a formal process and can be only partially defined explicitly because of relatively frequent changes to the process (such as a brand management, billing, or management exception handling process). BPM of semi-formal processes require access to more people with relevant tacit knowledge than do formal processes, because the frequency of changes to the process make explicitly documenting the process more difficult. Thus, there tends to be less explicit knowledge of documented BPI available to managers compared to a formal business process. BPM Systems support semi-formal business processes by providing explicit BPI that helps trigger managers' to apply their relevant tacit BPM knowledge. Because of the timely comprehension of explicit knowledge portrayed by BPM Systems, managers are more easily able to communicate and codify their tacit BPM knowledge to make BPM decisions.
- An <u>emergent business process</u> is either highly dynamic or can emerge through creativity of the participants (such as a new product development or strategy-making process). BPM of an emergent business process relies heavily on the tacit knowledge of the managers involved, which cannot be easily documented, because it is highly situational and experience-based. Thus, an emergent process is difficult to support with BPM Systems due to the dynamic nature of the business process and lack of explicit BPM knowledge available for control of an emergent process.

Therefore, BPM Systems are primarily used to support formal and semi-formal business processes.

2.1.1.2 BPM Knowledge Resources Required for Cognition

As discussed briefly in Chapter 1, related literature describes two types of knowledge required for BPM: tacit and explicit knowledge. *Explicit knowledge* is codified and transmitted in a systematic and formal representation or language (Gronau & Weber, 2004; Ramesh & Tiwana, 1999). Examples of explicit knowledge include emails, reports, documentation, and GPMs. In contrast, *tacit knowledge* is difficult to formalize, record, articulate, or encode, because it is developed through personal experimentation and experience (Gronau & Weber, 2004; Markus et al., 2002; Ramesh & Tiwana, 1999). Tacit knowledge includes things such as values, assumptions, beliefs, intuition, knowledge, or wisdom gained from experience that helps individuals recognize and solve problems. Tacit knowledge can be either context-specific or general domain knowledge, but is difficult to codify or communicate without prompting or context-specific stimuli (Gronau & Weber, 2004; Markus et al., 2002; Ramesh & Tiwana, 1999). Several authors describe different types of BPM tacit and explicit knowledge as being embedded in either the process itself, the procedures for managing the process (i.e., explicit knowledge), or the experiences of people managing the process (e.g., tacit knowledge) (Amaravadi & Lee, 2005; Eppler et al., 1999; Madhavan & Grover, 1998).

Tacit and explicit BPM knowledge are found in both individuals and information artifacts. *Individuals* (e.g., BPM process managers, executives, and IT managers) possess both tacit and explicit knowledge in their long-term and working memories. *Information artifacts* represent knowledge in the world that augments and amplifies users' cognition (Norman, 1988, 1993). Information technology (IT) artifacts, also referred to as information artifacts, are defined by Orlikowski and Iacono (2001, p. 121) as "those bundles of material and cultural properties packaged in some socially recognizable form such as hardware and/or software." Thus, information artifacts, such as email, databases, documents, information systems, and GPMs, store and portray explicit BPM knowledge for user comprehension and decision-making (Basu & Blanning, 2000; Hollan, Hutchins, & Kirsh, 2000).

In summary, BPM Systems use GPMs (i.e., the information artifacts) to portray required BPI (i.e., the explicit knowledge) and stimulate managers to apply their educational training and experience (i.e., tacit knowledge) to make BPM decisions. Transformation of these three BPM cognitive resources into BPM decisions and outcomes are only accomplished through efficient and effective GPM user comprehension (Gronau & Weber, 2004; Markus et al., 2002; Sampler & Short, 1998).

2.1.2 Unique Features of BPM Systems Supporting Knowledge-Intensive BPM

Most enterprise systems, including ERP systems, CRM systems, and SCM systems, are: (1) data-focused as opposed to process-focused, meaning they are solely based on models of the data structures of business processes they support; (2) cannot be readily adapted or reconfigured as business processes change; and (3) provide only limited support for the different phases of the BPM lifecycle (Basu & Blanning, 2000; Basu & Kumar, 2002; Weske et al., 2004). In contrast, BPM Systems possess several characteristics that distinguish them from other types of enterprise systems in addition to the fact that they are based on unique types of GPMs.

2.1.2.1 Graph Theory Formalisms are a Critical Component of BPM Systems

First, the GPMs that underlie BPM Systems are "actual representation(s) of the business process in terms of a business process model using a process language" (Weske et al., 2004, p. 1). These GPM process languages are derived from graph theory formalisms, which permits mathematical modeling and direct control business processes (Aguilar-Saven, 2004; Basu & Kumar, 2002; van der Aalst, ter Hofstede, & Weske, 2003; Weske et al., 2004). Examples of these formal GPMs include metagraphs, Petri nets, and Unified Modeling Language (UML) diagrams. Informal graphical modeling techniques (such as flowcharts) do not permit this kind of mathematical analysis and control.

In general, BPM Systems use formal GPMs for three levels of abstraction and control of business processes: the business level, the execution level, and the evaluation level. These formal GPMs are used to model business-level graphs that define business processes symbolically in ways that capture and communicate BPI between various BPM managers (e.g., business managers, operational process managers, and IT personnel). These business graphs are then transformed into execution graphs to effect control of business processes. Finally, specific executions of business processes are evaluated, creating an audit trail that is then dynamically mapped back to the business graphs. which allows BPM managers the ability to understand the dynamics and performance of the business process (Basu & Blanning, 2000; Basu & Kumar, 2002; Karagiannis, Junginger, & Strobl, 1996). Thus, BPM managers make decisions that manage and control the business processes based on how they comprehend the GPMs used in BPM Systems.

2.1.2.2 BPM Systems Support all Phases of the BPM Lifecycle

Second, BPM Systems support all phases of the BPM lifecycle illustrated in Figure 2-2. Weske (2004, p. 3) explains that BPM Systems support the design, configuration, enactment, and diagnosis phases of BPM. Other process-oriented enterprise systems, such as workflow management systems[1], provide only partial support for the BPM lifecycle (2004c, p. 86).

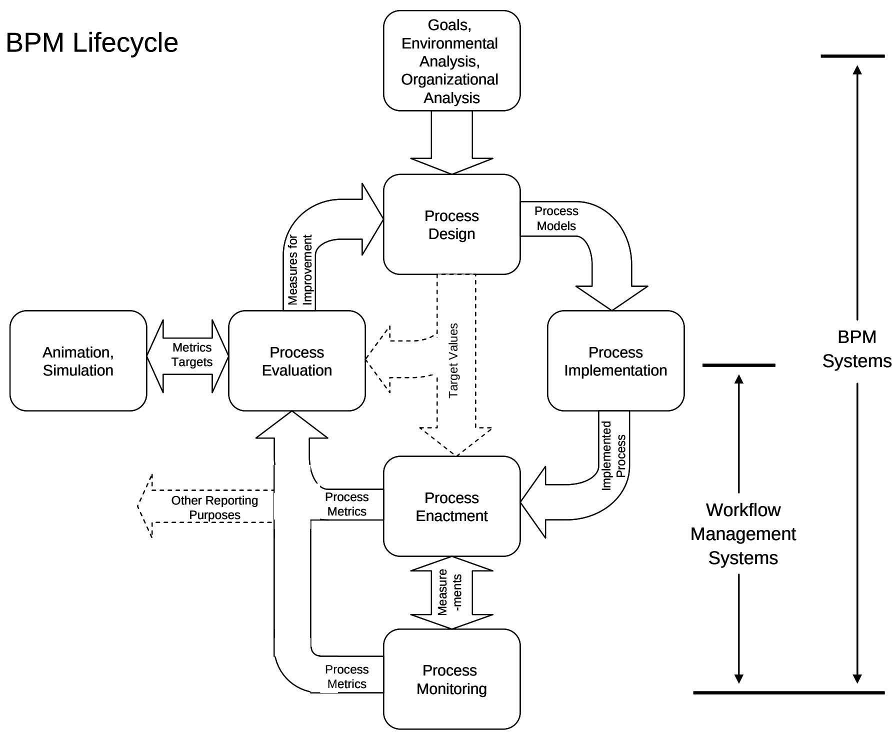


Figure 2-2. Support for the phases of the BPM lifecycle by BPM Systems compared to workflow management systems[2].

[2-1] The term *workflow management* refers to another area of research that includes process-aware information systems (called workflow management systems) that are considered predecessors of *BPM Systems*. In recent literature, the terms *workflow management* and *workflow management systems* are often used synonymously with the terms *BPM* and *BPM Systems* respectively (van der Aalst, 2004; Weske et al., 2004).

[2-2] Adapted from zur Muehlen (2004c, p. 86). Used by permission.

2.1.2.3 BPM Systems Can Control and Reconfigure Business Processes

Third, BPM Systems are "process-aware" in that they facilitate the management and control of business processes by operational-level managers in ways that other enterprise systems cannot (van der Aalst, 2004; Weske et al., 2004). BPM Systems allow "BPM process owners armed with business process management orchestration tools [the capability to] change process and information flows using graphically based tools with little or no involvement of the traditional IT department" (Light, 2005, p. 1). Most enterprise systems are limited to the management and control of the flow of data that aids BPM. They are not designed to allow the direct control of the business processes by operational-level managers. This unique feature of BPM Systems has allowed managers to monitor, change, and rapidly adapt business processes and data flows to meet the changing needs of dynamic business environments despite these managers being geographically dispersed (Basu & Blanning, 2000; Basu & Kumar, 2002; Light, 2005; Ould, 2003; Weske et al., 2004).

2.1.2.4 BPM Systems Integrate with Various Enterprise Architectures

Lastly, BPM Systems support the collection and integration of real-time BPI by interfacing with a variety of enterprise systems, architectures, and technologies (Hall & Harmon, 2006; Vernadat, 2002a). Enterprise integration literature describe how information technologies both model and utilize information for enterprise management (Vernadat, 2002a; Wagter, 2005; Zachman, 1999). However, other enterprise systems do not typically support access to real-time business process data across a variety of enterprise architectures without significant modifications; nor do they support direct control of these business processes (van der Aalst, 2004; Weske et al., 2004). A BPM System integrates several major IT components and areas of research, including: process modeling tools, simulation tools, business rule management tools, BPM applications, business process monitoring tools, software modeling and development tools, enterprise architecture integration tools, workflow tools, business process modeling languages, and organization and enterprise modeling tools (Hall & Harmon, 2006).

2.1.3 Empirical GPM User Comprehension Is Needed

Using BPM Systems efficiently and effectively requires the study of how managers cognitively perceive, comprehend, and apply the explicit BPM knowledge portrayed by GPMs so that they can be used to prompt managers to apply their tacit BPM knowledge in a given situation (Agarwal, De, & Sinha, 1999; Aguilar-Saven, 2004; Basu & Blanning, 2000; Karagiannis et al., 1996; Osborn, 1998; zur Muehlen, 2004a).

2.1.3.1 The Importance of GPM User Comprehension Research

BPM Systems and enterprise modeling literature describes modeling techniques for the development and implementation of enterprise systems. Yet, these bodies of knowledge suffer from a lack of empirical research on GPM user comprehension (cf. Aguilar-Saven, 2004; Curtis, Kellner, & Over, 1992; Lenz & Oberweis, 2003; Morabito, Sack, & Bhate, 1999; O'Rourke, Fishman, & Selkow, 2003; Wagter, 2005; Zachman, 1999; zur Muehlen, 2004b). According to Aguilar-Saven (2004), the primary purpose of business process modeling is to enable common understanding, analysis, and comprehension of business processes by users across an enterprise. Boland et al. (1994, p. 457) describe why efficient and effective GPM user comprehension is so important to BPM:

> "…[managers] who act autonomously within a decision domain, make interpretations of their situation and exchange them with others with whom they have interdependencies so that each [individual] may act with an understanding of their own situations and that of others."

Unfortunately, managers often experience a lack of timely access and comprehension of BPI due to information overload, trouble locating the necessary information in a timely manner, and difficulty in understanding the way the information was portrayed (Basu & Blanning, 2000; Zhang, 1996a).

Research describing the need for GPMs that standardize the interchange and communication of business process information, knowledge, and expertise is identified as the single greatest need by BPM practitioners. BPM managers are often geographically distributed across an enterprise with limited ability to identify and interact in a timely manner with other managers that possess relevant BPI (Agarwal et al., 1999; Basu & Blanning, 2000). Agarwal et al. (1999, p. 542) describe this need using an enterprise systems development example:

> "The lack of attention to model comprehension is all the more disturbing as models play a crucial role in providing a communication mechanism among different stakeholders during the systems development process. For instance, systems analysts use requirements analysis models to verify with users if all their requirements have been captured, as well as to communicate those requirements to systems designers. For large software systems [such as BPM Systems], teams may be geographically distributed and models constitute the primary communication vehicle among developers."

The Delphi Group, in their BPM 2005 Market Milestone Report, state that the visualization of business processes is the single biggest benefit of BPM Systems (Palmer, 2005, p. 8):

> "The indication of visualizing and simulating business processes as the single greatest benefit (nearly a 100% increase over 2003 findings) represents the growing awareness for the need of process visibility"

Additionally, the Delphi Group report the standardized interchange of process models is the most important feature defined by respondents as needed in BPM Systems but is missing in current commercial offerings (Palmer, 2005). Agarwal et al. (1999, p. 542) summarize why empirical research on user comprehension of GPMs is so important:

> "Because effective communication can only result if the models themselves are easily comprehensible, and because the ultimate quality of any large-scale system is, in turn, dependent on the quality of communication among the multiple parties involved, it is imperative that we examine the issue of comprehension of models developed using different [research] methods."

2.1.3.2 BPM Research Lacks Empirical Studies

There is a lack of empirical research that has studied whether the GPMs used in BPM Systems truly facilitate user comprehension of tacit and explicit BPM knowledge. There has been a great deal written in recent years about GPM modeling in relation to BPM Systems (cf. Basu & Blanning, 2000; Curtis et al., 1992; van der Aalst, Desel, & Oberweis, 2000; zur Muehlen, 2004c). Several papers illustrate a particular application, define a derivative GPM, describe potential user benefits of different GPM techniques, or discuss issues related to the development of BPM Systems (Basu & Blanning, 2000; Curtis et al., 1992; van der Aalst, 2004; Vernadat, 2002b; zur Muehlen, 2004a). However, no empirical research was found that has sought to validate claims that one type of GPM facilitates better user comprehension than another in this context.

2.1.3.3 GPM User Comprehension Research is Lacking in BPM Contexts

Several authors cite a general lack of empirical research that relate enterprise systems to organizational contexts. Basu and Kumar (2002, pp. 11-12), in a recent literature review of BPM System-related issues in E-business, recommend that future research needs to focus on linking the BPM Systems with the organizational context:

> "Traditional information systems research has focused on problems such as application development and database management, which have gained significant maturity. On the other hand, the inherently hybrid (combination of automation and manual) nature of business process workflows, particularly when spread across multiple locations, resources, and organizational entities, present new challenges for IS researchers [i.e., referring to the challenges inherent to independencies between individuals and information artifacts in distributed work environments]. In the volatile, dynamic context of E-business, these problems not only become more complex, but their solutions also become critical determinants of success."

There is empirical research in the information systems and enterprise modeling literature that has studied user comprehension of different GPM techniques on topics such as requirements analysis and systems design (cf. Agarwal et al., 1999; Kabeli & Shoval, 2005a; Mayes, Sims, & Koonce, 2001). However, no empirical research was found that has studied user comprehension of formal GPMs in the either BPM Systems literature or in the general context of BPM.

2.1.4 Summarizing GPM User Comprehension Research in BPM Systems Contexts

A critical issue impacting BPM Systems and supporting knowledge-intensive business processes is that managers and stakeholders must be able to accurately and efficiently comprehend BPM tacit and explicit knowledge resources and envision the impact of their decisions on business processes using GPMs (Basu & Blanning, 2000; Eppler et al., 1999; Markus et al., 2002; Osborn, 1998; Sampler & Short, 1998; Schael, 1998; Sheth, van der Aalst, & Arpinar, 1999). The GPMs used in BPM Systems are the primary information artifacts that portray essential BPI and facilitate communication among different BPM managers that tap into their tacit BPM knowledge (Agarwal et al., 1999; Aguilar-Saven, 2004; Basu & Blanning, 2000; Curtis et al., 1992). There has been a great deal written in recent years about GPM techniques and the development of BPM Systems. However, there is apparently no empirical BPM System research, nor GPM research that utilize theory integrating the key variables affecting GPM user comprehension in the context of BPM and BPM Systems.

Users of formal GPMs used in BPM Systems must be able to be accurately and efficiently comprehend the BPI they portray. To accomplish this, it is suggested that GPM user comprehension research include how GPM techniques used in BPM Systems (Basu & Blanning, 2000):

(a) <u>Facilitate user comprehension of a variety of BPI</u> (e.g., task-centric, resource-centric, and information-centric BPI) by operational managers.

(b) Minimize unnecessary process complexity that impair user comprehension, thus minimizing the time and effort required to comprehend and interpret BPI while maintaining accuracy of user comprehension.

(c) Facilitate comprehension of relevant tacit and explicit BPM knowledge despite cognitive differences between individual users.

Zur Meuhlen (2004, p. 288) in his review of BPM/workflow management organizational issues state that experimental research on process modeling approaches is a necessary next step:

> "The use of workflow technology for human-centric processes presents both a technical and organizational challenge. Consequently, it has to be addressed from both the community of workflow vendors and the community of workflow users…. An evaluation and validation of the different modeling and management approaches presented in this paper is the next step. Experimental research is needed to determine the effects of workflow applications on organizational structures and their management, and to establish the success factors for workflow-enabled organizations."[3] [emphasis added]

Therefore, this study seeks to address this need by experimentally studying GPM user comprehension in the context of BPM and BPM Systems. This experiment includes three BPM cognitive resources required for user cognition during user comprehension: the type of GPM, BPI, and user educational training. The next section reviews research related to GPM user comprehension and the cognitive differences between individuals.

2.2 User Comprehension in Related Literature

Because of the lack of research studying GPM user comprehension in the context of BPM and BPM Systems, several reference literatures were needed to study this topic including Human Computer-Interaction (HCI), cognitive ergonomics, and cognitive psychology. HCI is "concerned with understanding how people make use of devices and systems that incorporate or embed computation, and how such devices and systems can be more useful and more usable" (John M. Carroll, 2003, p. 1). HCI literature overlaps and borrows from social, behavioral, and IT literature. As a result, the dominant theoretical perspective in

[2-3] Zur Meuhlen uses the term "workflow" to refer to an executed instance of a business process. Thus, when he refers to "workflow management," "workflow-enabled," or "workflow management systems," he is discussing essentially the same concepts as what this study calls "BPM" or "BPM Systems" (zur Muehlen, 2004c).

comes from information processing theory from cognitive psychology to aid in the study and development of more effective environments and information artifacts (John M. Carroll, 2003). Cognitive ergonomics research intersects the HCI, ergonomics, and cognitive science literatures. Relative to this study, cognitive ergonomics helps with the design of information artifacts and contexts so that individuals are capable of perceiving information, making decisions, and performing tasks more effectively and efficiently (Boff, 2006; Hollnagel & Woods, 2005; MacLeod, 2004). Both HCI and cognitive ergonomics research borrow from cognitive science and cognitive psychology literature because they study the processes and individual differences that affect cognition, learning, and decision-making (Baddeley, 2003a; Huitt, 2004; Neisser, 1967). This section defines the terminology theoretical relationships from these reference literatures that relate to user comprehension.

2.2.1 Cognition and User Comprehension

Cognition is a core concept in behavioral and cognitive sciences, but there is no single, generally accepted definition and efforts to reach one is a matter of controversy in the cognitive sciences (van Duijn, Keijzer, & Franken, 2006). Ulric Neisser, who coined the term *cognitive psychology*, defines *cognition* as referring to all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used (Neisser, 1967, p. 4), however transformation is no longer generally considered part of cognition. In a more practical sense, the term *cognition*, from the Latin *cognoscere* meaning "to know," generally refers to the process of knowing, acquiring knowledge, or knowledge that is acquired by the use of reasoning, intuition, or perception (Kintsch, 2005; Wickens, 1992). Varela, Thompson, and Rosh (1999) define cognition as “embodied action” (p. 172) or an enactment that results in a new version “from a background of understanding” (p. 149).

According to van Duijn, Keijzer, and Franken (2006), there is a strong consensus that cognition involves perception, thinking, memory, and action. Gershenson (2006, p. 151) summarizes cognitive systems as having the following general characteristics:

- “Systems can be judged to be cognitive only inside a specific context. For example, in a chess-playing context, a bee is not cognitive, but in a navigational context, it is. People agree in contexts, and these are contrasted with experience of a shared world….

- "Cognition is a description we give of systems, not an intrinsic constituent of them, i.e. systems do not have cognition as an element, we observe cognition from a specific context. The cognition of a system does not depend on its implementation.
- "If a system performs a successful action, we can say that it knows what to do in that specific situation. This success is tied to a context and to an observer. Therefore, any system performing a successful action can be considered to be a cognitive system."

Gershenson (2006, p. 151) refers to this conceptualization as a "general notion of cognition" with which other definitions and conceptualizations of cognition can be applied "in different contexts with different purposes: without contradicting these general characteristics. Cognitive psychology seeks to understand the thinking processes that influence human actions and behavior. This literature has studied various aspects of cognition including perception, thinking, language, memory, attention and problem solving.

Comprehension is viewed by cognitive psychologists as one aspect of cognition (Just & Carpenter, 1992). Cognitive psychology literature depicts *comprehension* as a vague term that is difficult to define because it represents a continuum that depends on context as opposed to possessing a specific meaning (Kintsch, 2005). Kintsch (2005, p. 125) explains the comprehension continuum, "We can talk about comprehending a problem, which would put us at one end of the continuum, or comprehending a perceptual scene, which would put us at the other end." In the cognitive psychology literature, *comprehension* has come to have roughly the same meaning as *understanding* in that it refers to the ability of a person to grasp the meaning of something (Agarwal et al., 1999; Just & Carpenter, 1992; Kintsch, 2005). For example, text comprehension research measures the understanding of a passage of text (Kellogg, 2001). User comprehension outcomes are achieved through the mental processing (i.e., reasoning, intuition, or perception) of cognitive resources (i.e., information, knowledge, and experience).

2.2.2 Outcomes of User Comprehension

Because many cognitive differences, components, capacities, and processes are not directly observable, their outcomes have to be assessed indirectly through behavior, recall, and self-evaluation (Huitt, 2004; Strickland, 2001a). It is typical for researchers to assess comprehension by asking participants to recall, summarize, or verify statements and answer questions about cognitive resources. User comprehension research often assess three different outcomes: task accuracy, task timeliness, and mental workload. (cf. Baddeley, 2003a; Kintsch, 1988; Marmaras & Kontogiannis, 2001; Nordbotten & Crosby, 1999; Shoval, Danoch, & Balabam, 2004; Sinha & Vessey, 1992)

Task accuracy is a measure of correctness of an individual's task solution compared to a known, correct answer for example:

> "Discourse comprehension, from the viewpoint of a computational theory, involves constructing a representation of a discourse upon which various computations can be performed, the outcomes of which are commonly taken as evidence for comprehension. Thus, after comprehending a text, one might reasonably expect to be able to answer questions about it, recall or summarize it, verify statements about it, paraphrase it, and so on" (Kintsch, 1988, p. 164).

Consequently, comprehension is often assessed by the number or percent of correct answers to questionnaires. Similarly, GPM user comprehension is measured by the accuracy of participant responses to questions that assess understanding of information portrayed by GPMs (Agarwal et al., 1999; Kabeli & Shoval, 2005a; Moody, 2004). In this study, task accuracy is assessed by the percent of correct answers to questions asking users to interpret GPMs.

Task timeliness is a measure of the amount of time spent by an individual in performing a task (Baddeley, 2003a; Dunn & Grabski, 2001; Sinha & Vessey, 1992). For example, Mayes, Sims, and Koonce (2001) conducted two experiments to determine if reading information from a computer monitor vs. paper resulted in poorer user comprehension outcomes. Thus, the time participants take to learn, understand, or interpret information is often a dependent variable in studies of user comprehension. In this study, task timeliness refers to the time a user took to complete their interpretation of GPMs.

Subjective mental workload and self-efficacy are also common outcomes of user comprehension found in user comprehension research, and is included in this study. Literature reviewing each of these outcomes are discussed in Sections 2.4.1 and 2.4.2, respectively.

2.2.3 Information Processing Theory and User Comprehension

The history of cognitive psychology states that its original purpose was to study and understand the cognitive processes at work within the minds of individuals that help explain differences in task performance, based primarily on Human Information-Processing (IP) theory (Baddeley, 2003b; Eysenck & Flanagan, 2000; Miller, 1956). IP theory was created as cognitive psychologists sought to explain *cognition* and *comprehension* (Newell & Simon, 1972). The purpose of IP theory is to help describe the components, structures, and functions related to the way people take in, process, and act on information within specific contexts, environments, or ecologies (Huitt, 2004). Prior to IP theory which focuses on the innate mental capacities of individuals, cognitive theory was based on behaviorist approaches focused on conditioned, externally observable behavior (Strickland, 2001a). Beginning in the 1950s, both cognitive psychology and IP theory emerged from the work of George A. Miller, Herb Simon, and others, because there was a growing dissatisfaction with behaviorist theory and the realization that stimuli and feedback internal to the individual play a significant role in affecting task performance (Eysenck & Flanagan, 2000; Huitt, 2004). IP theory is used extensively in cognitive psychology, because it seeks to understand intellectual task performance on topics such as:

- Attention - e.g., directing mental effort towards important aspects of a situation or event.
- Memory strategies - e.g., using mnemonics such as Every Good Boy Deserves Fruit for the notes on a music staff.
- Study and comprehension skill - e.g., highlighting key points and making summaries.
- Concept mapping - e.g., setting out the relationship between key ideas in a topic in diagram forming.
- Problem solving - e.g., understanding the role of knowledge, the way problems may be represented.
- Metacognition - e.g., thinking about thinking and deciding how best to manage mental processes.
- Pattern recognition - e.g., identifying meaningful relationships.
- Elaboration - e.g., bringing together what we know about something in order to integrate our knowledge.
- Learning – e.g., Primarily through the study of memory (Miller, 1956).

Because of these properties, IP theory has become the fundamental theoretical perspective underlying cognitive psychology (Huitt, 2003; Neisser, 1967), cognitive ergonomics (Marmaras & Kontogiannis, 2001), and HCI research (Hollan et al., 2000; Perry, 2003).

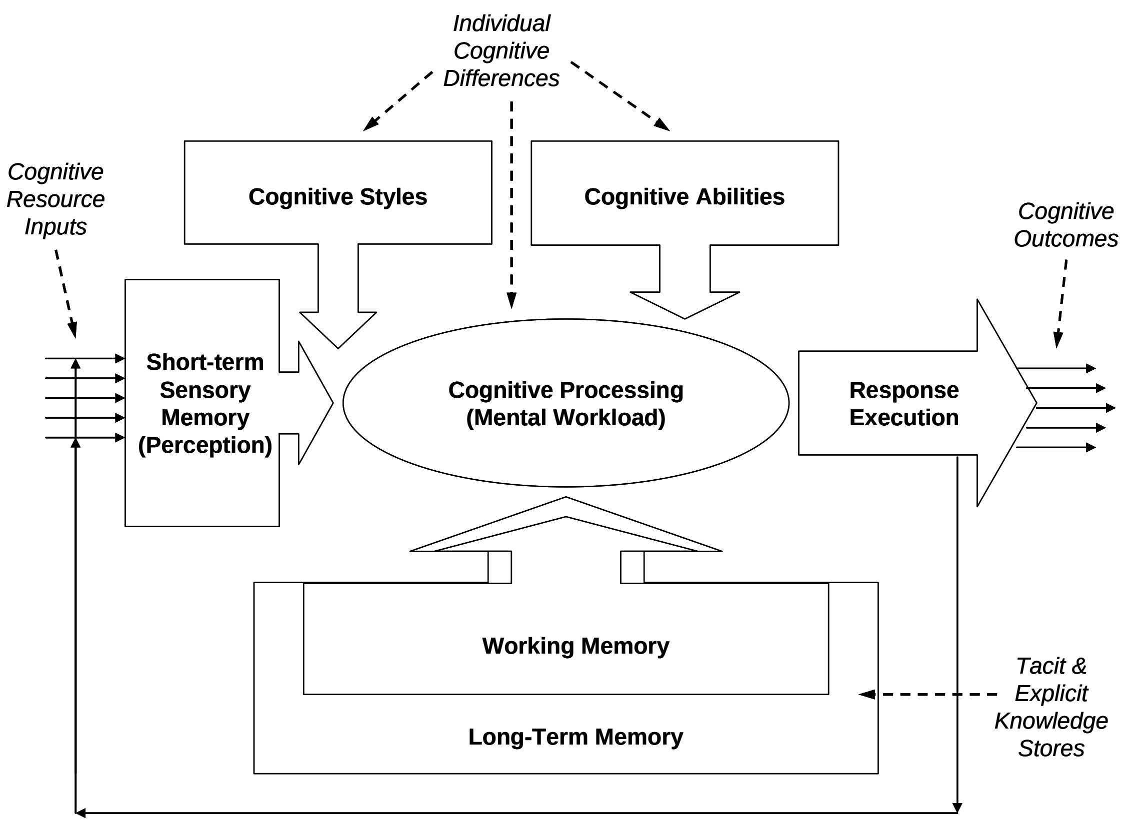


Figure 2-3. An Information-Processing Theoretical Model of a Cognitive System.

2.2.3.1 An Overview of Information-Processing Theory

IP theory compares the human mind to a computer and, consequently, characterizes human cognition in terms of an information processing system (Eysenck & Flanagan, 2000; Newell & Simon, 1972). The development of computers "led to the realization that computer-oriented information processing models could provide new insight into how the human mind receives, stores, retrieves, and uses information" (Strickland, 2001b, p. 1). According to IP theory, the human brain is the processor, and data is both input and output from the brain. Similar to a computer, the human mind takes in, performs operations, stores, and locates information and then generates responses (Eysenck & Flanagan, 2000). The different components of cognition and the physical parts of the brain form an information-processing network.

IP theory is often used to study individuals' cognitive differences, resources, limitations, abilities, preferences, and mental processes to explain observable behavior (Eysenck & Flanagan, 2000; Huitt, 2004). Figure 2-3 illustrates how IP theory models a cognitive system that is limited to the processing of information within the mind of an individual and involves relationships between several cognitive components (Baddeley, 2003a; Huitt, 2004; Marmaras & Kontogiannis, 2001). IP theory hypothesizes that cognition is accomplished through several stages including gathering and representing information in sensory and working memory (also called encoding), holding information in short-term and long-term memory (also called retention), mental processing of information (processing), and accessing the stored information when needed (called retrieval) (Huitt, 2004). Sensory memory retains an exact copy of what is experienced by the senses at a given moment. Working memory is limited and retains information from the sensory and long-term memories that is focused on a given moment. This information can be held in working memory for approximately 20 seconds without maintenance or rehearsal. Long-term memory is the brain's permanent storehouse for information and is virtually unlimited in capacity.

During cognition information received from external or internal stimuli (such as representations of GPM symbols) is inputted through the senses and transformed by a variety of mental operations. The mind receives information through the perceptual processes and then is stored in either working or long-term memory. There the newly perceived information interacts with previously-stored information (i.e., tacit and explicit knowledge) to generate a response. Research has shown that when an individual experience problems with recall of information the reason is usually related to the method of retrieval from long-term memory (Huitt, 2004; Strickland, 2001a).

These cognitive stages take place in a number of different arrangements: serial, parallel, and in hybrid combinations of the two (Huitt, 2003). A serial model of cognitive processing takes place when these stages are executed in succession, like a chain reaction, with the output of each stage becoming the input of the succeeding one. These stages can also occur simultaneously; an event known as parallel processing. Serial and parallel processing can combine in what is known as a hybrid arrangement.

2.2.3.2 Four Principles of IP Theory

There are four main principles of IP theory that guide its application in several research domains. The first principle is the assumption that certain components of a cognitive system have a limited capacity: short-term and working memory. In contrast, long-term memory and sensory memory are theorized as having unlimited capacity. This means that restrictions in the flow and processing of information occur at specific points in a cognitive system. Therefore, the amount of information that can be processed is constrained by differences in the cognitive capabilities of different individuals (Huitt, 2003; Just &

Carpenter, 1992; Kellogg, 2001; Miller, 1956). For example, Miller (1956) found that short-term memory has a limited capacity of 7 ± 2 "chunks" of information. This principle has become a basic element of all subsequent theories of memory and is the basis of Cognitive Load Theory (CLT) in learning literature and the concept of mental workload in cognitive ergonomics and cognitive science literature (Hart & Staveland, 1988; Hollnagel, 1997; Hollnagel & Woods, 2005).

The second principle of IP theory is that a control mechanism is required (commonly referred to as the executive function) to oversee the encoding, transformation, processing, storage, and retrieval of information in the cognitive system (Baddeley, 2003b) much like the central processing unit (CPU) in a computer. Like the computer, the human mind takes in information, stores and locates the information, performs operations to change the form and content of the information, and generates responses to the information it perceives and comprehends. Like the CPU in a computer, the executive function uses some of the limited capacity of the mind's cognitive system to oversee cognitive processing. For example, when an individual is learning a new task or seeks to understand new information, the executive function requires more of an individual's limited cognitive processing power than when the same individual is either performing a routine task or possesses some form of prior expertise or experience with the task (i.e., tacit knowledge) (Baddeley, 2003b; Huitt, 2003). This increase in cognitive processing power is often referred to as cognitive load or mental workload. The mental workload and efficiency of each stage in the cognitive process depends on whether certain other stages are operating at the same time (Baddeley, Chincotta, & Adlam, 2001).

The third principle of IP theory is the assumption of a two-way flow of information as individuals try to comprehend information, tasks and the environment around them. People constantly gather information through their senses (referred to as bottom-up processing) and from their memory (referred to as top-down processing) as they dynamically construct meaning from other people, information resources, and the task environment (Kintsch, 2005). Huitt (2003) says that these two ways of perceiving information is analogous to the differences between inductive reasoning (going from specific instances to general conclusions) and deductive reasoning (going from a general principle to specific examples).

Finally, the fourth principle of IP theory is that humans are genetically predisposed to process information in specific ways that are influenced by specific individual differences affecting a person's cognitive processing (Huitt, 2003). Consequently, two individuals can be predisposed to processing the same information in different ways resulting in different outcomes and behaviors. These individual cognitive differences affect user comprehension outcomes and can be genetic or influenced by practice and experience (Sadler-Smith, 2001). Examples of two categories of individual cognitive differences affecting user comprehension in all people are their cognitive styles and cognitive abilities. According to Sadler-Smith (2001, pp. 609-610) cognitive styles and abilities of individuals represent different layers of a cognitive "onion":

> "The 'core' of the onion is the central personality dimension; as one passes outwards from the centre, the constructs (cognitive style, learning style [i.e., cognitive abilities], and learning preferences) become increasingly open to introspection, more context-dependent and less fixed….If the field is to progress there is a need to delineate … separate constructs [along this continuum] (if indeed they are such)."

A large amount of cognitive science research studies how individual cognitive differences affect user comprehension. (See Sections 2.4.3 and 2.4.4 for further discussions on cognitive styles and cognitive abilities.)

One noticeably missing element of IP theory is the influence of differences in cognitive resources. As mentioned above, this is because the original purpose of IP theory was to discover the components and processes going on within the mind of individuals (Baddeley, 2003b; Eysenck & Flanagan, 2000; Miller, 1956). Although not explicitly included in the IP theoretical model, cognitive psychologists recognize that constraints on cognitive resources help explain individual differences in comprehension (Carpenter, Miyake, & Just, 1995).

2.2.4 Information Processing Theory in Related Research

As the role of computers and information artifacts has grown in society, IP theory has been applied to the study of study socio-technical systems in various disciplines where information is presented, perceived, and task outcomes are observed. Cognitive psychology research describes both language or text comprehension as involving the processing of a sequence of symbols that are produced and perceived over time (Just & Carpenter, 1992). In similar fashion, IP theory is used in HCI, cognitive ergonomics, information systems, and computer-assisted learning literatures to help explain how an individual's behavior is affected by external representations, influences, and mental capabilities. For instance, Kuutti (1995, p. 16) classifies HCI-related research in three broad "traditions":

> "The 'technical' one, having roots already in the old 'know-and-dial' ergonomics, concentrating human perceptive abilities and motor skills and corresponding features of technical devices, the 'conceptual' one that has formed the information processing

> psychology-based mainstream of HCI research, and the emerging new one searching new frameworks and theories in order to deal with the complexity."

There are several topic areas that study user comprehension in relation to individuals and information artifacts. Psychology of Programming research apply cognitive psychology to the study of how to improve computer programming practices by studying the relationship between programming languages and cognitive differences between individuals to create more desirable comprehension outcomes among programmers (cf. Curtis, 1984; Irons, 1982; Morris, Speier, & Hoffer, 1999; Rosson, 1996; Schneiderman, Mayer, McKay, & Heller, 1977; Sheil, 1981). Cognitive Load Theory (CLT), in part, emerged from the computer-assisted learning literature and seeks to explain learning task outcomes, including task accuracy, task timeliness, and mental workload, experienced by individuals as they perform learning tasks (cf. de Croock, van Merrienboer, & Paas, 1998; Martin-Michiellot & Mendelsohn, 2000; Mayer & Moreno, 2003; Paas, Tuovinen, Tabbers, & Van Gerven, 2003; van Merrienboer, Kirschner, & Kester, 2003). CLT theory also studied the relationship between mental workload and task performance using a calculated assessment of mental efficiency (Paas & Van Merrienboer, 1994; van Merrienboer, Schuurman, de Croock, & Paas, 2002). Topics that are directly or indirectly based on IP theory in reference literature related to this study include:

- <u>In HCI and cognitive ergonomics literature</u>: topics such as cognitive task design (Marmaras & Kontogiannis, 2001), user-centered system design (Norman, 1986, 2002), mental workload (Hart & Staveland, 1988), computer-supported cooperative work systems (CSCW) (Boland & Tenkasi, 2001; Halverson, 2002), information visualization (Wright, Fields, & Harrison, 2000; Zhang, 1996a), aviation (Morrow et al., 2003), and work design (Hollnagel, 1997; Hollnagel & Woods, 2005) research.
- <u>Information systems literature</u>: topics such as system development (Agarwal et al., 1999; Agarwal, Sinha, & Tanniru, 1996) and psychology of programming (Sheil, 1981; Winslow, 1996) research.
- <u>In computer-assisted learning literature</u>: in topics such as Cognitive Load Theory (CLT) (Kirschner, 2002; Paas, Renkl, & Sweller, 2003) and educational technologies (van Gerven, Paas, van Merrienboer, & Schmidt, 2002; van Merrienboer et al., 2003) research.

In this study, GPM user comprehension is stimulated by sequences of symbols that are perceived over time by an cognitive processes that are influenced by an individual's cognitive differences.

2.3 BPM Cognitive Resources and User Comprehension

Based on the review of literature thus far, three categories of BPM cognitive resources are inputs to GPM user comprehension:

- The primary information artifact used by the BPM System to portray BPI (operationalized as the type of GPM).
- The explicit BPM knowledge portrayed using GPMs in a BPM System (operationalized as the type of BPI needed to perform a specific BPM task).
- Managers' tacit BPM knowledge related to interpreting the BPI portrayed by a BPM System (operationalized as the type of user educational training).

This section reviews theoretical bases for relating these BPM cognitive resources to GPM user comprehension outcomes to test the research questions of this study.

2.3.1 Type of Graphical Process Model and GPM User Comprehension

Research Question 1: *How do different types of GPM influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*

2.3.1.1 Types of GPMs Used in BPM Systems

As mentioned above, BPM Systems use formal GPM techniques because they permit the mathematical analyses and control of business processes (Basu & Blanning, 2000; Curtis et al., 1992). This means that for a formal GPM to control a business process, this process model must describe the control flow of the business process (Curtis et al., 1992; Green & Rosemann, 2000). Although informal process modeling is not new, the basic formal process modeling grammar, called Petri nets, on which most formal GPMs are based comes from Petri's (1962) doctoral dissertation. Since that time, a great deal of research on formal process modeling has resulted (Curtis et al., 1992; Vernadat, 1996). Examples of these formal GPM techniques used to model business processes include Petri nets (van der Aalst, 2000), Unified Modeling Language (UML) diagrams (Vernadat, 2002b), state charts (Harel & Gery, 1997), and metagraphs (Basu & Blanning, 2000).

Green and Roseman (2000, p. 79) summarize the research and state that formal process modeling to address the various purposes of BPM needs three new main requirements[4]. First, the process model must include more BPI than the just the control flow. They propose that a comprehensive, formal process model should include at least:

1. Information about the organizational units (e.g. internal and external persons, departments, (project) groups) that are involved in the process by having to execute certain tasks or be responsible for the performance of those tasks.

2. The input and output data that are necessary for a function to process and the data that result from the execution of a function.

3. References to existing libraries or repositories that describe the functions and business processes within an enterprise.

4. The output (product and services) which describes the results of the business processes.

5. The integration of business objectives, business partners (e.g., customers and vendors), temporal aspects (e.g., deadlines), access to BPM knowledge (e.g., tacit and explicit), and/or other resources such as application systems.

Second, a formal GPM should not only be comprehensive but it must also be easy to understand because (1) manual organizational activities are involved and (2) so that it can be used as a platform for communication between various business people and managers who may not be familiar with process modeling. They quote Curtis et al. (Curtis et al., 1992, p. 751) to further explain, “Process modeling is distinguished from other types of modeling in computer science because many of the phenomena modeled must be enacted by a human rather than a machine.” Third, formal GPMs should be based on a meta model that serves as a well-defined starting point for the development of workflow-based applications, such as BPM Systems. Additional applications of process models include animation and simulation. They conclude by stating, “All in all, process models that are not only used for the purpose of developing software must be comprehensive, understandable and formal at the same time.” (Green & Rosemann, 2000, p. 79).

[4] This paragraph is paraphrased directly and in its entirety from Green and Roseman (2000, p. 79)

Regarding the comprehensibility of GPMs, most BPM practitioners have some experience with informal graphical modeling techniques. Business processes are often modeled using informal graphical methods, such as basic flowcharts, because these techniques are perceived to be more intuitive to novice users. On the other hand, most managers have not been trained to interpret formal GPM techniques (Basu & Blanning, 2000; Schael, 1998). Van der Aalst et al. (2003, p. 8) believe that formal GPM techniques can be easily comprehended by novice users:

> "In some products, a pragmatic approach to process modeling is preferred to a formal one; especially if the main goal of process modeling is discussion with domain experts rather than process analysis or process enactment. However, we mention that formal semantics of process languages and intuitiveness and ease of use are not contradicting goals, and recent approaches seem to support this observation."

This study of formal GPM user comprehension focuses on two types of GPMs: Unified Modeling Language (UML) diagrams (Eriksson & Penker, 2000; Marshall, 2000; Vernadat, 2002b) and metagraphs (Basu & Blanning, 2000). There are several reasons why these two GPM techniques were chosen for this study. First, metagraphs and UML diagram extensions have been specifically developed be used in BPM Systems, while other GPM techniques can only partially meet the needs of BPM Systems (Basu & Blanning, 2000; Eriksson & Penker, 2000; Marshall, 2000; Vernadat, 2002b). Second, UML diagrams are becoming the defacto standard for modeling business processes for development of enterprise systems (Basu & Blanning, 2000; Eriksson & Penker, 2000; Marshall, 2000; Vernadat, 2002b), and thus should be included in GPM user comprehension research. Metagraphs have apparently not actually been used in the development of enterprise systems, however metagraphs have been developed and proposed as an alternative to counter the weaknesses of UML diagrams (Basu & Blanning, 2000). Third, metagraphs and UML diagram extensions have been specifically developed be used to model business processes in BPM Systems. Other GPM techniques can only partially meet the needs of BPM Systems (Basu & Blanning, 2000). For example, although Petri-net related research is extensive, they have not been comprehensively applied to model the necessary BPI needed in a business applications (Green & Rosemann, 2000). However, UML version 2.0 does include a version of a Petri net to offer control flow

Finally, the nature of UML diagrams and metagraphs lend themselves nicely to being compared and tested for user comprehension using the theoretical principle of Ontological Completeness (see Section 2.3.1.4 for further discussion on this topic). For these reasons, metagraphs and UML diagrams were selected as the best possibly alternatives to test GPM user comprehension using the theoretical framework developed for this research.

2.3.1.2 Using UML Diagrams in BPM Systems to Model Business Processes

UML diagrams possess several advantages for use in BPM Systems: they support object-oriented systems analysis and design, are easily extended to specific BPM contexts, and include a variety of diagrams to thoroughly model both processes and data from different BPI perspectives (Eriksson & Penker, 2000; Marshall, 2000; Vernadat, 2002b). UML version 2.0 includes thirteen different diagramming techniques, each for modeling a different perspective or aspect of an information system (Anonymous, 2007; Eriksson & Penker, 2000; Marshall, 2000; Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2004).

UML diagrams have several advantages when used in BPM Systems. One advantage is that several individual UML diagram modeling techniques closely resemble traditional, informal flow charting techniques that may be more familiar to novice users, while allowing the formal mathematical analyses required for BPM Systems development and process analysis and enactment. Another advantage is that UML techniques have been extended to model enterprise business processes. For example, Vernadat (2002b) proposes UML extensions for use in enterprise systems that he calls the Unified Enterprise Modeling Language (UEML). Eriksson and Penker (2000) propose different BPM extensions of UML diagrams to model different perspectives of a business process; for example, task-centric, resource-centric, and information-centric BPI.

On the other hand, critics argue that UML diagrams can be difficult to learn and comprehend because users must learn to read and understand a different set of modeling notations, symbols, and component relationships for each type of BPI being modeled. For example, UML diagram depictions[5] of task, resource, and information-centric BPI are each modeled using different set of GPM symbols and notations (see Figures 2-4, 2-5, and 2-6 respectively). This significantly increases the learning curve and complexity for novice users, particularly non-IT BPM managers having limited exposure to UML diagrams (Basu & Blanning, 2000; Gou, Huang, Liu, & Li, 2003). As a result, only a few of the UML diagrams are typically utilized in practice, and then only by information systems professionals – not the operational

[2-5] The UML diagrams used in this experiment are created using Eriksson and Penker (2000) extensions for BPM modeling and are simplified by eliminating extraneous syntax. Also, the terminology used to describe the actual UML diagrams were replaced with the tack-centric, resource-centric, and information-centric BPI so that participants could focus on learning the symbols and what they represented, not on the names of the diagrams.

managers and executives envisioned to be the users of BPM Systems (Basu & Blanning, 2000; Gou et al., 2003).

2.3.1.3 Using Metagraphs in BPM Systems to Model Business Processes

Metagraphs, as a graph theoretic formalism, have been around for decades, but have only recently been recommended by its proponents for users and developers of workflow management and BPM Systems (Basu & Blanning, 2000, 2003). Metagraphs are proposed by Basu and Blanning (2000; 2003) as a superior alternative to UML diagrams for use in BPM Systems. Like UML diagrams, metagraphs can be used to model different business process perspectives. Unlike UML diagrams, metagraphs use the same graphical symbols, semantics, and nomenclature to model different types of BPI. The following figures illustrate metagraph depictions of task-centric BPI (Figure 2-7), resource-centric BPI (Figure 2-8), and information-centric BPI (Figure 2-9) perspectives of the same bank loan application process portrayed by UML diagrams in Figures 2-4, 2-5, and 2-6, respectively.

Consequently, one proposed advantage of using metagraphs is that users are required to learn only one set of modeling symbols and notations. Basu and Blanning (2000) argues that this makes metagraphs easier to comprehend for a variety of BPM managers who are novice users who possess a variety of BPM-related education, training, and experience. The main disadvantage of metagraphs is that they have not been used by either researchers or practitioners in the development of actual workflow management or BPM systems. Therefore, claims of metagraph user comprehension superiority over UML diagrams have yet to be empirically studied.

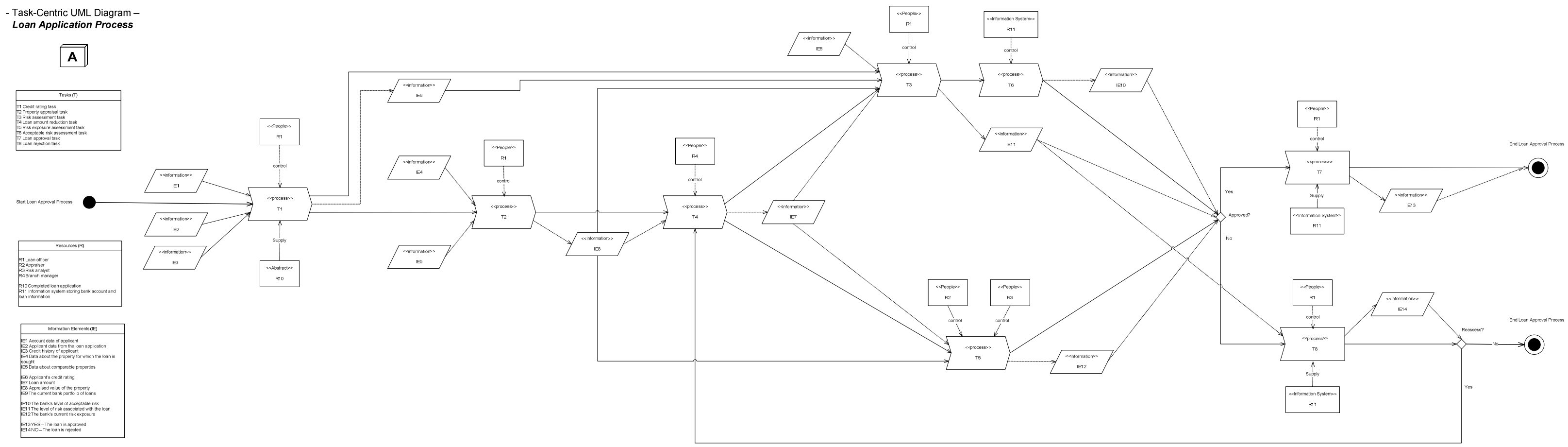


Figure 2-4. A UML conceptual model of a task-centric BPI of a loan application process as may be found in a BPM System[6].

[2-6] This is an original drawing based on UML extensions for business process modeling found in Eriksson and Penker (2000).

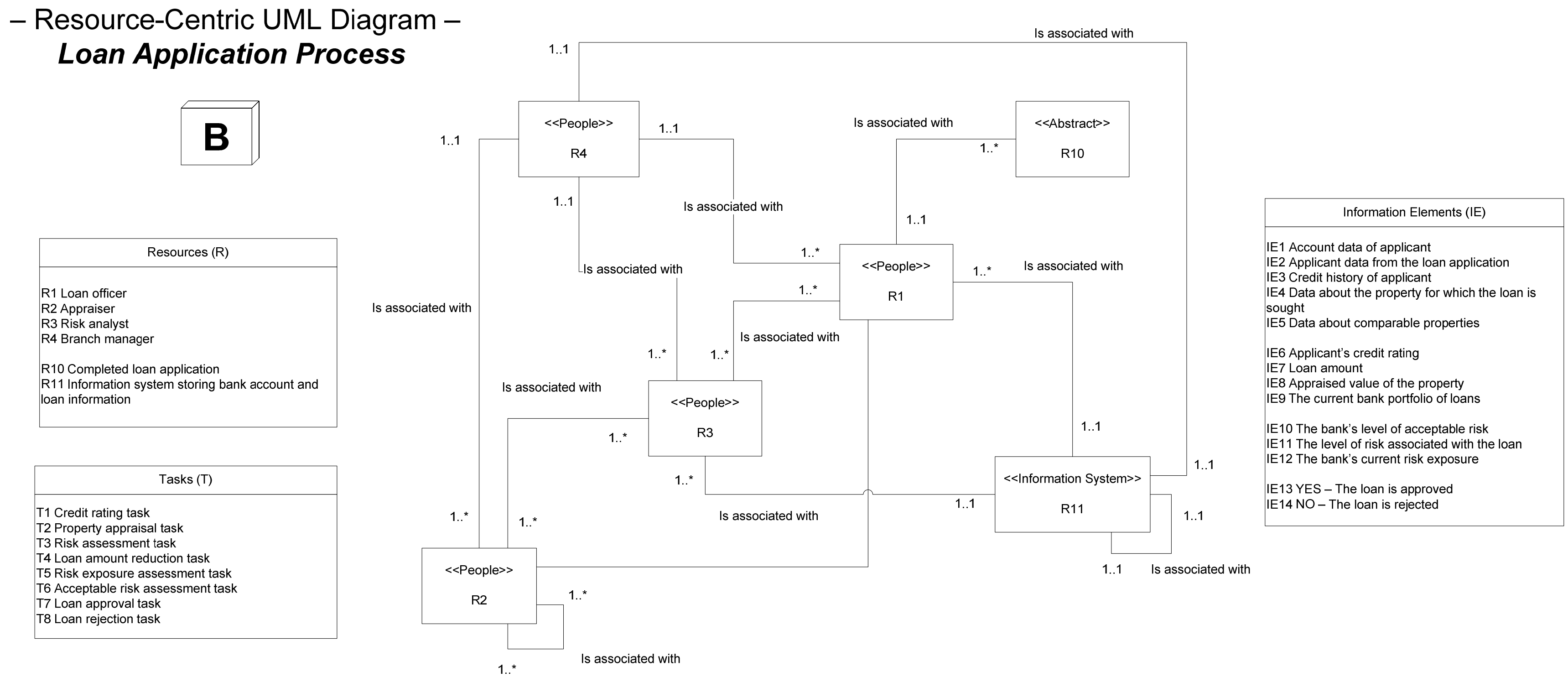


Figure 2-5. A UML conceptual model of a resource-centric BPI of a loan application process as may be found in a BPM System[7].

[2-7] This is an original drawing based on UML extensions for business process modeling found in Eriksson and Penker (2000).

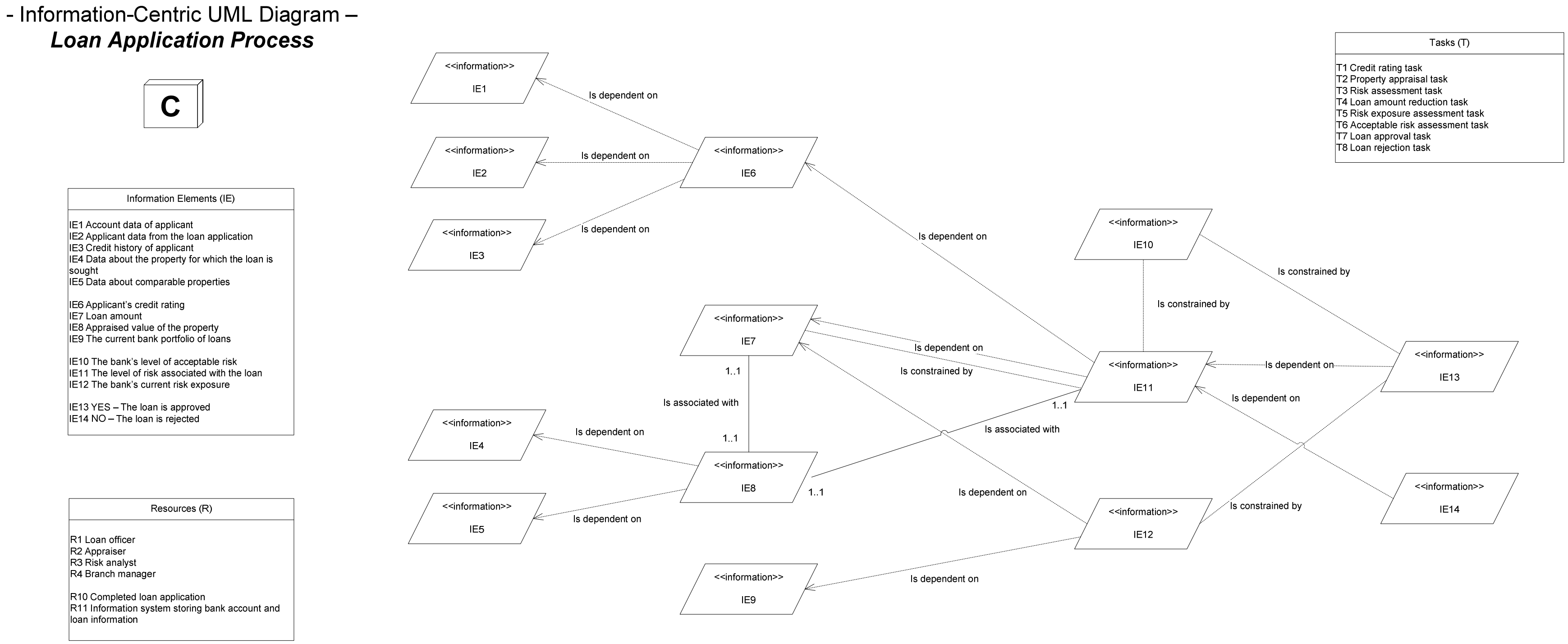


Figure 2-6. A UML conceptual model of the information-centric BPI of a loan application process as may be found in a BPM System[8].

[2-8] This is an original drawing based on UML extensions for business process modeling found in Eriksson and Penker (2000).

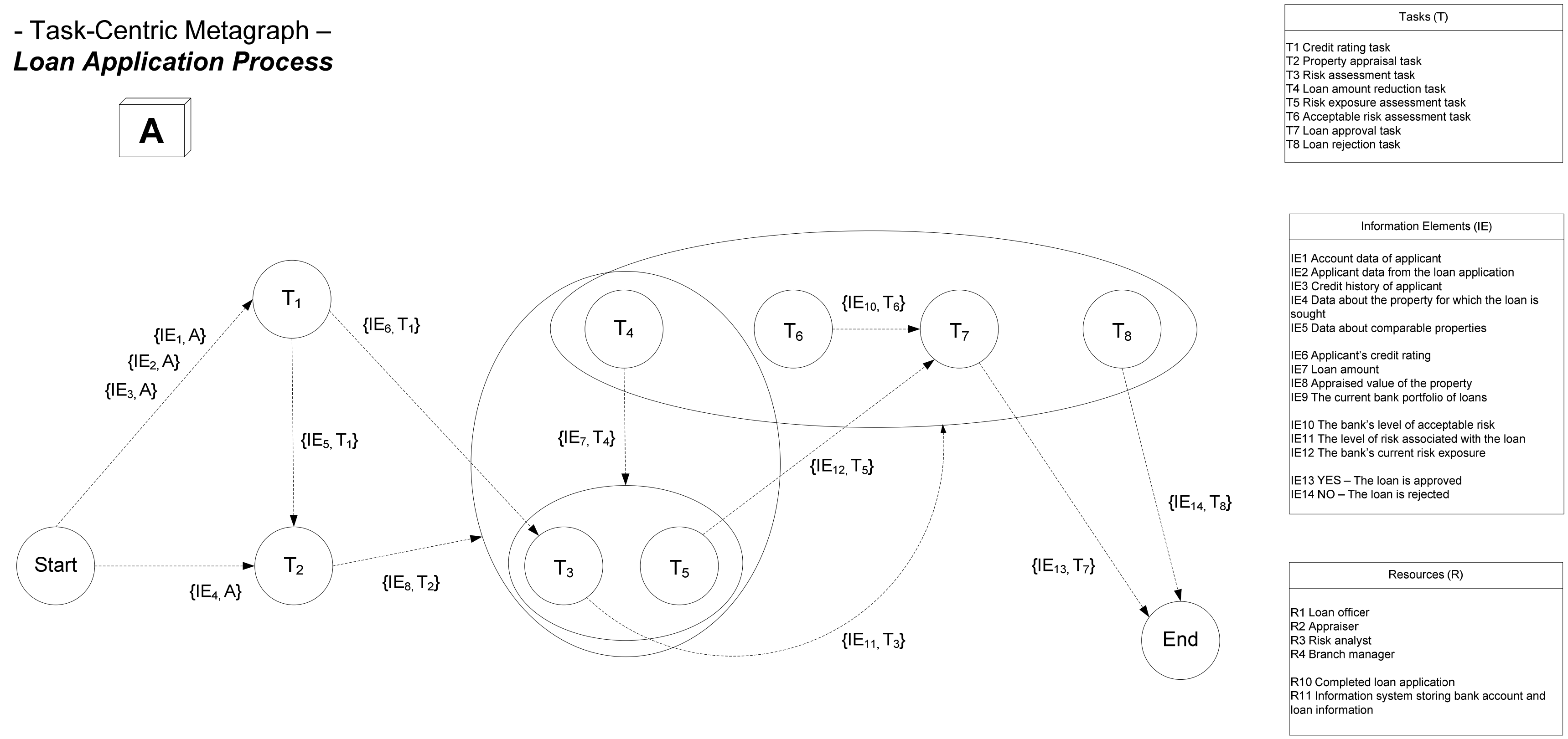


Figure 2-7. A metagraph of the task-centric BPI of a loan application process as may be found in a BPM System[9].

[2-9] This drawing is an adaptation of a metagraph diagram from Basu and Blanning (2000). Used by permission.

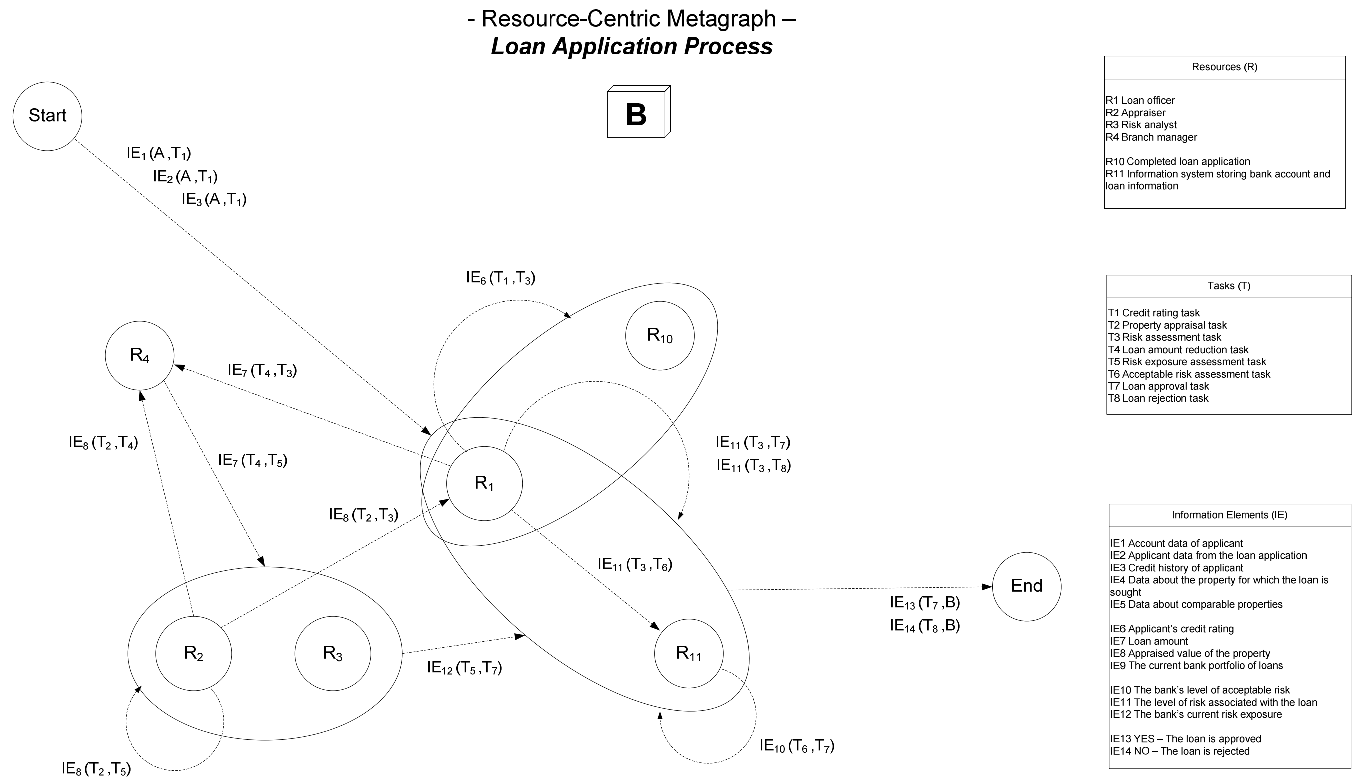


Figure 2-8. A metagraph of the resource-centric BPI of a loan application process as may be found in a BPM System[10].

[2-10] This drawing is an adaptation of a metagraph diagram from Basu and Blanning (2000). Used by permission.

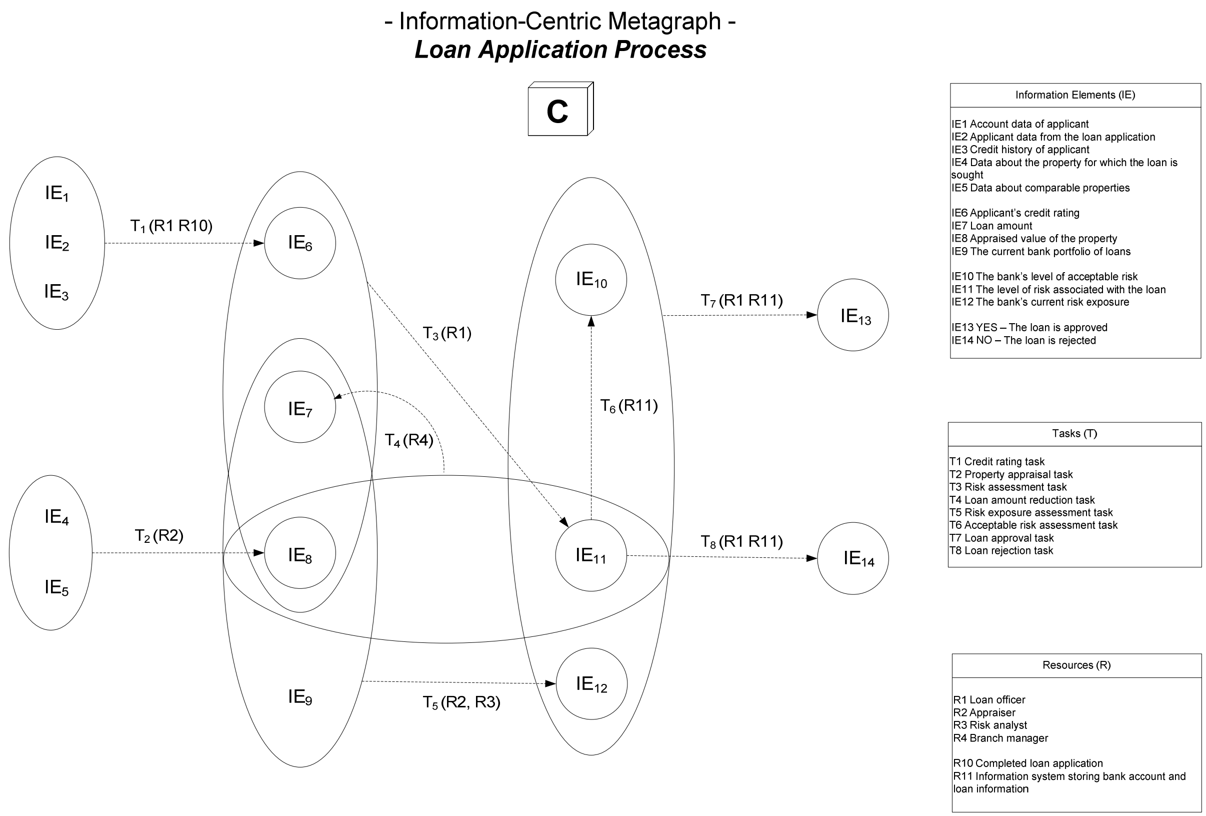


Figure 2-9. A metagraph of the information-centric BPI of a loan application process as may be found in a BPM System[11].

[2-11] This drawing is an adaptation of a metagraph diagram from Basu and Blanning (2000). Used by permission.

No empirical BPM Systems research was found that has studied the effects of formal GPMs on user comprehension of essential tacit and explicit BPM knowledge. Most of the BPM Systems literature has studied topics such as the application of GPM techniques to solve different BPM issues (cf. Basu & Blanning, 2000; Curtis et al., 1992; van der Aalst, 1994; Wohed et al., 2004), BPM Systems development issues (cf. van der Aalst et al., 2000; zur Muehlen, 2004c), BPM enterprise architectures and integration (cf. Vernadat, 2002a; Zachman, 1999; Zelm, Vernadat, & Kosanke, 1995), and case studies of BPM Systems (cf. Palmer, 2005; van der Aalst et al., 2003; Weske et al., 2004; zur Muehlen, 2004c). However, a primary goal of this research is to investigate if one type of GPM is more easily comprehended by novice users than another.

Some empirical research was found in cognitive ergonomics, information systems, and computer-assisted learning literature that has studied different GPM techniques in relation to user comprehension and task performance. For example, Agarwal, De, and Sinha (1999) experimentally compare user comprehension of object-oriented (OO) and process-oriented (PO) models in requirements analysis. Comprehension was assessed using the accuracy of participants' responses to questionnaires. Kabeli and Shoval (2005b) also compares user comprehension of PO vs. OO modeling approaches in the context of system development. In two controlled experiments, researchers compare GPM user comprehension of both industrial engineers and information systems analysts using advanced undergraduate students from two universities. Although these studies compare specific PO vs. OO modeling techniques, they do not provide a theoretical basis to help guide this study, because in this study, both UML and metagraph GPMs contain elements of both PO and OO models. These studies are typical of the topics and GPMs in prior empirical GPM user comprehension literature.

In a broader context, a great deal of research explores the use of external representations in stimulating memory and mental model development. For example, Cognitive Fit research seeks to explain task performance as the outcome of the “fit” between the external problem representation (i.e., an information artifact such as a GPM) and characteristics of the problem solving task (Agarwal et al., 1999; Sinha & Vessey, 1992; Vessey, 1991). Research on user comprehension of computer vs. paper displays of relevant information has shown mixed results. For example, Mayes et al (2001) found that users of computer monitors took significantly longer to comprehend information than users reading from paper. They also found the way in which information is displayed on computer screens affects the time it takes someone to read the information. Additionally, the best medium for conveying information seems to depend on which aspect of performance was most important and on how the information was displayed (e.g., illustrations, text, or both) (Mayes et al., 2001).

These studies suggest that a GPM that produces more positive user comprehension outcomes would better "fit" or "match" the task or problem characteristics. However, these studies lack an explanation or theory for why one GPM is a better "fit" or "match" than another. They also do not include all three of the BPM cognitive resources of interest in this study, nor do they suggest theory describing the interactions of the three BPM cognitive resources.

Another problem is that prior GPM user comprehension research does not typically involve the formal GPMs used in BPM Systems. Although GPM user comprehension research helps identify variables and assessment instruments for this study, prior research provides little guidance on which to base theoretical models and hypotheses. What theory that exists does not explain inconsistencies in research results. Inconsistent results may be because cognitive differences in the way individuals process information are not taken into account in these studies.

2.3.1.4 Ontological Completeness and GPM User Comprehension

The principle of Ontological Completeness (Wand & Weber, 1993) provides a theoretical basis for generating hypotheses to test the impacts of different GPMs on user comprehension. A primary objective of GPMs in BPM Systems is to minimize the time and mental workload required for various managers to accurately comprehend cross-functional BPI (Basu & Blanning, 2000; Luqi, Barnes, & Zyda, 1990; Vernadat, 2002b). BPM Systems literature suggests that some types of GPMs are better than others for reducing information overload that users experience when working with multiple views of a process (Basu & Blanning, 2000; Luqi et al., 1990; Vernadat, 2002b), but there is apparently no empirical research to support these claims.

The fundamental issue in this study is which type of GPM technique facilitates better user comprehension: a single modeling language to represent multiple views of a process (e.g., metagraphs) (Basu & Blanning, 2000; van der Aalst, 2004) or a different modeling language for each different view of a process (e.g., UML diagrams) (Eriksson & Penker, 2000; Vernadat, 2002b; Wand & Weber, 1993). Some authors claim that when a single GPM modeling technique is used to model multiple types of BPI, users have an easier time comprehending all the BPI portrayed. Basu and Blanning (2000) suggest that metagraphs are easier to comprehend, because there are only a few symbols used to model multiple types of business processes and BPI, compared to UML diagrams.

In contrast, several authors take the position that user comprehension is higher when different types of BPI are portrayed with different types of GPMs (Eriksson & Penker, 2000; Vernadat, 2002b; Wand & Weber, 1993). The principle of Ontological Completeness is an example of the latter position and provides a theoretical perspective to investigate this issue.

The principle of Ontological Completeness states that there needs to be a direct relationship between the design constructs used in GPMs and the ontological real-world constructs they represent (Wand & Weber, 1993). From an Ontological Completeness perspective, design constructs are symbols, notations, and semantics (i.e., GPM constructs) are used to explicitly map ontological (e.g., real-world) constructs. Users interpret these design constructs according to the meanings of the ontological constructs in the real-world from their individual points of view. Wand and Weber used the term 'completeness' to mean that a graphical grammar (e.g., the GPMs used in this study) must contain "constructs that enable it to model any real-world phenomenon in which a user is interested" (Wand & Weber, 1993, p. 220).

Therefore, ontologically speaking, once users are trained to read the symbols, they should be able to comprehend the BPI portrayed in GPMs when there is a one-to-one relationship between the graphical symbol and its meaning in the real-world (Wand & Weber, 1993). UML extensions designed for enterprise modeling are examples of this principle. Each type of BPI is mapped using different sets of graphical design constructs (symbols, semantics, notations, etc.). For example, activity diagrams use different symbols for modeling task-centric BPI than class diagrams use for modeling resource-centric BPI (compare Figures 2-4 to 2-5). Although proponents of UML expect it to take longer for users to learn to interpret the various UML diagrams, once trained the principle of Ontological Completeness suggests that user comprehension will be more accurate and timely than metagraphs (Wand & Weber, 1993) (see Figure 2-10 below).

This is because, from an ontological completeness point of view, metagraphs are expected to produce just the opposite result – construct overload (see Figure 2-10). Metagraphs are expected to cause construct overload because it uses the same set of symbols to represent multiple meanings in the real world. For example, metagraphs use the same symbols to represent all types of BPI, whether task-centric, resource-centric, or information-centric. Construct overload causes a user to have a difficult time comprehending the real-world meanings of the graphical design constructs represented by the GPMs because each graphical construct represents multiple meanings in the real-world. Therefore, metagraph user comprehension outcomes are expected to be less desirable than the results for users of UML diagrams (see Figure 2-10 below). Although this is a logical argument, no empirical evidence has been found to support either of these two positions.

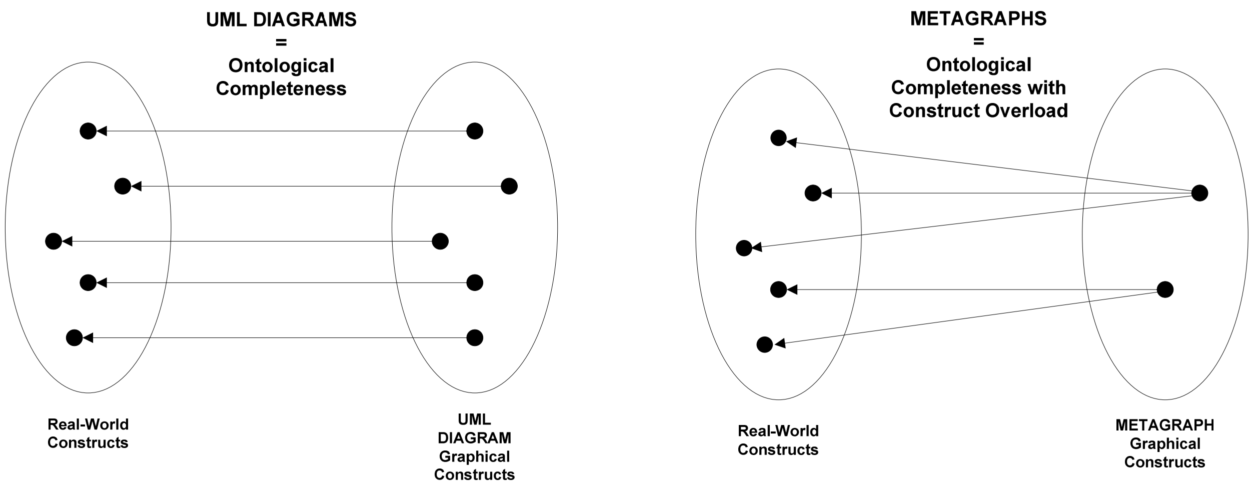


Figure 2-10. Metagraph vs. UML diagrams and how they relate to the principle of Ontological Completeness[12].

2.3.1.5 Hypotheses Concerning the Type of Graphical Process Model

Based on the theory of Ontological Completeness, it is hypothesized that UML diagrams will produce more favorable GPM user comprehension outcomes than metagraphs.

Hypothesis 1: The type of graphical process model will significantly affect participants' task performance (i.e., accuracy and timeliness), subjective mental workload, and self-efficacy.

Hypothesis 1.1: Participants using UML diagrams will produce significantly higher accuracy than participants using metagraphs.

Hypothesis 1.2: Participants using UML diagrams will produce significantly better timeliness time than participants using metagraphs.

Hypothesis 1.2: Participants using UML diagrams will experience significantly lower subjective mental workload than participants using metagraphs.

[2-12] Adapted from Wand & Weber (1993). Used by permission.

> **Hypothesis 1.4:** Participants using UML diagrams will experience significantly higher self-efficacy than participants using metagraphs.

2.3.2 Explicit BPM Knowledge Operationalized as the Type of Business Process Information

Research Question 2: *How do different types of BPI influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*

When using BPM Systems, making good decisions requires managers to comprehend different types of BPI portrayed by GPMs (Crosman, 2004; van der Aalst et al., 2003; Weske et al., 2004). For example, Green and Roseman (2000) analyzed five different views of a business process and concluded that the process-BPI view (what is referred to as the task-centric BPI view) alone is not enough to model all the real-world constructs required in relation to BPM. This study compares three types of BPI necessary for BPM (Basu & Blanning, 2000; Vernadat, 2002b):

- Task-centric BPI documents the sequential flow of business process activities so that BPM systems can simulate, monitor, analyze, and control aspects of these business processes. Relationships between tasks and their supporting resources and information elements can also be displayed (see Figures 2-4 and 2-7).

- Resource-centric BPI depicts relationships between resources (i.e., physical, personnel, or information-related resources). They also depict relationships between tasks and information elements in order to show the impacts of resource allocation configurations on business processes (see Figures 2-5 and 2-8).

- Information-centric BPI defines BPM documentation, information flows, data relationships, and aid in checking completeness and correctness of BPI. They can also show the relationships of information elements to resources and tasks (see Figures 2-6 and 2-9).

2.3.2.1 Type of Business Process Information and GPM User Comprehension

Nevertheless, a variety of research suggests that the type of BPI will affect GPM user performance (Basu & Blanning, 2000; Vessey, 1991; Zhang, 1996b). For example, Relationship Informational Display (RID) research states that better task performance will result when the information perceived from an information display exactly matches the information required for task performance (Zhang, 1996b, 1997; Zhang & Norman, 1994). For example, if users of information-centric BPI perform worse than users of task-centric BPI, the RID perspective says that the reason for poor task performance is that there is a poor match between the way information-centric BPI is portrayed and the BPI requirements of the task. However, RID literature does not explain why the relation between the information and the task produces good or poor performance.

2.3.2.2 Hypotheses Concerning the Type of Business Process Information

Based on the previous research, albeit limited, it is hypothesized that differences in the type of BPI will produce more favorable GPM user comprehension outcomes. Specific sub-hypotheses are based more on practical logic than prior research, because there was no specific research found that provide guidance for these sub-hypotheses. Training on process flowcharts is a common element across all BPM manager education and experience (to one extent or another). Thus, GPM portrayals of task-centric BPI is expected to be more familiar to all participants, because task-centric BPI is interpreted to be similar to process flowcharts. Regarding resource-centric BPI, the impacts of one resource on another is seldom modeled. Thus, resource-centric BPI is hypothesized to be the least recognizable and most difficult for users to comprehend. Information-centric BPI is hypothesized to be more familiar than resource-centric BPI, because its graphical portrayal often resembles task-centric BPI diagrams but it is not interpreted in the same way.

> **Hypothesis 2:** The type of business process information will significantly affect participants' task performance (i.e., accuracy and timeliness) and subjective mental workload[13].
>
> > **Hypothesis 2.1:** Participants using GPMs portraying task-centric BPI will produce significantly higher accuracy compared to resource- or information-centric BPI.
> >
> > **Hypothesis 2.2:** Participants using GPMs portraying task-centric BPI will produce significantly better timeliness compared to resource- or information-centric BPI.
> >
> > **Hypothesis 2.3:** Participants using GPMs portraying task-centric BPI will experience significantly lower subjective mental workload compared to resource- or information-centric BPI.

---

[13] Self-efficacy was not measured within-subjects so it is not included in this hypothesis.

Hypothesis 2.4: Participants using GPMs portraying resource-centric BPI will experience significantly lower accuracy compared to task- or information-centric BPI.

Hypothesis 2.5: Participants using GPMs portraying resource-centric BPI will produce significantly worse timeliness compared to task- or information-centric BPI.

Hypothesis 2.6: Participants using GPMs portraying resource-centric BPI will experience significantly higher subjective mental workload compared to task- or information-centric BPI.

Hypothesis 2.7: Participants using GPMs portraying information-centric BPI will produce significantly higher accuracy compared to resource-centric BPI.

Hypothesis 2.8: Participants using GPMs portraying information-centric BPI will produce significantly better timeliness compared to resource-centric BPI.

Hypothesis 2.9: Participants using GPMs portraying information-centric BPI will experience significantly higher subjective mental workload compared to resource-centric BPI.

2.3.3 Tacit BPM Knowledge Operationalized as Different Types of User Educational Training

Research Question 3: *How do different types of User Educational Training influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*

Thus, this question seeks to understand the effect of tacit BPM knowledge on GPM user comprehension. As described above, tacit knowledge can be acquired through both education and experience but is difficult to express or document without specific situational cues (Hislop, 2002). Because GPMs portray explicit BPM knowledge, GPMs are capable of only partially mapping the knowledge necessary to manage business processes, especially when these processes become more dynamic and knowledge-intensive (Gronau & Weber, 2004) (see Section 2.1.1). Consequently, BPM Systems can only portray explicit BPM knowledge and do not portray tacit BPM knowledge. However, GPM comprehension of BPI facilitates and stimulates users to apply their tacit knowledge to make BPM decisions (see Section 2.3.3). Therefore, BPM Systems are expected to facilitate user comprehension, irrespective of the type of tacit BPM knowledge and educational training a manager may possess (Basu & Blanning, 2000; Light, 2005; Weske et al., 2004; zur Muehlen, 2004a):

> "*Senior executives* need to understand what information elements are required and produced by a process and what resources are needed. *Process managers* need to

> understand how the tasks in each workflow[14] interact with each other through the information elements they use and produce. *Information technology managers* need to understand how information elements, tasks, and resources interact, so that effective operational and decision support systems can be designed." (Basu & Blanning, 2000, p. 17) [emphasis added]

However, past research describes how differences in user tacit knowledge affect their comprehension of the same information.

2.3.3.1 Schema Theory and GPM User Comprehension

Prior tacit and explicit knowledge significantly affects user comprehension outcomes because of their cognitive schema and mental models. A schema, introduced by Bartlett (1932), are ''mental representations of general categories of objects, events, or people'' (Bernstein, Roy, Skrull, & Wickens, 1991, p. 321). Schema theory also include knowledge structures used in human memory (Satzinger, 1998). Piaget described schemas as the basic building blocks of knowledge, learning, and intellectual development that people use to understand the world around them and suggests learning is achieved by forming new schemas and building upon previous schemas (Piaget, 1983). He proposed that two processes that guide learning: the creation of new schemas and the adaptation of existing schemas. According to Piaget, the adaptation of schemas involves the incorporation of new information into existing schemas or the adaptation of existing schemas to include new information that may not fit into existing schemas (Gruber & Gruber, 1977; Piaget, 1983). Schemas are interrelated, and multiple conflicting schemata can be applied to the same situation.

People use their schemas to reduce the amount of effort they used to understand the situations they experience. People quickly organize new perceptions into schemas and then use these schemas to act effectively, almost automatically, with little mental effort. In cognition theory, this is referred to as accessibility; meaning how easily and quickly a schema comes to mind. Accessibility is determined by individual experience and expertise (Chalmers, 2003). For example, expert interpreters of GPMs will rely on their schemas to quickly process and understand information portrayed by GPMs. Novice learners are those who have little or no knowledge of a given topic or situation. Novice GPM users possess few schemas that can aid them in user comprehension, therefore the mental workload they experience will be

[2-14] In this instance, the term workflow refers to a single execution of an instance of a business process (Basu & Kumar, 2002). Thus, when "workflow" is used in this study, it means essentially the same as the term "business process."

high due to a much higher amount of cognitive effort to perceive and process GPM information and organize it into new schemas.

Relating schema theory to this study means that an individual's tacit knowledge related to BPM and GPMs is expected to allow greater accessibility and application of an individual's relevant schema. Consequently, GPM user comprehension should produce higher accuracy, greater timeliness, lower mental workload, and greater self-efficacy than those that cannot access or create relevant schemas. For example, a manager with tacit knowledge in computer science and object modeling should comprehend information-centric views of a business process more accurately, quickly, and efficiently than a manager without tacit knowledge gained from computer science education.

2.3.3.2 Mental Models, Schema Theory, and GPM User Comprehension

Within these cognitive schemas, individuals develop specific mental models from their experiences which they use to cognitively process and understand information in specific situations (Gentner & Stevens, 1983). Individuals instinctively rely on their mental models, as well as their cognitive schema, to cognitively process information when making decisions and taking action when performing a new task. Even though an individual may possess schemas that apply to a general topic or situation, without the associated mental models, they will not be able to understand the specific complexities of different situations. For example, novices may possess an understanding of the syntax of a programming language, but without the associated mental models they will be unable to successfully understand complex concepts or employ more difficult aspects of problem solving in their programming (George, 2000).

A mental model is an explanation of an individual's thought process for how something works in the real world (Gentner & Gentner, 1983; Gentner & Stevens, 1983; Norman, 1983). The concept of mental models in relation to cognition was introduced by Craik (1943). He proposed that individuals use their internal mental models of the external world to help them better understand and react to the situations they encounter. Mental models are created by an individual's interaction with external events in their life. Craik suggests that people think, reason, or understand by manipulating internal symbolic representations and translate them back into actions, or that they recognize relationships between their internal mental models and external events. There are at least two bodies of research related to mental models: (1) mental models concerned with analogy and insight problems involving classical syllogisms (Johnson-Laird, 1983) and (2) mental models as theoretical constructs used to account for various aspects of behavior especially in novel problem solving situations (Gentner & Gentner, 1983; Norman, 1983).

This research primarily concerned with mental models as a participant's specific mental representations, knowledge of processes, or complex tasks or systems related specifically to how to interpret different types of GPMs which allows the participant to reason, predict and understand the particular GPM syntax, GPM type, or business process (c.f. J. M. Carroll & Olson, 1987; Eysenck & Keane, 1990; George, 2000; Kieras & Bovair, 1984). As a result, more positive outcomes should result when an individual's schema and mental models are aligned with GPM user comprehension task requirements.

2.3.3.3 Prior Expertise and GPM User Comprehension

Several literatures report that individuals possessing specific tacit knowledge from prior education or experience achieve higher levels of task performance than individuals without prior expertise (Shayo, Olfman, & Teitelroit, 1999). For example, Agarwal, Sinha, and Tanniru (1996) found that prior experience helped in developing solutions to object-oriented tasks, but did not have an impact on developing solutions to process-oriented tasks (Agarwal et al., 1996; Morris et al., 1999). Several studies in the psychology of programming literature report that when an individual had prior knowledge or experience in interpreting different types of information, their task performance was improved (cf. Schneiderman et al., 1977; Sheil, 1981; Soloway, Ehrlich, & Bonar, 1982; Winslow, 1996). Several other experimental studies show prior education and experience affects task performance in a variety of research topics, including educational technologies (cf. Kalyuga, Ayres, Chandler, & Sweller, 2003; Moreno, 2002; Valcke & Dochy, 1992) and HCI (cf. Decortis, Noirfalise, & Saudelli, 2000; Hollnagel, 1997; Marmaras & Kontogiannis, 2001; Morrow et al., 2003; Postrel, 2002).

Literature describing just how "expert" users should be in UML or metagraphs is nonexistent. Related literatures, such as operations research and the psychology of programming literatures, have explored various ways to determine if someone is an expert or not. Winslow (1996) reviews research related to determining the characteristics of novice vs. expert programmers. Shanteau, Weiss, Thomas, & Pounds (2002) propose the use of the Cochran-Weiss-Shanteau survey instrument "in the absence of a gold standard" for determining expertise in specific domains. Developing an approach to determine novice vs. expert GPM users that includes specific BPM expertise characteristics may be of value in the future.

2.3.3.4 GPMs are Expected to Mitigate Differences in Prior Expertise

Wand and Weber (2002, p. 372) suggest that a goal of GPM techniques and training is to mitigate expert-novice differences in user comprehension. This outcome may possibly result from GPMs being able to validate both conceptual models and users conceptual schema at the same time (Fonseca, 2007). Although apparently never studied, Wand and Weber's (1993) theoretical assertions explain the mixed results in prior GPM user comprehension research. In other words, the principle of Ontological Completeness may explain why more variation in GPM user comprehension outcomes than differences between user education and tacit knowledge.

2.3.3.5 Hypotheses Concerning the Type of User Educational Training

Despite Wand and Weber's (1993; 2002) assertions, the preponderance of research on prior expertise cannot be ignored. Therefore, Hypothesis 3 says there will be differences in user comprehension between participants possessing different user educational training. In this study, tacit BPM knowledge is operationalized as user educational training in a BPM-related general functional domain (e.g., industrial engineering (IE), business management (MGT), or computer science (CS)). Participants with MGT educational training are selected to approximate the education of senior executives' and other business managers and, as a result, approximate a major part of their management tacit BPM knowledge. Participants with IE educational training are selected to approximate the education of process managers' and, as a result, approximate a major part of their business process tacit BPM knowledge. Lastly, participants with CS educational training are selected to approximate the education of IT managers and, as a result, approximate their IT tacit BPM knowledge (see also Section 3.9.2.1).

Specific sub-hypotheses are based more on practical logic than previous research, because there was no specific research on BPM-related GPM user educational training to provide guidance for these sub-hypotheses. These sub-hypotheses propose that CS majors will perform more favorably than both IE and MGT majors for several reasons. CS students are highly trained in mathematical modeling, which is the fundamental difference between the formal GPMs used in BPM systems and traditional flowcharts. CS students also receive training in information systems development, such as object-oriented programming and database modeling, which should help them understand the resource and information-centric BPI relationships being modeled in this study, regardless of which type of GPM they use.

In contrast to CS and IE student education, MGT students typically do not receive training in the mathematical modeling of processes, information system development, object-oriented programming, or database modeling. However, most MGT students have been exposed to traditional process flowcharting techniques.

In contrast to MGT and CS students, IE students are highly trained and experienced in mathematical modeling, particularly of business processes, but typically do not receive training or experience in information systems development or database modeling-related knowledge. Therefore, it is hypothesized that CS students will produce more positive user comprehension outcomes, followed by IE students. MGT students will product the worst overall user comprehension outcomes. The following research hypotheses are proposed to test the direct effects of user educational training on GPM user comprehension outcomes:

Hypothesis 3: The type of user educational training of participants will significantly affect participants' task performance (i.e., accuracy and timeliness), subjective mental workload, and self-efficacy.

Hypothesis 3.1: Computer science majors will produce significantly higher accuracy compared to Industrial Engineering and Management majors.

Hypothesis 3.2: Computer science majors will produce significantly better timeliness compared to Industrial Engineering and Management majors.

Hypothesis 3.3: Computer science majors will experience significantly lower subjective mental workload compared to Industrial Engineering and Management majors.

Hypothesis 3.4: Computer science majors will experience significantly higher self-efficacy compared to Industrial Engineering and Management majors.

Hypothesis 3.5: Management majors will produce significantly lower accuracy compared to Industrial Engineering and Computer Science majors.

Hypothesis 3.6: Management majors will produce significantly worse timeliness compared to Industrial Engineering and Computer Science majors.

Hypothesis 3.7: Management majors will experience significantly higher subjective mental workload compared to Industrial Engineering and Computer Science majors.

Hypothesis 3.8: Management majors will experience significantly lower self-efficacy compared to Industrial Engineering and Computer Science majors.

Hypothesis 3.9: Industrial Engineering majors will produce significantly higher accuracy compared to Management majors.

Hypothesis 3.10: Industrial Engineering majors will produce significantly better timeliness compared to Management majors.

Hypothesis 3.11: Industrial Engineering majors will experience significantly lower subjective mental workload compared to Management majors.

Hypothesis 3.12: Industrial Engineering majors will experience significantly higher self-efficacy compared to Management majors.

2.4 Individual Cognitive Differences and User Comprehension

GPM user comprehension is influenced by individual cognitive differences between users that impact how the BPM cognitive resources are mentally processed during user comprehension. Pearson et al. (2002) said the consideration of social phenomena and human factors in modeling enterprise networks has been neglected and must be considered. As a result, related literature, such as HCI and cognitive ergonomics, often includes variables assessing individual cognitive differences based on IP theory and cognitive psychology research.

This section reviews three primary types of individual cognitive differences between individuals that cognitive science literature suggest can jointly influence user comprehension: mental workload, cognitive styles, and cognitive abilities. Mental workload attempts to assess, subjectively or physiologically, how taxing the mental processing of information is on a user when performing a task. The cognitive styles of a user corresponds to personality-based filters that affect how a user cognitively processes information. The cognitive abilities of a user corresponds to a variety of inherent and learned cognitive and attentional abilities that affect an individual's ability to cognitively process information.

2.4.1 Mental Workload, Task Performance, and the Yerkes-Dodson Law

Research Question 4: *When interpreting graphical business process information, does the relationship between user subjective mental workload and task performance follow the Yerkes-Dodson Law (an inverted-U relationship)?* This question investigates the relationship between mental workload, task accuracy, and task timeliness in the context of BPM and BPM Systems.

Wickens (1992) defines workload as the relationship between task demand and the supplied resources. According to Wickens' definition, both task complexity and the type of cognitive resource can be seen as elements of mental workload. When the information that is inputted to an individual's mind approaches or exceeds the limits of an individual's cognitive capacity, the mental workload experienced by the individual is increased and the individual manifests physical and psychological indicators (cf. Baddeley, 2003b; Braarud, 2001; Kirschner, 2002; Miyake, 2001; Paas, Tuovinen et al., 2003; Wickens, 1992).

2.4.1.1 Physiological Indicators of Mental Workload

Mental workload is used as both an indicator of cognitive processing load and an outcome of comprehension. Often physiological indicators of mental workload are used to indirectly assess the cognitive load a person experiences during task performance (Wilson & Russell, 2003). Physiological mental workload indicators that are found in the literature include heart rate variability (Miyake, 1997), blood pressure (Van Roon, Mulder, Althaus, & Mulder, 2004), respiration patterns (Wilson & Russell, 2003), perspiration (Miyake, 2001), finger plethysmogram amplitude (Miyake, 2001), electrodermal assessments (Collet, Petit, Champely, & Dittmar, 2003), neurophysiological measures such as electroencephalography (EEG) and electrocardiography (ECG) (Dussault, Jouanin, Philippe, & Guezennec, 2005), and eye movements related to the operator's blinking and fixation on regions of interests (Ha, Kim, Lee, & Seong, 2006).

Physiological measures of mental workload have not proved consistently reliable (Miyake, 2001; Rubio, Díaz, Martín, & Puente, 2004; Vitense, Jacko, & Emery, 2003). They have been shown to produce inconsistent results when assessing mental workload (cf. Hart & Wickens, 1990; Miyake, 1997, 2001; Vitense et al., 2003; Wickens, 1992; Wilson & Russell, 2003). Although sensitive to workload, Miyake (1997) found heart rate variability, respiration patterns, and perspiration has not been found to be consistent and reliable indicators of mental workload. On the other hand, Dussault (2005) asserted that electrophysiological changes expressed variations in mental workload during different flight simulator sequences. These inconsistencies are partly due to a variety of environmental and psychological factors that can influence physiological indicators but they have little to do with mental workload. Additionally, results of the task specific physiological responses are affected by individual characteristics like a Type A behavior patterns (Miyake, 1997). Another disadvantage is that physiological measures cannot be easily administered to a large number of people at one time (Yeung, Lee, Pena, & Ryde, 2000).

2.4.1.2 Subjective Indicators of Mental Workload

Subjective self-reports of mental workload are assessed immediately after task performance, where individuals are asked to evaluate the mental workload they experience during task performance. Assessments of subjective mental workload are generally accepted as being composed of multiple subscales or dimensions (cf. Hart & Staveland, 1988; Paas, Tuovinen et al., 2003; Yeung et al., 2000):

- The task is highly mentally or physically demanding (cf. Hart & Staveland, 1988; Paas, Tuovinen et al., 2003; Yeung et al., 2000).
- A high level of concentration or mental effort is required (cf. Fisher & Ford, 1998; Hart & Staveland, 1988; Yeung et al., 2000).
- Time pressure in performing the task (cf. Fisher & Ford, 1998; Hart & Staveland, 1988; Mullane & McKelvie, 2001; Yeung et al., 2000).
- Negative affect or frustration with the task (cf. Hart & Staveland, 1988; Yeung et al., 2000).
- Satisfaction with the individual's task performance (cf. Dunn & Grabski, 2001; Hart & Staveland, 1988; Reinig, 2003; Yeung et al., 2000).

A variety of subjective mental workload research is found in cognitive ergonomics literature (cf. Braarud, 2001; Hart & Staveland, 1988; Miyake, 1997; Wickens, 1992). For example, the NASA Task Load Index (TLX) (Hart & Staveland, 1988) has been used to assess subjective mental workload in several contexts, including research on the use of mobile telephones while driving (Alm & Nilsson, 1995), radar systems for air traffic control (Bierwagen, Eyferth, & Helbing, 1996), as well as, nuclear reactor simulation or operational situations (Braarud, 2001). Another derivation of subjective mental workload is called Cognitive Load Theory (cf. Kirschner, 2002; Paas, Tuovinen et al., 2003; Yeung et al., 2000) found primarily in learning and educational technology literature.

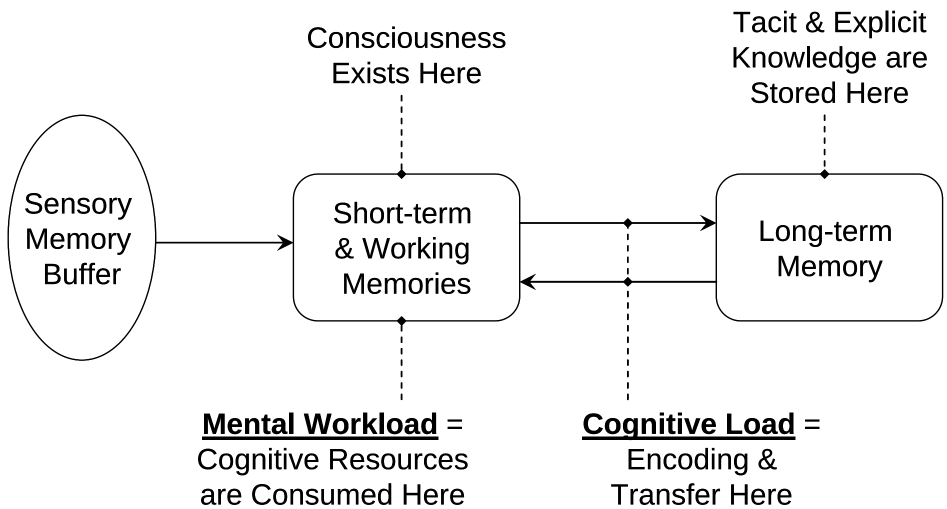


Figure 2-11. How mental workload and cognitive load relates to cognitive memory stores.

Although related, subjective evaluations of mental workload and cognitive load assess and influence different areas of memory and cognition (see Figure 2-11). Mental workload is associated with the processing of cognitive resources in short-term and working memories (Hart & Wickens, 1990; Miyake, 2001). Cognitive load is associated with the encoding and transfer of tacit and explicit knowledge between the short-term, working, and long-term memories (Kirschner, 2002; Paas, Renkl et al., 2003). This research is focused on mental workload and not cognitive load.

Self-report measures of subjective mental workload constructs, such as the NASA-TLX, were shown to be both valid and reliable (cf. Annett, 2002; Braarud, 2001; Collet et al., 2003; Hart & Wickens, 1990; Hill et al., 1992; Jung & Jung, 2001; Kirschner, 2002; Miyake, 2001; Moroney, Biers, & Eggemeier, 1995; Nygren, 1991; Paas, Tuovinen et al., 2003; Rubio et al., 2004; Vitense et al., 2003; Wickens, 1992; Wickens & Carswell, 1995; Wilson & Russell, 2003). However, subjective mental workload assessments can suffer from the disadvantages of self-report instruments and sometimes differences in statistical validity results (Annett, 2002; Braarud, 2001; Hart & Wickens, 1990; Moroney et al., 1995; Rubio et al., 2004). As a consequence, physiological assessments are often used in conjunction with subjective mental workload assessments to triangulate and interpret results (cf. Ha et al., 2006; Lee & Liu, 2003; Miyake, 1997, 2001; Vitense et al., 2003; Wickens, 1992).

2.4.1.3 The Yerkes-Dodson Law Relating Mental Workload and Task Performance

Research shows that mental workload and task performance (including task accuracy and task timeliness) are distinct but interrelated constructs. For example, different individuals may experience identical levels of task accuracy and timeliness when performing the same task, but the mental workload they experience may differ considerably. Paas, Tuovinen, Tabbers, and Van Gerven (2003, p. 67) explains this interrelationship:

> "Within the limits of their cognitive capacity, learners can compensate for an increase in mental load (e.g., increasing task complexity) by investing more mental effort, thereby maintaining performance at a constant level. Consequently, the cognitive costs associated with a certain performance level cannot be consistently inferred from performance-based measures. Instead, the combination of measures of mental effort and performance can reveal important information about cognitive load, which is not necessarily reflected by performance and mental load measures alone."

Although Paas et al. are proponents of Cognitive Load Theory, this quote describes the a generic relationship between mental workload and performance that is better conceptualized as the Yerkes-Dodson Law (Yerkes & Dodson, 1908).

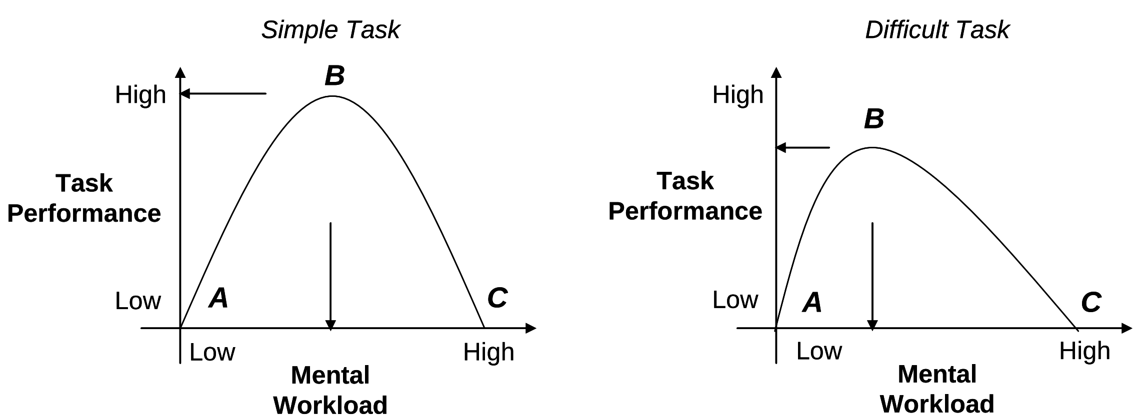


Figure 2-12. Illustration how differences in task difficulty is conceptualized by the Yerkes-Dodson Law.

Introductory psychology textbooks describe the relationship between mental workload and task performance as having an inverted-U relationship; commonly referred to as the Yerkes-Dodson Law (Hancock & Ganey, 2003; Teigen, 1994; Winton, 1987). In general, the Yerkes-Dodson Law suggests that an increase in mental workload is expected to create an increase in task performance. Reduced performance is expected when mental workload exceeds the available cognitive capacities of the individual. For example, a manager can compensate for increases in task complexity by applying greater concentration and mental effort when performing a task, and consequently may achieve higher levels of task performance (see A in Figure 2-12). When a manager reaches the limit of his or her mental capacity, the highest level of task performance is reached. At this point, an optimal relationship exists where the lowest level of mental workload an individual experiences produces the highest level of task performance without overwhelming or underwhelming the individual (see B in Figure 2-12). After this point, a manager has exceeded his or her mental capabilities and may feel overwhelmed or overloaded. Any increase in mental workload beyond this optimal point produces a decrease in task performance despite applying greater attention or mental effort (see C in Figure 2-12).

Figure 2-12 also demonstrates the effect of task difficulty on the relationship between mental workload and task performance as conceptualized by the Yerkes and Dodson Law. When people perceive a task as simple, a higher level of task performance can be achieved by exerting more mental workload. However, when a task is perceived as difficult, the optimal level of task performance in achieved as a lower level of mental workload. After this point, more mental effort only results in decreased levels of performance. As a result, simpler tasks can achieve relatively higher levels of performance compared to more difficult tasks.

Although widely accepted as a basic psychological relationship, empirical research has not reliably supported the Yerkes-Dodson relationship (Broadhurst, 1959; Teigen, 1994). For example, Fisher and Ford (1998) finds subjective mental workload subscales as strong predictors of time on task and learner outcomes (including accuracy). On the other hand, Rose et al.'s (2002) study of vigilance tasks[15] concludes that subjective mental workload and task performance do not always relate to one another (a finding also supported by several studies Rose et al. (2002) cite). This lack of support for the Yerkes-Dodson law was not entirely unexpected. Teigen's (1994) historical analysis found that the original Yerkes and Dodson research has been adapted over the last century to fit the needs of various researchers while often disregarding or ignoring the fundamental constructs Yerkes and Dodson originally studied. Teigen (1994, p. 543) traced the history of the Yerkes-Dodson law from its inception in 1908 until the present, summarizing their findings in this way:

[2-15] A "vigilance task" is a task that requires sustained, concentrated attention over time to complete (Rose et al., 2002).

> "These reanalyses underscore the discrepancy between the schematic, idealized textbook presentations of the [Yerkes-Dodson] 'law', and its more messy empirical and historical basis."

Most authors citing Yerkes' and Dodson's research have altered the meaning of the original variables and excluded task difficulty as a key factor (Broadhurst, 1959; Teigen, 1994). As a result, the so-called Yerkes-Dodson, inverted-U relationship has primarily come to be more of a simplified tool for communicating psychological relationships than an empirically verifiable psychological "law."

Nevertheless, the Yerkes-Dodson Law is well-established in cognitive ergonomics and cognitive psychology literature. No alternative theory was found; therefore, this study will test this relationship to extend this concept to BPM Systems and add more empirical evidence that either asserts or refutes its applicability to GPM user comprehension research.

2.4.1.4 Hypotheses Relating Subjective Mental Workload to User Comprehension Outcomes

These hypotheses test the Yerkes-Dodson Law in the context of GPM user comprehension. Both measures of task performance in this study (accuracy and timeliness) are hypothesized to produce an inverted-U relationship when graphed against NASA TLX assessments (Hart & Staveland, 1988) of subjective mental workload.

> **Hypothesis 4**: Participants' subjective mental workload will significantly affect task performance (i.e., task accuracy and timeliness) in inverted-U relationships (in accordance with the Yerkes-Dodson Law).
>
> > **Hypothesis 4.1**: Low subjective mental workload will be associated with low accuracy.
> >
> > **Hypothesis 4.2**: Moderate subjective mental workload will be associated with high accuracy.
> >
> > **Hypothesis 4.3**: High subjective mental workload will be associated with low accuracy.
> >
> > **Hypothesis 4.4**: Low subjective mental workload will be associated with low timeliness.
> >
> > **Hypothesis 4.5**: Moderate subjective mental workload will be associated with high timeliness.
> >
> > **Hypothesis 4.6**: High subjective mental workload will be associated with low timeliness.

2.4.2 Subjective Mental Workload and Self-Efficacy

Research Question 5: *When interpreting graphical business process information, how does user subjective mental workload relate to their self-efficacy after task completion?*

As more and more users utilize BPM Systems, user self-confidence in interpreting formal GPMs is important to take into account. Therefore, the relationship between self-efficacy and subjective mental workload is important to study in the context of GPM user comprehension tasks.

2.4.2.1 Self-Efficacy

Most self-efficacy research is based on Social Cognitive Theory (Bandura & Locke, 2003; Wood & Bandura, 1989). Self-efficacy is defined by Bandura (1986, p. 391) refers to:

> "People's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances. It is concerned not with the skills one has but with the judgments of what one can do with whatever skills one possesses."

Self-efficacy has been studied as an antecedent, mediator, and outcome of such dependent variables as anxiety, task performance, outcome expectancy, and computer usage (cf. Bandura & Locke, 2003; Compeau, Higgins, & Huff, 1999; Fagan, Neill, & Wooldridge, 2003; Marakas, Yi, & Johnson, 1998; Ryan, Bordoloi, & Harrison, 2000; Wood & Bandura, 1989). "People with strong self-efficacy beliefs exert greater efforts to master a challenge while those with weak self-efficacy beliefs are likely to reduce their efforts or even quit." (Staples, Hulland, & Higgins, 1999, p. 759). Consequently, self-efficacy is considered an outcome of user comprehension, as well as an antecedent of task performance.

2.4.2.2 Self-Efficacy is Highly Task-Specific

Self-efficacy refers to what a person perceives their capabilities to be with regard to a specific task (Marakas et al., 1998). Self-efficacy is highly task or context-specific (Staples et al., 1999). For example, Staples et al. (1999) empirically concludes that there is a difference between remote work self-efficacy vs. information technology self-efficacy. Wood, Atkins, & Tabernero (2000) study asserted that there are distinctive differences between information search efficacy and information processing efficacy on complex tasks. However, no research has studied GPM user comprehension self-efficacy or self-efficacy in the context of BPM. Consequently, no self-efficacy instrument exists for use in this study.

2.4.2.3 Self-Efficacy as an Outcome of Mental Workload

Self-efficacy literature discusses antecedents of self-efficacy that directly relate to subjective mental workload constructs and provides a basis for establishing a conceptualizing self-efficacy in the context of GPM user comprehension tasks. Self-efficacy has been studied as an antecedent or mediator of such dependent variables as anxiety, task performance, outcome expectancy, and computer usage (Bandura & Locke, 2003; Compeau et al., 1999; Fagan et al., 2003; Marakas et al., 1998; Ryan et al., 2000; Wood & Bandura, 1989). Although, apparently no research has explicitly studied subjective mental workload as an antecedent to self-efficacy, several studies have shown specific antecedent relationships between self-efficacy and emotional arousal (i.e., stress, anxiety) that is associated with mental workload (Fagan et al., 2003; Staples et al., 1999). For example, Bandura's Social Cognitive Theory listed several antecedents or correlates of self-efficacy that are directly related to the subjective mental workload constructs discussed in Section 2.4.1 (Bandura, 1986; Hart & Staveland, 1988; Johnson & Marakas, 2000; Staples et al., 1999):

- Anxiety is associated with the TLX construct *frustration*.
- Outcome expectancy is associated with TLX *perception of performance*.
- Physical load is associated with TLX *physical demand*.
- Mental effort is associated with *self-efficacy*.

Only the TLX mental workload constructs relating to mental demand and temporal demand are not explicitly linked to self-efficacy in previous literature. It is logical that mental demand and temporal demand are not antecedents of self-efficacy because they are defined as originating from the nature of the task itself instead of from an individual's perception of their capabilities (Hart & Staveland, 1988). Therefore, it is reasonable to hypothesize that TLX subjective mental workload subscales are antecedents of GPM user self-efficacy in this study.

Because participants in this study are university students, with no prior task-specific BPI comprehension experience, there is no basis to determine users' prior GPM self-efficacy. In order to establish a baseline for future GPM self-efficacy research, this experiment explores the antecedents of GPM self-efficacy.

2.4.2.4 Hypotheses Relating Subjective Mental Workload to Self-Efficacy

Based on the literature reviewed, it is reasonable to expect that improved BPM should result if managers increase their self-efficacy about their abilities to interpret different types of BPI portrayed by GPMs. Therefore, participants who experience higher or negative subjective mental workload, are expected to experience lower GPM user comprehension self-efficacy.

> **Hypothesis 5:** Participants' subjective mental workload will significantly and negatively affect self-efficacy results.

2.4.3 Cognitive Styles and User Comprehension

Research Question 6: *How do user cognitive styles affect the subjective mental workload they experience when interpreting graphical business process information?*

Cognitive science literature suggests that mental workload and task performance will vary according to differences in user cognitive styles (Garner, 2002; Myers & Myers, 1995). Cognitive styles have been defined as "consistent individual differences in preferred ways of organizing and processing information and experience" (Sadler-Smith, 2001, p. 610). They are often described as different dimensions of human personality (Gardner & Martinko, 1996; Myers & Myers, 1995).

Cognitive styles act as filters people use when perceiving and cognitively process information. They represent a "bridge between two fairly distinct areas of psychological investigation: cognition and personality" (Sternberg & Grigorenko, 1997, p. 700). They are considered primarily genetically-based rather than experience-based, and consequently, are less affected by practice and experience than an individual's cognitive abilities (Gardner & Martinko, 1996; Moreno, 2002; Myers & Myers, 1995; Sadler-Smith, 2001). Cognitive styles are used in several literatures to explain or predict behaviors and performance in areas such as social information processing (Edwards, Lanning, & Hooker, 2002), telework (Barkhi, 2002), job performance (Gardner & Martinko, 1996), and decision support systems (Davis & Elnicki, 1984). Thus, it is important to include cognitive styles in this study so that the impact of BPM cognitive resources on user comprehension outcomes can be better understood. Two general cognitive styles are of interest in this study: (1) how users prefer to cognitively interact with the world around them (i.e., the extroversion vs. introversion), and (2) how users prefer to perceive information (i.e., the sensing vs. intuition dimension).

2.4.3.1 Cognitive Style: Extraversion vs. Introversion

The cognitive style of extroversion vs. introversion has been studied in the psychology literature for a number of years primarily based on self-report data. Individuals' who are extroverts tend to be motivated by stimuli external to their own mind and tend to not be as easily mentally overloaded by information as introverts. In contrast, individuals who are introverts seek stimuli from within their own mind and tend to be more easily mentally overloaded when processing information than extroverts (Garner, 2002; Myers & Myers, 1995).

Extrovert vs. introvert tendencies have been found to display some measure of biological and psychological validity (Gardner & Martinko, 1996). Biological research in cognitive science shows a direct link between extroversion-introversion and brain biology. Neuroscience and cognitive psychology literature has identified two independent motivational systems that exist within the human brain. These two motivational systems, the Behavioral Activation System (BAS) and the Behavioral Inhibition System (BIS), are based on Gray's personality model and describe appetitive or aversive behavior in individuals (J. A. Gray, 1981, 1987; J. R. Gray & Burgess, 2004). The BAS is activated by conditioned signals or perceptions of reward and nonpunishment that result in outputs such as enhancement of arousal, an inhibition toward ongoing behavior, and a redirection of attention toward relevant environmental stimuli. The BIS is activated by conditioned signals or perceptions of punishment or nonreward that promote suppression of inappropriate behavior, facilitation of stimulus analysis, and enhanced response selection. All people possess both motivational systems to some extent over and above other individual differences (cf. Avila, 2001; J. A. Gray, 1972, 1981, 1987; J. R. Gray & Burgess, 2004). Additionally, recent neurobiological evidence has linked people with an overactive BAS and/or an underactive BIS to positive affect and extroversion. Conversely, people with an overactive BIS and/or an underactive BAS have been linked to negative affect and introversion (cf. Chi et al., 2005; Gable, Reis, & Elliot, 2000; J. R. Gray et al., 2005; Hewig, Hagemann, Seifert, Naumann, & Bartussek, 2006; Jorm et al., 1999; Sutton & Davidson, 1997).

Psychological research has produced years of subjective, self-report data collection, and analysis that have shown individuals whose extrovert-introvert cognitive styles exhibit consistent behavioral tendencies in task performance (cf. Gardner & Martinko, 1996; Myers & Myers, 1995; Wheeler, Jessup, & Martinez, 2002). On the one hand, Myers-Briggs Type Indicator (MBTI) research (Myers & Myers, 1995) conceptualizes extroversion-introversion as two ends of a single dimension, and states that under conditions of stress, extroverts experience lower mental workload and become more cognitively overloaded later than introverts (Gardner & Martinko, 1996). Introverts tend to approach new tasks from a holistic perspective, while extroverts tend to take on new tasks in manageable parts, one step at a time. Thus, extroverts are more easily overwhelmed by large amounts of information than introverts.

BPM managers who are extroverts may not like GPM user comprehension tasks, but they may perform better than introverts because they typically approach the task in small pieces, one step at a time, rather than try to holistically understand it as introverts tend to do. However, extroverts may be more easily overwhelmed than introverts at the same task, because of the large amount of information they have to process in order to answer a user comprehension question. Because of these contradictory tendencies related to GPMs, it is difficult to predict the specific ways in which cognitive styles will influence GPM user comprehension.

The BAS/BIS literature suggests that participants high on introversion should experience higher subjective mental workload in user comprehension tasks. When faced with large quantities of information and the complexity of the GPM user comprehension task, they should experience a negative stimulus and their BIS should be activated. Participants with higher MBTI extrovert scores are expected to be less overwhelmed than introverts; activating their BIS to a lesser degree than introverts and experiencing less subjective mental workload on the same experimental task. This is in part because extroverts only seek to understand enough information to answer the immediate question and also because their BIS does not activate as quickly as introverts.

2.4.3.2 Cognitive Style: Sensing vs. Intuition

Cognitive style describes how individuals prefer to input and process the information they perceive. MBTI research conceptualizes cognitive style as a continuous scale of one dimension with two ends: sensing and intuitive. Individuals scoring high on the sensing end of the dimension prefer to process information for decision-making through their five senses. Also, as long as detailed information is available, sensors will tend to be more confident and take more time compared to intuitives (Gardner & Martinko, 1996; Myers & Myers, 1995; Wheeler et al., 2002). Individuals scoring high on the intuitive end of the scale prefer to use their intuition to process information. Sensors prefer operational level of decision-making tasks that are structured, routine, systematic, logical, and analytical compared to intuitives (cf. Gardner & Martinko, 1996; Myers & Myers, 1995; Wheeler et al., 2002).

According to Gardner and Martinko's (1996) review of the MBTI literature, research on the sensing vs. intuition cognitive style has produced mixed results. On the one hand, participants with MBTI scores leaning toward sensing are expected to expend less subjective mental workload than intuitives in learning tasks. This is because sensors only try to comprehend enough information to answer each individual question, tended to lose or ignore details when overwhelmed with information, and are less frustrated with losing details when overwhelmed with information (cf. Barkhi, 2002; Gardner & Martinko, 1996; Myers & Myers, 1995; Rubio et al., 2004). Participants scoring higher on the MBTI intuitive scale experience more subjective mental workload than participants scoring higher in sensing, because intuitives are less overwhelmed with the amount of information on the GPMs as they try to holistically gather and understand all of the information presented (cf. Barkhi, 2002; Gardner & Martinko, 1996; Myers & Myers, 1995; Rubio et al., 2004).

On the other hand, intuitives are expected to expend less mental workload, because they prefer graphically-oriented information (i.e., GPMs) while sensors prefer raw data (Gardner & Martinko, 1996). Participants with MBTI scores leaning toward the intuitive dimension should prefer abstract summaries that stress possibilities. They also try to holistically gather and understand more information than is necessary to answer a user comprehension question (cf. Barkhi, 2002; Gardner & Martinko, 1996; Myers & Myers, 1995; Rubio et al., 2004). These examples illustrate the mixed results that MBTI research has produced related to GPM user comprehension.

2.4.3.3 Hypotheses Relating Cognitive Styles to Subjective Mental Workload

Due to the lack of cognitive style research related to GPM user comprehension in the context of BPM Systems, hypotheses are developed based on the BAS/BIS literature and the MBTI research described in the previous section.

> **Hypothesis 6:** Participants' cognitive styles will significantly affect the subjective mental workload they experience during task performance.
>
> > **Hypothesis 6.1:** Participants' scoring high on the cognitive style of extroversion will experience significantly lower subjective mental workload than participants scoring high on introversion.
> >
> > **Hypothesis 6.2:** Participants' scoring high on the cognitive style of sensing will experience significantly lower subjective mental workload than participants scoring high on intuition.

2.4.4 Cognitive Abilities and User Comprehension

Cognitive abilities refer to an individual's intellectual abilities and mental aptitudes that affect learning and the ability to manipulate different types of information (Bowman, Markham, & Roberts, 2001; Jensen & Weng, 1994; Schmidt, 2002; Woodcock, 1990, 2002). Cognitive abilities act as mental tools people use to control or manage the cognitive processing of information when performing a task (Goldstein, Yusko, & Nicolopoulos, 2001; Hartmann, Sunde, Kristensen, & Martinussen, 2003; Schmidt, 2002; Woodcock, 2002). An individual's cognitive abilities are affected to a greater extent by practice and experience than the cognitive styles of the individual. Using the cognitive 'onion' analogy mentioned in Section 2.2.3.2, cognitive abilities are conceptualized as another layer further out from the "core" of the cognitive "onion" than the cognitive styles layer. Cognitive abilities bridge the gap between cognitive styles and what Sadler-Smith (2001) refers to as learning styles.

Several different types of cognitive abilities have been studied. For example, an individual's ability to learn (cf. Bowman et al., 2001; Jensen & Weng, 1994; Schmidt, 2002; Schmidt & Hunter, 2004; Woodcock, 2002) or to focus attention during learning or performing a task (Crawford, Brown, & Moon, 1993; Lyons & Crawford, 1997; Schmidt, 2002; Yeung et al., 2000). Consequently, the two types of cognitive abilities included in this study are users General Cognitive Abilities (GCA), a broad assessment of users' cognitive aptitudes that affect their ability to learn, and their attentional abilities.

2.4.4.1 General Cognitive Abilities and User Comprehension

Research Question 7: *How do user general cognitive abilities affect the subjective mental workload they experience when interpreting graphical business process information?*

Recent literature organize various cognitive abilities into nine broad categories and more than sixty narrow cognitive aptitudes of thinking abilities, acquired-knowledge abilities, and cognitive efficiencies that an individual may possess (Woodcock, 2002). Salgado et al. (2003, p. 1068) define GCA as "any measure that combines two, three, or more specific aptitudes, or any measure that includes a variety of items measuring specific abilities (e.g., verbal, numerical, spatial)." Examples of different GCA assessments include compilation tests, such as the Wonderlic Personnel Test (WPT), Otis Employment Test, Raven's Progressive Matrices Test, and the Wechsler Adult Intelligence Scale. Examples of other specific tests on narrow cognitive aptitudes combined into a single test battery of tests include the General Aptitude Test

Battery, Differential Aptitude Tests, or the Primary Mental Aptitude Tests (Salgado et al., 2003; Schmidt, 2002). The theories on which most GCA assessments are based include Cattell-Horn-Carroll (CHC) three-stratum theory of intelligence, the general factor of intelligence (also referred to as "g"), and the Intelligence Quotient (IQ) theory (Jensen & Weng, 1994; Woodcock, 2002).

Cognitive and industrial psychology literature contains a large body of empirical research reporting how GCA affects learning (Bowman et al., 2001; Woodcock, 2002) and task performance (Schmidt, 2002; Schmidt & Hunter, 2004). For example, Eyring, Johnson, and Francis (1993, p. 810) found that GCA (as assessed by the WPT) significantly predict the learning-rate constant, meaning that, for every unit of change in GCA, there is a 0.19 increase in the learning-rate constant. In other words, those subjects with higher GCA took longer to achieve the same percentage of performance increase than those subjects with low ability. Subjects with high GCA scores learned faster and reported higher self-efficacy than those with low GCA scores. In general, individuals with higher GCA experience lower mental workload and higher task performance than individuals with low GCA (cf. Edinger, Shipley, Watkins, & Hammett, 1985; Jensen & Weng, 1994; Salgado et al., 2003, p. 1068; Schmidt, 2002; Schmidt & Hunter, 2004; Woodcock, 2002).

However, given the above discussion of the relationship between mental workload and task performance, and the fact that cognitive abilities affect the processing of information, the relationship between cognitive abilities and task performance is indirect. According to IP theory, cognitive abilities should directly impact an individual's mental workload (see Figure 2-12 in Section 2.4.1.3 above), but no research was found that has studied this relationship. No research was found that assessed GCA in the context of BPM and BPM Systems. Therefore, GCA is assessed in this study to determine its effects on mental workload in GPM user comprehension tasks.

2.4.4.2 Hypotheses Relating General Cognitive Abilities to Subjective Mental Workload

According to the research reviewed, the GCA of BPM managers is important to include in GPM user comprehension research. BPM Systems literature indirectly indicates that GPMs are expected to facilitate user comprehension irrespective of the cognitive abilities a manager may possess (cf. Basu & Blanning, 2000; Light, 2005; Weske et al., 2004; zur Muehlen, 2004a). However, prior research on cognitive abilities suggests that participants with high GCA should experience less mental workload and, consequently, improve their task performance, compared to participants with lower GCA. Therefore, this hypothesis explores whether general cognitive abilities (GCA), as assessed by the Wonderlic Personnel Test (WPT), affects the subjective mental workload users experience during GPM use.

> **Hypothesis 7:** Participants with high general cognitive abilities will experience significantly lower subjective mental workload.

2.4.4.3 Attentional Abilities and User Comprehension

<u>Research Question 8</u>: *How do user attentional abilities affect the subjective mental workload they experience when interpreting graphical business process information?*

Whether an individual is able to pay attention and not get distracted during task performance is another important cognitive ability (cf. Aks & Coren, 1990; Crawford et al., 1993; Lens & de Volder, 1980; Teigen, 1994). For example, Aks and Coren (1990) assess the effects of individual differences in attentional focus on measures of different cognitive abilities using 272 university undergraduates. They found that highly distractible students scored an average of 9.4 percentile points lower than low-distractible students on assessments of narrow cognitive aptitudes. This study suggests that attentional abilities are an important facet of measured intelligence.

Several different attentional abilities are considered independent of GCA (Lyons & Crawford, 1997; Yeung et al., 2000). Crawford et al. (1993) identifies four cognitive abilities related to an individual's ability to focus attention and ignore distractions in both single and dual task situations:

1. <u>Moderately focused attention</u> refers to an individual's perceived ability to sustain moderately focused attention despite being surrounded by and aware of distractions.
2. <u>Extremely focused attention</u> assesses an individual's perceived tendency to engage one's total attention to a task without being aware of outside stimuli and distractions.
3. <u>Dual attention to cognitive-cognitive tasks</u> assesses an individual's ability to focus their attention while performing two cognitive tasks simultaneously.
4. <u>Dual attention to cognitive-physical tasks</u> assesses an individual's ability to focus their attention while performing a cognitive task and a physical task simultaneously.

Several studies found that when individuals are not motivated to perform a task (e.g., they are distracted, overwhelmed, or do not feel challenged by the task) they most likely exert less attentional control and mental effort (Lens & de Volder, 1980; Teigen, 1994). Consequently, these individuals experience a subsequent decrease in task performance and, possibly, higher mental workload (Lyons & Crawford, 1997; Yeung et al., 2000). In contrast, other studies show that individuals who can easily focus their attention on a task can experience lower mental workload and improve task performance (Crawford et al., 1993; Lyons & Crawford, 1997). Therefore, the attentional abilities of the participants are expected to impact the subjective mental workload they experience during GPM user comprehension.

2.4.4.4 Hypotheses Relating Attentional Abilities to Subjective Mental Workload

Attentional abilities have not been considered in the GPM user comprehension research. This study will evaluate the effect of participants' attentional abilities on the subjective mental workload they experience during GPM use. Therefore, individuals reporting higher abilities to focus their attentional resources (i.e., higher DAPI scores) will experience less mental workload, and, consequently, more favorable task performance than individuals with lower DAPI scores.

Hypothesis 8: Participants scoring high on attentional abilities will experience significantly lower subjective mental workload during task performance.

Hypothesis 8.1: Participants' that score high on moderate-focus attentional abilities will experience significantly lower subjective mental workload.

Hypothesis 8.2: Participants' that score high on extreme-focus attentional abilities will experience significantly lower subjective mental workload.

Hypothesis 8.3: Participants' that score high on dual cognitive-cognitive task focus attentional abilities will experience significantly lower subjective mental workload.

Hypothesis 8.4: Participants' that score high on dual cognitive-physical task focus attentional abilities will experience significantly lower subjective mental workload.

2.4.4.5 A Theoretical Framework is Needed to Study GPM User Comprehension

It follows from this review of the literature that, conceptually, users of BPM Systems must interpret and apply BPM cognitive resources, facilitated by GPMs, to make BPM decisions. Users cognitively process and interpret these BPM cognitive resources via their cognitive reasoning and perceptual abilities (i.e., cognitive differences between individuals) thus producing outcomes of user comprehension (see Figure 2-13).

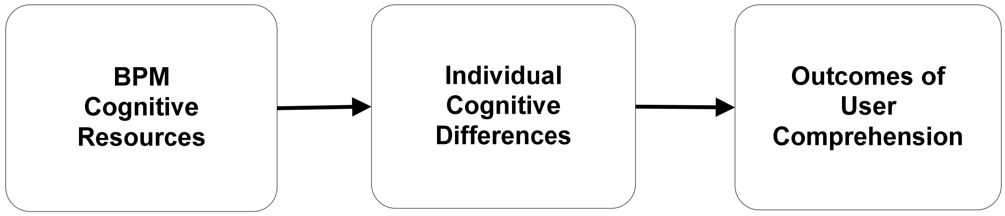


Figure 2-13. Conceptual relationships between BPM cognitive resources and individual differences affecting GPM user comprehension.44

2.5 Theoretical Frameworks to Integrate Hypotheses Related to GPM User Comprehension

A problem with the hypotheses in this study is that no conceptual or empirical research was found that takes into account all the BPM cognitive resources and individual cognitive differences that affect GPM user comprehension outcomes in this study. Additionally, no single theory or theoretical framework was found that has been used to guide empirical GPM user comprehension in the context of BPM and BPM Systems. The previously reviewed theoretical relationships are limited in their ability to account for and include all the variables of interest in this study.

2.5.1 <u>The Need for a Theoretical Framework for GPM User Comprehension Research</u>

2.5.1.1 Limitations of Related Literature

The literature reviewed in relation to this study suffers from several weaknesses. First, several theoretical perspectives applicable to GPM user comprehension take into account variations in different cognitive resources, but they do not account for influences of cognitive psychological factors (e.g., like those related to IP theory), such as the Cognitive Fit Model (Sinha & Vessey, 1992; Vessey, 1991) and Relational Informational Display studies (Zhang, 1996b; Zhang & Norman, 1994) (discussed in Section 2.3.1),. Nor do these theoretical perspectives specifically explain or predict why variations in cognitive resources affect or do not affect task performance.

As mentioned earlier, contextual factors are not typically accounted for in IS research. In their review of research on conceptual modeling and IS research, Wand and Weber (2002, p. 372) state that several individual contextual factors have received little attention in IS research related to GPM user comprehension: including expert-novice differences, cognitive abilities, cognitive complexities, cognitive styles, and context-specific issues. They recommend these factors be included in future IS research agendas. They specifically recommend that future research include the impact of the types of GPMs, differences in user cognitive abilities, and differences in user cognitive styles. Also that future research should seek understand how modeling techniques can be used to mitigate expert-novice differences in GPM user comprehension.

Although theoretical relationships can be found to individually account for all the factors of interest in this study, no theoretical framework was found that integrates and accounts for relationships between all the factors proposed as necessary for this research. The related literature reviewed in relation to this study lacks a coherent underlying theoretical framework because (1) it is fragmented in terms of sub areas and theoretical approaches, and (2) much of this literature has difficulty finding a connection between simple cognitive psychology theory and practical guidelines. For example, HCI research has approached the problem by studying successful solutions in an effort to understand why they are successful. But, for the most part, this research is unable to provide guidance on how successful HCI should be developed (Kuutti, 1995). "The guide-lines then are usually derived from practical experience and there is no connecting background model behind them" (Kuutti, 1995, p. 18). In recent years, there has been a concerted effort to develop, adapt, and apply theory to overcome this shortcoming.

To address this need, a good deal of related literature borrows IP theory from cognitive science. Although IP theory accounts for variations in individual cognitive differences, it does not provide a theoretical framework that can account for variations in cognitive resources (see Section 2.5.1.2). In recent years, IP theory has received a great deal of criticism in the HCI, cognitive ergonomic, and cognitive science literature.

2.5.1.2 Limitations of IP Theory in Studying GPM User Comprehension

IP theory has several limitations that make it inadequate as a guiding theoretical framework for studying GPM user comprehension. As originally applied in the cognitive psychology literature, IP theory defines a cognitive system as limited to the mind of an individual (Boland et al., 1994; Hollan et al., 2000; Hutchins, 1995). Thus, IP theory cannot account for the impact of variations in cognitive resources, because it was designed to model and explain the individual cognitive differences and mental processes going on within the mind of an individual (Madhavan & Grover, 1998; Wright et al., 2000; Zhang, 1996a). Another limitation is that IP theory is not designed to account for variations in the quality of knowledge resources (i.e., tacit and explicit BPM knowledge) that affect user comprehension (Marmaras & Kontogiannis, 2001; Wright et al., 2000). In summary, IP theory cannot account for how individuals offload information to external representations (i.e., information artifacts such as GPMs) when performing user comprehension tasks (Hollan et al., 2000; Norman, 2002; Perry, 2003).

2.5.1.3 Characteristics Needed in a Theoretical Framework for HCI User Comprehension

A user comprehension theoretical framework is needed that provides direction for integrating differing variables and theoretical relationships into a cohesive research model. This framework must account for variations in cognitive resources, i.e., tacit and explicit BPM knowledge as well as information artifacts. This framework must also incorporate relationships between individual cognitive differences from IP theory and cognitive psychology that affect user comprehension. For example, this means the integrative framework must incorporate the affects of mental workload, cognitive styles, and cognitive abilities on user comprehension outcomes. The framework must be able to be adapted to different cognitive tasks and contexts. This framework can then be used to map and compare past research as well as guide future research.

2.5.2 Theoretical Perspectives to Guide Development of the Theoretical Framework

These issues and constraints have provided recent impetus for development of the HCI theoretical perspectives known Activity Theory (Kuutti, 1995; Leont'ev, 1974; Nardi, 1998) and Distributed Cognition theory (Hollan et al., 2000; Hutchins, 1995; Norman, 1988). Activity Theory and Distributed Cognition theory account for both cognitive resources and individual cognitive differences, and therefore, can provide a theoretical basis on which to develop a conceptual theoretical framework and operational research model that integrates the variables and relationships relevant to this research.

2.5.2.1 Activity Theory

Activity Theory (AT) originated in the former Soviet Union and referred to a cultural-historical research tradition that explored the relationships between activities, objects, subjects, tools, and outcomes over time (cf. Kuutti, 1995; Leont'ev, 1978, 1989; Nardi, 1998). AT is not interested in “activities” in general, nor is it a well-defined operational “theory” in the classic scientific tradition (Kuutti, 1995).

Broadly defined, AT is a philosophical and multi-disciplinary theoretical framework for studying different forms of human practices, such as development processes, that are interconnected at both the individual and social levels of analysis at the same time (Kuutti, 1995; Nardi, 1998). AT theory encompasses at least three key principles (Decortis et al., 2000; Kuutti, 1995; Nardi, 1998): (1) activities as the basic unit of analysis, (2) activities as dynamic, not static, entities, and (3) activities as involving mediated components.

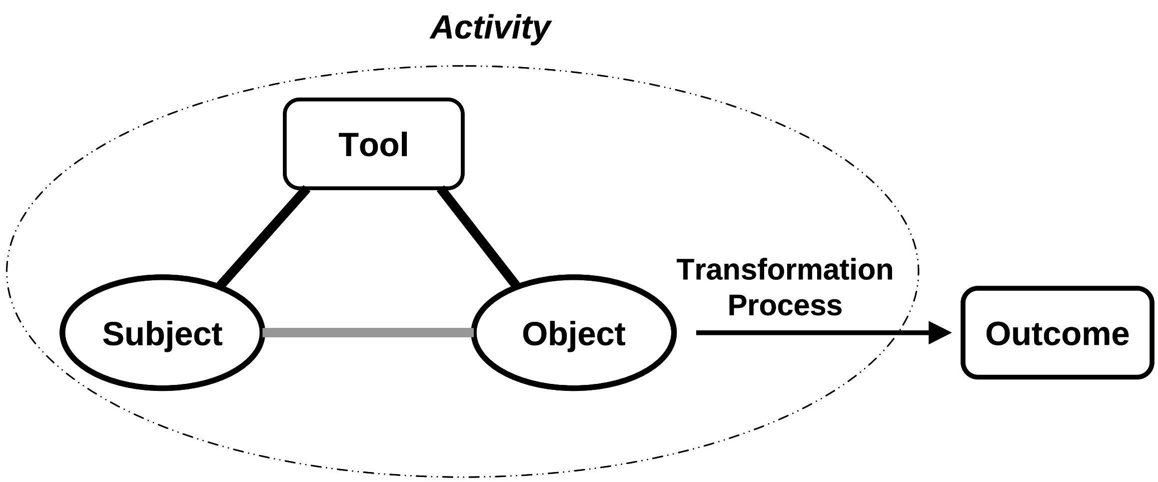


Figure 2-14. The structure of an AT activity includes the relationship between the subject and object mediated by the tool to produce an outcome[16].

First, the activity is the basic unit of analysis in AT, but is not defined in the same way as traditional psychological theories. According to AT, "an activity is the meaningful context to understand individual actions" (Kuutti, 1995, p. 30). Typical psychological theories have often used a static human action as the unit of analysis. This approach made it easier to design laboratory experiments, but created problems with external validity. To address this shortcoming, AT theory postulated that the reason the classical research tradition created external validity problems is that, in reality, human actions are always situated in a context, and therefore, human actions are impossible to understand without considering the context. AT provided a solution to this problem by conceptualizing the context as part of an activity (cf. Decortis et al., 2000; Halverson, 2002; Kuutti, 1995; Nardi, 1998; Suchman, 1987).

[2-16] Adapted from Kuutti (1995). Used by permission.

Second, AT theory conceptualizes activities as dynamic, as opposed to static, entities. Activities are under continuous change and development. As a result, activity development is usually uneven, sporadic, and non-linear. AT theory postulates that an activity has a history that contains the remnants of previous phases of the activity. Therefore, historical analysis of the activity is often required to understand the context and situation of interest (cf. Decortis et al., 2000; Halverson, 2002; Kuutti, 1995; Nardi, 1998; Suchman, 1987).

Third, an activity contains various artifacts that mediate relationships between the components that make up the activity. These artifacts, such as tools, are themselves created and transformed using the history and development of the activity itself. These artifacts are one way that activities are dynamic, because the tools carry a culture or history of the development of the artifact. For example, according to AT, a basic activity is made up of the relationship between a subject and an object mediated by a tool[17] (see Figure 2-14). A basic activity takes place in a given context and is structured to include a minimum of four components: the subject, the object, the tool (or artifact) and an outcome. An object is a physical thing, something less tangible (like a plan) or something intangible (like an idea). The critical issue is that objects must be able to be shared and manipulated by participants in the activity (Kuutti, 1995). The activity is motivated by the transformation of the object into an outcome. Because an AT activity is a dynamic process, the component relationships are transformed over time, producing outcomes of the activity. The object and motivation are revealed and undergo changes only in the process of how the activity is done. The tool mediator possesses the history of the relationship. Kuutti (1995, p. 29) explains the role of the tool mediator in this way:

> "Thus, the (reciprocal) relationship between the subject or actor and the object of activity is mediated by a 'tool' into which the historical development of the relationship between the subject and object thus far is condensed. The 'tool' is at the same time both enabling and limiting: it empowers the subject in the transformation process with the historically collected experience and skill 'crystallized' to it but it also restricts the interaction to be from the perspective of that particular tool or instrument only - other potential features of [the] object remain 'invisible' to [the] subject."

[2-17] An *activity* can be extended to include relationships between the *subject* and the *community* mediated by *rules* and between the *object* and *community* mediated by the *division of labor*. This multilevel, systemic conceptualization is beyond the scope and needs of this study. However, if this study is extended to field studies of users of actual *BPM Systems*, this more extensive conceptualization of an *activity* will be necessary. For further information see Kuutti (1995), Decortis (2000), Halverson (2002), and Nardi (1998).

Kuutti (1995) identifies three perspectives in which AT contributes related research. First, AT provides a theoretical conceptualization for studying multilevel attributes and activities in an integrated framework. Second, AT enables the study of interaction embedded in a social context. AT and how it conceptualizes an activity creates a starting point for studying and comparing the dynamics of interactions embedded in their context. Third, AT studies the dynamics and development of an activity. According to Kuuti (1995), how research deals with the dynamics and developmental attributes of human practices has largely been ignored. By conceptualizing the dynamics and development of activities across levels of analysis, AT provides an opportunity to address these fundamental issues.

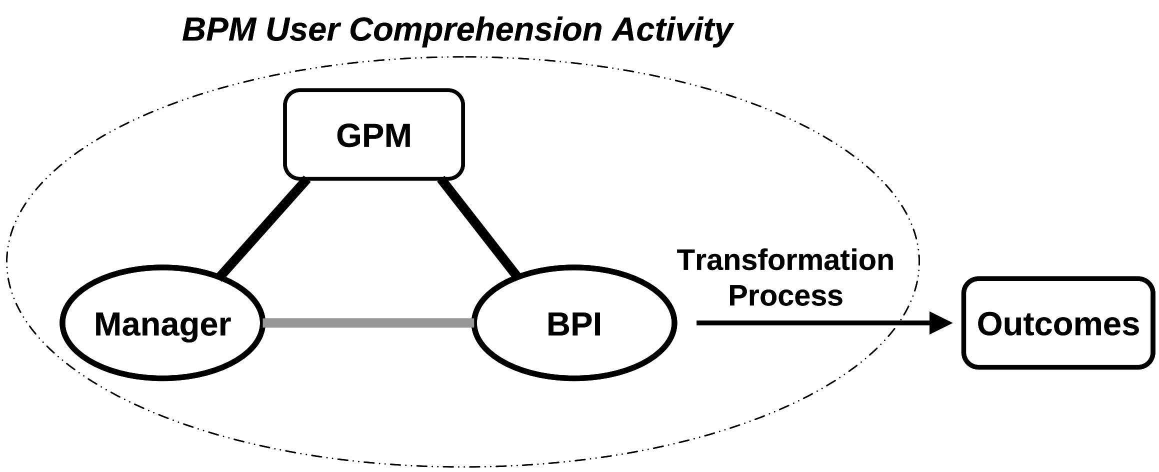


Figure 2-15. AT applied to a GPM user comprehension activity[18].

Figure 2-15 illustrates how AT is applied to this study of a GPM user comprehension activity in the unique context of BPM and BPM Systems. The subject is the individual BPM manager. The object of the activity is the BPI. The tool that mediates the relationship between the manager and the BPI is the GPM. The transformation process of this activity produces user comprehension outcomes.

2.5.2.2 Distributed Cognition Theory vs. Information-Processing Theory

The theory of Distributed Cognition (DC) was developed more recently than AT, but, similarly addresses the limitations of IP theory as they apply to both practical and theoretical issues emerging in related research. DC theory was first suggested by Norman (1988) and then popularized by Hutchins (1995)

[2-18] Adapted from Kuutti (1995). Used by permission.

and Hollans et al. (2000). Almost all the current DC literature is comprised of conceptual papers, qualitative ethnographies, or case studies in various contexts. For example, DC theory has been applied in U.S. Navy ship navigation (Hutchins, 1995), airplane cockpit design (Hollan et al., 2000), new product development (Madhavan & Grover, 1998), business representation online (Flor & Maglio, 1997, 2004), and computer-supported collaborative work (CSCW) (Boland et al., 1994; Hislop, 2002). DC literature also contains several conceptual papers on topics such as medical informatics (Cimino, 1998; Horsky, Kaufman, Oppenheim, & Patel, 2003), collaborative learning (Daradoumis & Marques, 2002; Dehler, 1998), interactive graphical representations (Garbis, 2000; Giordano, 2002), knowledge sharing (Ackerman & Halverson, 2000; Cabrera & Cabrera, 2002; E. Davenport & Hall, 2002; de Haan, 2002; Wright et al., 2000), and papers that compare DC theory to other research perspectives (Decortis et al., 2000; Halverson, 2002; Kaptelinin et al., 2003; Norman, 1988; Susi & Ziemke, 2001).

DC theory is a socio-technical systems approach designed to account for the practical reality that a great deal of human cognitive activity is mediated through information artifacts, because individuals cannot access, store, or cognitively process within their heads all information necessary for task performance (Perry, 2003; Wright et al., 2000). According to DC theory, cognition is defined as being “distributed” because the available tacit and explicit knowledge needed to perform a task is often divided between both individuals and information artifacts, which is in sharp contrast to IP theory (see Figure 2-16) (Hollan et al., 2000; Hutchins, 1995).

DC theory has several advantages over IP theory-based research models. First, DC theory seeks to explain how the distribution of cognitive resources between individuals and information artifacts affects task performance. When performing tasks, people free up their limited internal cognitive resources whenever possible by off-loading cognitive processing and information storage needs onto information artifacts and the task environment (Hollan et al., 2000; Wright et al., 2000). For example, individuals create to-do lists, take notes, create appointments in a calendar, and maintain contact lists of important information that they cannot immediately recall or remember without help. In a classic ethnographic study, Hutchins (1995) describes how ship navigation is accomplished using several individuals and information artifacts working together in a distributed cognitive system. Related to this study, DC theory reflects the reality that a BPM task performance is achieved through the interaction of the individual manager and the GPMs used in BPM Systems.

Second, DC theory can be used to study tasks and task outcomes beyond the individual level of analysis. The DC perspective allows researchers the flexibility to define a cognitive system at a level of analysis appropriate for their research. Because IP theory restricts the boundaries of a cognitive system to what takes place within the mind of an individual, it limits the level of analysis to the cognitive system boundaries, resources, mechanisms, and processes to those that occur within the mind of a single individual (Hollan et al., 2000; Huitt, 2004). By extending the boundaries of the cognitive system, DC theory inherits the advantages of IP theory while taking into account a variety of cognitive resources that can be used to conceptualize multiple levels of analyses (Boland & Tenkasi, 2001; Madhavan & Grover, 1998; Wright et al., 2000). Using DC theory, a cognitive system can be defined as small as one individual with no information artifact or as large as multiple individuals and information artifacts interacting to produce both individual and collective task outcomes (Hollan et al., 2000; Perry, 2003; Rogers, 1997). For example, Hutchins (1995) uses DC theory to study both (a) the collective task of navigating a U.S. naval vessel, and (b) the individual performance of one crewmember using a single piece of navigation equipment.

Third, although it extends the cognitive system beyond the mind of the individual, DC theory continues to incorporate traditional psychology and IP theory constructs in socio-technical research models (Hollan et al., 2000; Norman, 1988). Because DC theory is rooted in traditional cognitive psychology and IP theory, it is inherently inclusive of constructs and relationships describing the mental processing of cognitive resources within the minds of individuals (see Figure 2-16) (Boland et al., 1994; Hollan et al., 2000; Norman, 1988). Several DC studies suggest that superior task accuracy, task timeliness, and mental workload can be achieved when interfaces are designed that take into account DC principles. For example, Madhaven and Grover (1998) describe how cognitive abilities and cognitive styles, such as T-shaped and A-shaped skills, affect both trust and the richness of personal interaction in the creation of new knowledge. Hollan et al. (2000) describe DC research that identifies individual cognitive differences in how pilots perceive information as important factors to consider in cockpit design. Therefore, using DC theory, a theoretical framework that includes variables from IP theory as well as BPM cognitive resources can be theoretically justified and compared. (cf. Boland et al., 1994; Cimino, 1998; Daradoumis & Marques, 2002; de Haan, 2002; Dehler, 1998; Giordano, 2002; Hollan et al., 2000; Madhavan & Grover, 1998; Moore & Rocklin, 1998; O'Donnell, 1998; Perry, 2003; Winsor, 2001; Zhang & Norman, 1994).

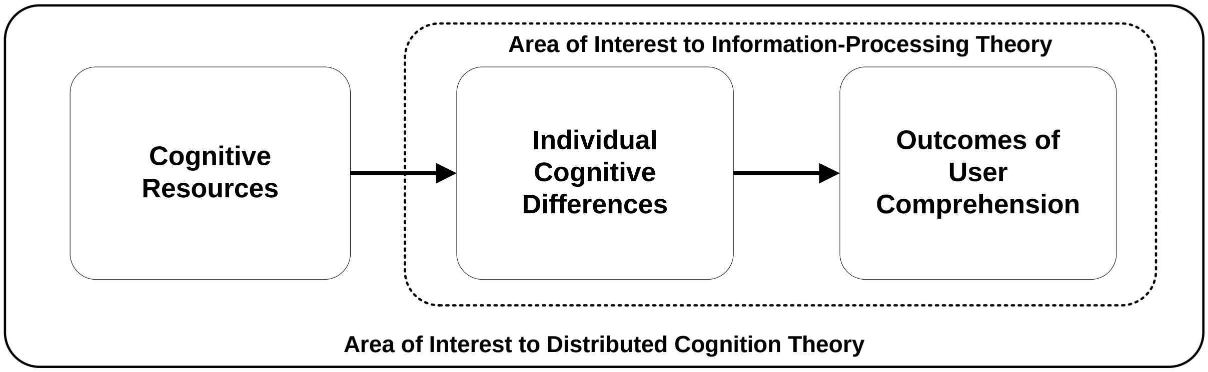


Figure 2-16. Areas and constructs of interest to DC vs. IP theory.

Finally, DC theory seeks to assess and understand the effect of variations in tacit and explicit knowledge resources on task performance (see Figures 2-16 and 2-17) (Boland & Tenkasi, 2001; Wright et al., 2000). Variations in the quality, amount, and interactions between tacit and explicit knowledge resources can affect task performance. Several authors describe different types of BPM tacit and explicit knowledge resources that are embedded in either the process itself, the procedures for managing the process (i.e., explicit knowledge) or the experiences of people managing the process (i.e., tacit knowledge) (Amaravadi & Lee, 2005; T. H. Davenport & Beers, 1995; Eppler et al., 1999; Madhavan & Grover, 1998). Hutchins (1995) study of ship navigation illustrate how variations in these knowledge resources can produce different or similar task performance. For example, a ship can be navigated into a harbor using different configurations of knowledge resources. Novice navigators (i.e., with limited tacit knowledge) tend to rely more on sophisticated navigation equipment (i.e., large amounts of explicit knowledge) that assist ship navigation. On the other hand, because of their extensive experience navigating the ship (i.e., high tacit knowledge), experienced navigators tend to rely less on navigational equipment than novice navigators (i.e., limited reliance on explicit knowledge). In the context of this study, this means that novice managers with limited tacit BPM knowledge may rely more on the GPMs that underlie BPM systems, but may be able to perform some tasks equally as well as experienced managers that possess a great deal of tacit BPM knowledge.

DC literature lacks examples of empirical research and operational research models for empirical research. Despite the preponderance of literature on the topic, there is apparently no DC research that has developed a theoretical research model and its associated hypotheses that can be tested using empirical research. Compared to AT, DC research has been primarily ethnographic and studies DC systems over time. Also as opposed to AT, DC theory lends itself to classic, static research models that can be easily adapted to lab settings. Finally, in describing the needs for future DC research agendas, Hollan et al. (2000) cites empirical research as a critical next step in the advancement of DC theory. This study makes a contribution to the DC literature by proposing and testing a research model based on DC theory in an empirical study.

2.6 SUMMARIZING THE LITERATURE - THE RESEARCH MODEL

AT and DC theory provide theoretical justification for integrating BPM cognitive resources and individual cognitive differences into a theoretical framework for assessing their impact on GPM user comprehension. However, no theoretical model was found in either of these theories that defined the relationships between the variables on interest in this study. Therefore, a research models is created for this study by integrating the various theoretical construct relationships reviewed in Sections 2.3 and 2.4 using a framework based on AT and DC theory.

The research model relates the constructs (in bold type) and conceptual relationships of interest in this study (see Figure 2-17). It incorporates relationships between three BPM cognitive resources, three factors evaluating cognitive differences between individuals, and outcomes of GPM user comprehension. Conceptually, variations in tacit and explicit BPM knowledge, as well as variations in the BPM information artifact (that portrays the explicit BPM knowledge), are perceived and cognitively processed by users of BPM Systems. During cognitive processing, the user's cognitive styles, cognitive abilities, and mental workload are effected. Besides the mental workload users experience, user comprehension produces task performance (accuracy and timeliness) and self-efficacy outcomes specific to GPM user comprehension in the context of BPM and BPM Systems. The operationalized variables and eight hypotheses, described in this chapter, are integrated to create the relationships depicted in the research model in Figure 2-17. Chapter 3 discusses the research methodology used to experimentally test this research model and its hypotheses.

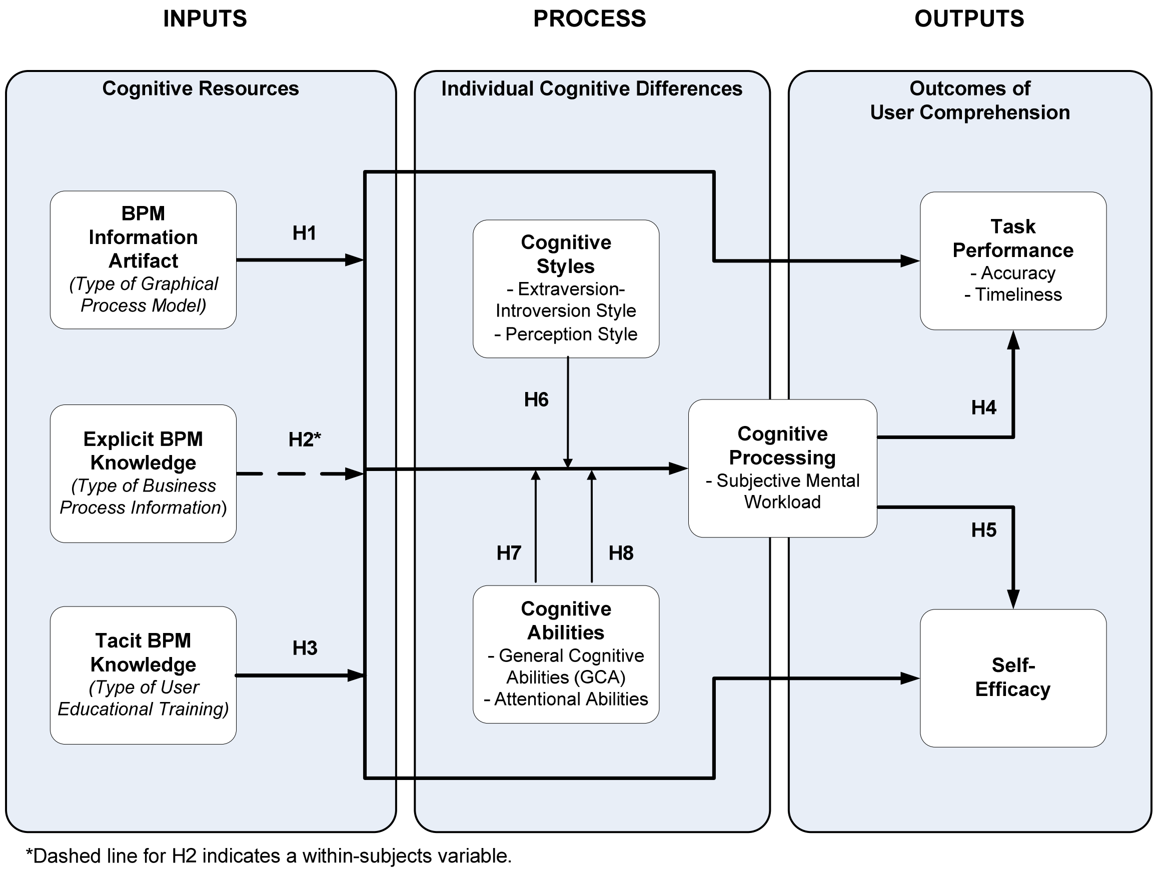


Figure 2-17. Operational Research Model that tests GPM user comprehension.

C h a p t e r   T h r e e

CHAPTER 3 - RESEARCH METHODOLOGY

The purpose of this chapter is to describe how the laboratory experiment was conducted to test the following research hypotheses:

Hypothesis 1: The type of graphical process model will significantly affect participants' task performance (i.e., accuracy and timeliness), subjective mental workload and self-efficacy.

Hypothesis 2: The type of business process information will significantly affect participants' task performance (i.e., accuracy and timeliness) and subjective mental workload[1].

Hypothesis 3: The type of user educational training of participants will significantly affect participants' task performance (i.e., accuracy and timeliness), subjective mental workload, and self-efficacy.

Hypothesis 4. Participants' subjective mental workload will significantly affect task performance (i.e., task accuracy and timeliness) in inverted-U relationships (in accordance with the Yerkes-Dodson principle).

Hypothesis 5: Participants' subjective mental workload will significantly and negatively affect self-efficacy results.

Hypothesis 6: Participants' cognitive styles will significantly affect the subjective mental workload they experience during task performance.

Hypothesis 7: Participants with high general cognitive abilities will experience significantly lower subjective mental workload.

Hypothesis 8: Participants scoring high on attentional abilities will experience significantly lower subjective mental workload during task performance.

This chapter proceeds by describing the GPM user comprehension tasks used in the experiment (Section 3.1). Section 3.2 describes the participants of this study. Section 3.3 describes the variables and instruments used to collect data. The materials and equipment needed to conduct the experiment are discussed in Section 3.4. The procedures for the experiment are explained in Section 3.5. Section 3.6 describes the experimental design that was used to collect data. Section 3.7 reports the analyses used to test

[3-1] Self-efficacy was not measured within-subjects so it is not included in this hypothesis.

the individual hypotheses. Section 3.8 describes the premises of this study. Finally, Section 3.9 describes potential threats to validity.

3.1 Description of the GPM User Comprehension Tasks

The GPM user comprehension tasks in this experiment were based on existing BPM System literature. The graphical process models, as well as the task accuracy questionnaires, used in the experiment were based on the real-world bank loan process presented found in Basu and Blanning (2000) (see Appendices B, C, and D).

3.2 Participants

The participants in this study were third and fourth year college students from two universities: a large southeastern U.S. university and a small U.S. university in the Hawaiian Islands. Participants were volunteers from students majoring in industrial engineering (IE), business management (MGT), and computer science (CS) recruited to represent BPM System users with different types of educational training. Students were recruited from courses where the instructors either elected to require students to participate or gave them the chance to volunteer based on specific courses in which they were currently enrolled. As a result, they were a sample of the population but were not selected in a strictly random fashion. The IE students were required to participate by their instructor. Instructors of all CS and MGT students elected to allow their students to volunteer for this experiment. See Section 4.2.1 for details about the number of participants.

3.3 Variables and Instrumentation

The instruments used in this study were specifically chosen to collect data to statistically test the research hypotheses in this study.

3.3.1 Independent Variables

The independent variables in this experiment operationalized three types of cognitive resources used to perform BPM tasks using BPM systems. The categories of these variables were selected from prior literature and were manipulated in different treatment combinations in this experiment. Table 3-1 lists the independent variables and their selected levels that were manipulated in this experiment.

Table 3-1. Independent Variables Descriptions and Levels

INDEPENDENT VARIABLES	CATEGORIES OF INDEPENDENT VARIABLE
Type of Graphical Process Model (GPM) (Between-Subjects Factor)	UML Diagrams Metagraphs
Type of Business Process Information (BPI) (Within-Subjects Factor)	Task-Centric BPI Resource-Centric BPI Information-Centric BPI
Type of User Educational Training (UET) (Between-Subjects Factor)	Industrial Engineering Management Computer Science

3.3.1.1 Type of Graphical Process Model

BPI was portrayed using one of two types of GPM techniques: UML diagrams and metagraphs. The type of GPM technique used to portray BPI was conceptualized as a between-subjects factor in the experimental design and the primary cognitive resource of interest in this study. (See Sections 2.3.1 for a description of these GPMs, and Appendices C, D, E, F, J and K for the GPMs used in the pilot study and the actual experiment.)

3.3.1.2 Type of Business Process Information

Each experimental treatment required participants to interpret and answer questionnaires assessing user comprehension of three types of BPI (see Section 2.3.2):

1. Process flow BPI using a task-centric GPM.

2. Resource allocation BPI using a resource-centric GPM.
3. Data structures using an information-centric GPM.

Each participant was asked to comprehend and interpret all three types of explicit BPM task information. Thus, the independent variable, type of BPI, was conceptualized as a within-subjects factor (see Section 2.3.2).

3.3.1.3 Type of User Educational Training

The type of UET was conceptualized as a between-subjects factor in this study. In order to take tacit BPM knowledge of users into account, operationalized as UET, participants were selected that possess a minimum level of expertise in three educational domains related to BPM task performance (i.e. industrial engineering, business management, and computer science) (see Section 2.3.3 for a more detailed discussion). Industrial engineering students possessed quantitative and analytic expertise in process-oriented analysis perspectives. Students majoring in computer science were educated and trained in quantitative and analytic expertise relative to object-oriented modeling and programming perspectives. Students majoring in business management were not usually trained in process-oriented or object-oriented analytic perspectives.

Table 3-2. Dependent Variables and Associated Sources of Data

DEPENDENT VARIABLES	SOURCE OF DATA
Task Accuracy	
Percent of questions answered correctly	Post-task Questionnaire
Task Timeliness	
Time on task (seconds)	Stopwatch
Subjective Mental Workload	
Mental Demand	NASA-Task Load Index (TLX)
Physical Demand	NASA-Task Load Index (TLX)
Temporal Demand	NASA-Task Load Index (TLX)
Performance	NASA-Task Load Index (TLX)
Effort	NASA-Task Load Index (TLX)
Frustration	NASA-Task Load Index (TLX)
Self-Efficacy	
Average rating	Post-task Questionnaire

3.3.2 Dependent Variables

The dependent variables in this experiment operationalized assessments of task performance (accuracy and timeliness), subjective mental workload, and self-efficacy in relation to GPM user comprehension outcomes. Table 3-2 summarizes these variables and how the associated assessment instruments.

3.3.2.1 Task Accuracy

Task accuracy was operationalized as a measure of correctness of an individual's task solution compared to a known, correct answer (Baddeley, 2003; Marmaras & Kontogiannis, 2001; Umanath & Vessey, 1994). It is a frequent measure of task effectiveness and solution quality in various HCI and cognitive science-related literature such as cognitive fit (cf. Dunn & Grabski, 2001; Vessey, 1991), cognitive load (cf. Paas, Renkl, & Sweller, 2003; van Merrienboer, Kirschner, & Kester, 2003), and user comprehension of IS data models (cf. Agarwal, De, & Sinha, 1999; Shoval, Danoch, & Balabam, 2004).

The task accuracy questionnaires used in this study were created based on recommendations by Basu and Blanning (2000) as to the kinds of BPM questions that managers should be able to comprehend and answer from the GPMs used in BPM Systems. Each type of question was asked at least twice in the questionnaire, one more difficult than the other. The questionnaire was designed with a total of 30 questions for participants to answer: eight task-centric GPM questions, eight resource-centric GPM questions, eight information-centric GPM questions, and six questions assessing participants' integration of BPI across maps[2] (see Appendix J.3 for experimental task questionnaires). Different versions of the questionnaire were created that changed the order of the questions based on the order that the task, resource, or information-centric GPMs were presented to participants.

Task accuracy was measured by calculating the percent of correct answers to these questionnaires. In this experiment, accuracy scores for each participant were collected three times within-subjects: once after users completed their interpretation of each GPM that portrayed each different type of BPI (see Appendices B and I for instructions and scripts, and Section 4.2.1 for task accuracy results).

[3-2] Data from these last six questions are not related to the hypotheses tested in this study but were used in future analyses.

3.3.2.2 Task Timeliness

Task timeliness was measured by the amount of time participants spent performing the task. "High" task timeliness is associated with smaller amounts of time. "Low" task timeliness is associated with larger amounts of time (see Section 2.2.2). In this experiment, separate measures of task timeliness for each participant were collected using a stopwatch as participants performed the training and experimental tasks. In this experiment, timeliness data for each participant were collected three times within-subjects: once after users completed their interpretation of each GPM portraying each different type of BPI (see Section 4.2.2 for timeliness results).

3.3.2.3 Subjective Mental Workload: The NASA-Task Load Index

This study used an established assessment of subjective mental workload: the NASA-Task Load Index (TLX) (Hart & Staveland, 1988a, 1988b). The latest version of the NASA-TLX is a product of several iterations, and has been demonstrated as both valid and reliable. For example, Rubio et al. (2004) evaluated the methodological and psychometric properties of three different types of subjective mental workload instruments. They found the NASA TLX to have acceptable correlations ($r > 0.65$) with their two measures of task performance (time and accuracy). In addition, Hill et al. (1992) comparisons of four subjective workload scales, found the TLX and one other measure to be consistently superior (cf. Hart & Staveland, 1988a; Hart & Wickens, 1990; Hill et al., 1992; Nygren, 1991; Rubio et al., 2004; Vitense, Jacko, & Emery, 2003) (Jung & Jung, 2001). (See Section 2.4.1 and 2.4.2 for a review of mental workload literature.).

The NASA-TLX is a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988a, 1988b). The definitions of these dimensions are shown in Table 3-3.

Ratings for each TLX dimension were obtained by participants responding to questions related to each dimension on a continuous, bipolar scale. In addition, a weighting procedure was used to combine ratings of the six individual dimensions into a global score for each participant based on paired comparisons between all combinations of the six dimensions. The number of times a dimension was chosen in the paired comparisons by the participant meant it received a heavier weighting for a given task. A TLX workload score from 0 to 100 was obtained for each rated task by multiplying the weight by the individual dimension scale score, summing across scales, and dividing by fifteen (the total number of paired comparisons). In this experiment, TLX subjective mental workload ratings on the six dimensions were collected three times within-subjects: once after users completed their interpretation of each GPM portraying each different type of BPI (cf. Hart & Staveland, 1988a; Hart & Staveland, 1988b) (see Appendices I.4, I.5, I.8, and L.5).

Table 3-3. Descriptions of the NASA TLX Dimensions

TITLE	ENDPOINTS	DESCRIPTIONS
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, simple or complex, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Bad	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

3.3.2.4 GPM Self-Efficacy Assessment

No self-efficacy instrument exists to assess self-efficacy of BPM Systems or GPM user comprehension tasks. Therefore, an instrument needed to be either created or adapted for use in this study. It was determined that the way to proceed was to adapt an established assessment of self-efficacy that is related to this study to minimize potential instrumentation issues. Although, this research does not use computer screens to portray GPMs to users, computers are used in BPM Systems and future GPM and BPM System research. Additionally, as explained in Appendix H.2, it was decided from the pilot study to not portray GPMs on screens so that user comprehension outcomes are not confounded by variables related to the manipulation of the GPM on the screen. Using the same self-efficacy instrument from this study, future studies can identify the effect of computer vs. paper portrayals on GPM user self-efficacy.

Therefore, it was decided that the self-efficacy instrument chosen for is study should also be able to be used in future studies using actual GPMs and BPM Systems. As a result, a often-used computer self-efficacy instrument was adapted for use in this study. Self-efficacy was assessed by adapting a computer self-efficacy instrument developed by Compeau and Higgins (1995). It was primarily developed as a general assessment of an individual's self-efficacy in using computers (Compeau & Higgins, 1995; Compeau, Higgins, & Huff, 1999; Fagan, Neill, & Wooldridge, 2003). This instrument was chosen because of its history of extensive use in the literature, and because computer self-efficacy was closely related to the self-efficacy needed by users of GPMs as part of BPM Systems. Compeau and Higgins's original computer self-efficacy instrument included ten statements for participants to evaluate. Nine of the ten statements were adapted to assess GPM user self-efficacy using a likert-type scale where 1 equals low self-efficacy and 10 equals high self-efficacy (see Appendix L.9):

- Self-Efficacy Question #1-If the user was alone and no one to tell them what to do.
- Self-Efficacy Question #2-If the user never used these types of diagrams before.
- Self-Efficacy Question #3-If the user had only the training handouts for reference.
- Self-Efficacy Question #4-If the user had seen others using these diagrams before trying them.
- Self-Efficacy Question #5-If the user could ask someone for help if they got stuck.
- Self-Efficacy Question #6-If someone helped the user get started.
- Self-Efficacy Question #7-If the user had a lot of time to complete the task.
- Self-Efficacy Question #8-If only the materials used in training were available.
- Self-Efficacy Question #9-If the user had used these diagrams before to do similar tasks.

The question that was not included asked if the user could complete the task if someone was there to show them how to do it first. This question was dropped because of the redundancy when the questions were adapted for this experiment. This question seemed redundant with Question #4. No other question seemed redundant, although several were related to one another.

While Compeau and Higgins (1995) questionnaire has been used in several computer self-efficacy studies, no sources were found that reported the internal consistency and validity for the instrument. Despite this drawback, Compeau & Higgins' questionnaire (1995) was selected for this research because it allowed the greatest comparison to other HCI self-efficacy research.

This assessment was applied at the end of the experiment for two main reasons. First, self-efficacy is typically assessed and conceptualized as an antecedent to performance (see Section 2.4.2). Participants in other studies that include computer self-efficacy, typically, have had some experience with computers and could provide an evaluation of self-efficacy prior to the specific study's experimental task. However, in this experiment, participants had limited or no prior experience with these GPMs or the with interpretation of BPI in the context of this experiment. Therefore, the participants in this experiment had no basis to judge their GPM user self-efficacy in this experiment until after the task was completed. Second, the primary issue studied in this research was the effect of GPM type on user comprehension. Thus, it was decided to assess self-efficacy after each participant completed their interpretation of their assigned GPM Type. The approach to assessing self-efficacy in this study laid a foundation for assessing future GPM user comprehension research in BPM task contexts.

Table 3-4. Description and Instrumentation of Control Variables

CONTROL VARIABLES	SOURCE OF DATA
Cognitive Styles	
Extrovert vs. Introvert	Myers-Briggs Type Indicator (MBTI) – Continuous Scores
Sensing vs. Intuitive	Myers-Briggs Type Indicator (MBTI) – Continuous Scores
Cognitive Abilities	
General Cognitive Ability (GCA)	Wonderlic Personnel Test (WPT)
Attentional Abilities (Overall)	
Moderately-focused attention	Differential Attentional Processes Indicator (DAPI)
Extremely-focused attention	Differential Attentional Processes Indicator (DAPI)
Dual attention to tasks (cognitive-physical)	Differential Attentional Processes Indicator (DAPI)
Dual attention to tasks (cognitive-cognitive)	Differential Attentional Processes Indicator (DAPI)

3.3.3 Moderating Variables

Table 3-4 summarizes the moderating variables and the instruments used to assess them. Because of the difficulty of manipulating these variables as independent variables, their covariate effects on the relationship between cognitive resources and GPM user comprehension task outcome variables were controlled for using statistical analyses.

3.3.3.1 Cognitive Styles: The Myers-Briggs Type Indicator

This study used the Myers-Briggs Type Indicator (MBTI) (Myers & Myers, 1995) to assess cognitive styles. The MBTI is described as an explicit operationalization of Jung's theory of psychological type (Myers, 1993; Myers & McCaulley, 1989). Form F of the MBTI includes 166 forced-choice items used to provide scores along four scales: Extraversion/Introversion (EI), Thinking/Feeling (TF), Sensing/Intuiting (SN), and Judging/Perceiving (JP). MBTI research has found that individuals' cognitive styles for perceiving and processing information consistently align along four different dimensions: extrovert-introvert, sensing-intuition, thinking-feeling, and judging-perceiving.

The MBTI is the most used instrument for assessing cognitive styles and personality traits in management and decision-making literature. For example, Hough and Ogilvie (2005), who studied the use of cognitive style as antecedents of strategic decision processes or performance, suggest three reasons why the MBTI dominate the strategic decision-making research on cognitive style. First, the cognitive styles represented by the MBTI are conceptually related to the information gathering and information evaluation aspects of decision making (Myers, 1993). Second, it is widely used and understood within organizations allowing for direct transfer from research to practice (Gardner & Martinko, 1996) primarily because the use of MBTI preferences is reported as less threatening to managers and more easily understood as opposed to absolute measures of cognitive ability, such as IQ (Hayes & Allinson, 1994). Finally, research supports the conceptual, construct, and predictive validity of the MBTI (Bess, Harvey, & Swartz, 2003; Capraro & Capraro, 2002; Myers & McCaulley, 1989; Myers, McCaulley, & Most, 1985; Tzeng, Outcalt, Boyer, Ware, & Landis, 1984).

Academic researchers have been divided over the subject of MBTI validity and reliability. Several studies have found MBTI research based on continuous scores to have high face validity and reliability (Gardner & Martinko, 1996). Related to continuous MBTI scores of Form F used in this dissertation research, Myers and McCaulley (1985) report Form F continuous scores for each of the four MBTI dimensions to have the following Cronbach's α coefficients: EI = 0.83, SN = 0.83, TF = 0.76, and JP = 0.80.

Additionally, Cronbach's α were computed for large sample studies collected from the Center for Applications of Psychological Type (CAPT) databank. These scores exhibited reliability coefficients averaging EI = 0.79, SN = 0.84, TF = 0.74, and JP = 0.82 on more than 32,000 participants and a range of EI = 0.74 to 0.83, SN = 0.74 to 0.85, TF = 0.64 to 0.82, and JP = 0.78 to 0.84 on more than 10,000 participants (Myers et al., 1985). Harvey (1996) reports results of a meta-analysis on the studies summarized in the MBTI Manual (Myers et al., 1985) for which data are given by gender on a sample of 102,174 respondents. This meta-analysis gave corrected split-half estimates on men and women, respectively: EI, 0.82 and 0.83; SN, 0.83 and 0.85; TF, 0.82 and 0.80; JP, 0.87 and 0.86. Thus, meta-analyses report that the administrations of the MBTI examined in the present study indicated that the MBTI, on average, tends to yield scores with acceptable reliability across studies (Harvey, 1996). Test-retest reliabilities for MBTI scores suggest score consistency over time. Test-retest coefficients from 1 week to 2.5 year intervals ranged from 0.93 to 0.69 on the SN scale, 0.93 to 0.75 on the EI scale, 0.89 to 0.64 on the JP scale, and 0.89 to 0.48 on the TF scale (Myers & McCaulley, 1989). It is reported that when respondents do show a change in type, it is usually only in one preference and then in scales where they were originally not strongly differentiated (Myers et al., 1985).

Several researchers have studied the construct validity of the MBTI scores. Validity of MBTI scores is typically established by correlating the scores with findings from various personality instruments and inventories of interest. Statistically significant correlations have been found between MBTI scores, behaviors reflective of MBTI constructs, and persons' self-assessment of their own MBTI type (De Vito, 1985; Myers & McCaulley, 1989). Additionally, confirmatory factor analysis found significant higher support for MBTI construct validity when using data from real-world managers compared to construct validity studies using students (Bess et al., 2003). Saggino, Cooper, and Kline (2001) report several studies examining research on the MBTI (Carlson, 1985; Carlyn, 1977; Carskadon, 1979; Murray, 1990) and conclude that the MBTI seems to be a reasonably valid instrument, even if further studies are needed on its construct validity. Tischler (1994, p. 30) state that "factor analysis provided unusually strong evidence that the MBTI items are correlated with their intended scales: the scales are almost factorially pure."

However, there are several controversies in the literature as to the reliability and validity of the MBTI, often related to the indicator's measurement characteristics (Capraro & Capraro, 2002; Saggino et al., 2001). For example, studies report that there is insufficient evidence to support the premises and conclusions of the MBTI (Pittenger, 1993). Other researchers do not believe the MBTI does not adequately represent Jungian theory (Saggino et al., 2001). The forced-choice response format and false assumptions that all people can be divided into groups have also been criticized (Vacha-Haase & Thompson, 2002). Another criticism is regarding gender weighting because different weights are applied for men and women on the TF. This leads to difficulties in comparing men and women on the TF scale (Vacha-Haase & Thompson, 2002). Also, criticism is related to either using student data to support reliability and validity (Bess et al., 2003). Like all measures, the MBTI yields scores that are dependent on sample characteristics and testing conditions. Most statistical validity problems and discrepancies in MBTI results were found to involve the use of categorical MBTI scales (Gardner & Martinko, 1996). Therefore, much of the criticism of MBTI research is reported to stem from a lack of MBTI research based on continuous data in analyses (Gardner & Martinko, 1996).

Despite these criticisms, the use of MBTI Form F was used in this study due to the amount of the amount of literature supporting its reliability and validity. This study used MBTI scores to assess two of these MBTI cognitive styles:

- Extroversion vs. Introversion: refers to the participants' preference for cognitively processing information based on their being more interested in the world around them, i.e. extroversion, or the world of ideas within their own minds, i.e., introversion.
- Sensing vs. Intuition: refers to the participants' degree of dependence on either their five senses, i.e., sensing, or on their intuition to gather and perceive information.

MBTI continuous data have been collected in two forms: individual dimension scores (e.g., separate sensing scores and intuition scores) and dichotomous scores (e.g., a single score representing both sensing and intuition). Due to the exploratory nature of this study and to address concerns in the MBTI literature, this study used dichotomous, continuous scores for the extroversion-introversion and sensing-intuition cognitive styles calculated from data collected using Form F of the MBTI. This approach maximized the potential reliability and validity of the MBTI Form F cognitive style data.

3.3.3.2 General Cognitive Abilities: The Wonderlic Personnel Test

Assessments of General Cognitive Abilities (GCA) have been generally misrepresented by practitioners as measures of "intelligence" instead of assessments of a broad range of cognitive abilities (Bowman, Markham, & Roberts, 2001; Schmidt, 2002; Woodcock, 2002). GCA was assessed in this study by a single numerical score resulting from each participant taking the Wonderlic Personnel Test (WPT)

Form A (Dodrill, 1983; Dodrill & Warner, 1988). Although a variety of instruments were available to assess broad cognitive abilities and narrow cognitive aptitudes, most of these instruments were long, cumbersome to administer, and better suited for specific cognitive psychological research. Because cognitive abilities were not the central focus of this study, it was decided that an instrument measuring a broad range of GCA that is widely used and relatively easy to administer was better suited for this exploratory research. The WPT was selected, because it fit these requirements. The WPT aggregates an individual's quantitative scores on a variety of cognitive abilities into a single score representing the individual's GCA (McCutcheon, 2002; Schmidt, 2002; Woodcock, 2002).

The WPT Form A is a self-administered, 12-minute, pencil-and-paper test designed as a brief assessment of a broad range of intellectual cognitive abilities. An individual's WPT score can range from one to fifty, where fifty equals high GCA. The WPT is based on the more extensive Weschler Adult Intelligence Scale (WAIS) (Dodrill & Warner, 1988). As a result, the WPT was reported to be highly correlated with the WAIS (0.91 to 0.93), with 90% of the subjects scores allowing IQ predictions with discrepancies of no more than ten points. Long-term validity comparisons of the WPT to the WAIS found that test-retest reliability of the WPT is 0.94, which is roughly equivalent to the WAIS (Dodrill, 1983) (Dodrill & Warner, 1988). Furthermore, the predictive validity of the WPT is reported as not being compromised by characteristics, such as, age, sex, years of education, and emotional adjustment (Dodrill, 1981) (cf. Dodrill, 1983; Dodrill & Warner, 1988; Hawkins, Faraone, Pepple, Seidman, & Tsuang, 1990) (See Appendix L.6 for a sample of the WPT).

3.3.3.3 Attentional Abilities: The Differential Attentional Processes Inventory

Attentional Abilities of participants were assessed using the Differential Attention Processes Inventory (DAPI) (Crawford, Brown, & Moon, 1993; Lyons & Crawford, 1997). The DAPI assesses participants' ability to focus their attention during task performance under various conditions. It consists of forty self-descriptive statements relating an individual's experiences with their ability to focus attention, ignore distractions, and, simultaneously carry out two types of tasks. Participants were asked to rate themselves as to the degree to which they typically can carry out the activities on a seven-point scale of 1 (not at all) to 7 (always). The DAPI includes four subscales previously validated by factor analysis (Crawford et al., 1993; Grumbles & Crawford, 1981):

1. Moderately-focused attention (8 items): this construct assesses an individual's perceived ability to sustain moderately focused attention amid distractions.
2. Extremely-focused attention (12 items): this construct assesses an individual's perceived ability to engage their total attentional resources to a task without awareness of outside stimuli or distractions.
3. Dual attention cognitive-cognitive tasks (4 items): this construct assesses whether two cognitive tasks can simultaneously be easily performed, for example, reading or studying easily while at the same time listening to the radio or TV.
4. Dual attention cognitive-physical tasks (5 items): this construct assesses whether one cognitive task and one physical task can be easily performed simultaneously, for example, carrying out a motor activity easily while listening to a conversation.

Yanchar (1984) reports on internal consistency for the DAPI (Cronbach's $\alpha = 0.88$). Lichtenberg et al. (2004) reports Cronbach α for different DAPI constructs: 0.84 for the extremely focused attention, 0.86 for moderately focused attention, 0.71 for cognitive-physical, and 0.88 for cognitive-cognitive subscales. A similar study reports that the test-retest reliability for a college sample over 4 weeks was 0.90, and the Cronbach's α for the two testing periods was 0.91 and 0.94 (Lyons & Crawford, 1997). (See Section 2.4.3 for a discussion of attentional abilities and Appendix L.7 for an example of the DAPI.)

3.3.4 Blocking Variables

In addition, the following blocking variables were analyzed to eliminate potential bias in the data:

- Age: Age in years of the participant.
- Gender: Male or female.
- Major: Declared academic educational training of the participants, i.e., IE, MGT, or CS.
- Prior Experience with specific GPM techniques: Including flowcharts, metagraphs, Petri nets, UML diagrams, etc.
- Prior Experience with business process modeling software: Participants listed software packages that they have used to model business processes.
- Experience modeling business processes: Participants rated their experience with modeling business processes as either beginner, adequate, or advanced.
- Order of BPI Tasks within Treatments: The order of the BPI tasks was varied to eliminate learning bias as much as possible.

- Treatment date: The date each participant completed the experimental task.
- Undergraduate/Graduate Courses Taken: Specific courses taken by participants related or their declared major.
- Undergraduate/Graduate Total Credits: Total credits completed at the time of the experiment.

3.4 MATERIALS, EQUIPMENT, AND FACILITIES

This section outlines the instrumentation and materials needed to perform this experiment. Details regarding each of these items is contained in Appendices B, C, D, E, F, G, H, I, J, K, and L.

3.4.1 Participant Materials

- IRB Experiment Purpose and Participant Rights (see Appendix A.2)
- IRB Participant Consent Form (see Appendix A.2)
- Demographics Questionnaire (see Appendix L.1 or L.2)
- MBTI Form F (see Appendix L.8)
- Differential Attentional Processes Inventory (DAPI) (see Appendix L.7)
- Wonderlic Personnel Test - Form A (see sample WPT in Appendix L.6)
- Training Task Instructions (see Appendix I.1)
- Training Task FAQ Sheet (see Appendix I.2 or I.3)
- Training Task GPMs (see Appendix J or K)
- Training Task Assessment Packet: It includes task accuracy questionnaires, the NASA-TLX, and the GPM self-efficacy questionnaire (see Appendix I.4 or I.5)
- Experimental Task Instructions and Scripts (see Appendix I.6 and I.7)
- Experimental Task GPMs (see Appendix C or D)
- Experimental Task Assessment Packet: It includes task accuracy questionnaires, the NASA-TLX, and the GPM self-efficacy questionnaire (see Appendix I.8 or I.9)

3.4.2 Equipment

- A clipboard was needed for each participant in a treatment group.

- Wall-mounted GPMs printed on 22” x 34” (Paper Size D) – two sets of three metagraph and three UML diagrams modeling the different BPI perspectives of the same business process. In this study, the process modeled was a bank loan application process.
- Microsoft Word 2003 software
- Microsoft Visio 2003 software
- Microsoft Excel 2003 software
- SPSS 14.0 software

3.4.3 Facilities

- Classroom Facilities with wall space to mount the GPMs.
- A desk and chair for each participant to fill out the assessments.

3.4.4 Incentives for Participation

3.4.4.1 Motivation to Participate

- Course instructor requirements and points toward course grade, or pizza and soda.

3.4.4.2 Motivation to Optimize Performance

- Three $100 gift certificates for top performer from each academic major (type of UET).
- $200 gift certificate for top overall performer.

3.5 EXPERIMENTAL PROCEDURE

A pilot study was conducted to test and refine the procedures prior to the actual experiment. The pilot study GPMs and materials are located in Appendices B, C, D, E, and F. Pilot study procedures and findings are discussed in Appendices G and H, respectively. This section describes the experimental procedures used in this study.

UML Tasks O_a —— R —— X_{11} —— $O_{11b}T_{11}$ —— X_{21} —— $O_{21b}T_{21}$ —— X_{31} —— $O_{31b}T_{31}$ O_4

MG Tasks O_a —— R —— X_{12} —— $O_{12b}T_{12}$ —— X_{22} —— $O_{22b}T_{22}$ —— X_{32} —— $O_{31b}T_{31}$ O_4

O_a =	Pretest assessments of prior expertise, GCA, DAPI, MBTI and demographics were conducted prior to the experiment.
R =	The random assignment of approximately equal numbers of participants with different types of User Educational Training (UET_1, UET_2, UET_3) were assigned to either metagraphs or UML GPM treatments.
$X_{\#1}$ =	Participants that were assigned the task set portraying BPI using UML diagrams ($GPM_1 = X_{\#1}$). The actual order of the UML diagrams representing different BPI types were assigned to each participant to minimize learning order bias.
$X_{\#2}$ =	Participants that were assigned the task set portraying BPI using Metagraphs ($GPM_2 = X_{\#2}$). The actual order of the metagraph diagrams representing different BPI types were assigned to each participant to minimize learning order bias.
$O_{\#\#b}$ =	Repeated measures of the same set of dependent variables was completed after each participant interpreted each type of BPI: subjective mental workload (NASA TLX) and task accuracy (questionnaire).
$T_{\#\#}$ =	Repeated measures of task timeliness was documented representing how long each participant took to interpret each type of BPI.
O_4 =	After completion of the entire experiment, participants completed the self-efficacy questionnaire and paired comparison weightings of the NASA-TLX mental workload dimensions.

Figure 3-1. Experimental strategy for each experimental treatment group.

Figure 3-1 illustrates and describes the order of the procedures that participants followed as part of a treatment group during the actual experiment. Participants completed three separate user comprehension tasks in a treatment: one about task-centric BPI, one about resource-centric BPI, and one about information-centric BPI. The following is a detailed outline of the procedure used to conduct the experimental treatments based on lessons learned from the pilot study:

1. Training and experimental GPM task sets, assessment packages, and timeliness data collection procedures were prepared for experiment participants.
2. Third and fourth year university students were recruited for the experiment in various IE, MGT, and CS courses. If they chose to participant, students were provided an overview of the experiment and the motivations for participation were described. Participants signed up for a treatment group time and were given a pre-experiment assessment packet that they were to complete and bring to the experiment. Pre-experiment assessment packets included:
   - A. The Experiment Announcement
   - B. An IRB Informed Consent form

   C. The Demographic and Prior Experience Questionnaire
   D. The MBTI Form F
   E. The Differential Attentional Processes Inventory (DAPI)
3. Treatment task sets (either MG or UML) were assigned to participant groups based on the time students signed up to participate.
4. Participants in a treatment group arrived at the scheduled time for experiment, and the experiment's purpose and initial instructions were given to the treatment group.
5. Pre-experiment assessments were collected including:
   A. A signed IRB Informed Consent form.
   B. A completed Demographic and Prior Experience Questionnaire
   C. A completed MBTI Form F.
   D. A completed Differential Attentional Processes Inventory (DAPI).
6. The 12-minute, Wonderlic Personnel Test (WPT) Form A was administered to participants in the treatment group.
7. Participants received the training handouts and training instruction from the facilitator. The facilitator was careful to answer questions using only the information available in the training handouts.
8. When the training began, participants interpreted simplified sample GPMs and worked through the sample questions checking their answers against correct answers on the back of the page. Time on task was not collected for the training task, because the training task involved participants studying the correct answers to the training. Thus, it did not reflect the actual time to complete a training task.
9. When students completed their interpretations and were given a chance to ask questions, the facilitator provided instruction on completing the NASA TLX dimensions, TLX paired comparison ratings, and the GPM self-efficacy questionnaire.
10. Participants completed the assessments in number 9 in relation to the training task they had recently experienced.
11. Training task assessments were collected by the facilitator.
12. The facilitator handed out the instructions and scenario for the experimental tasks. He verbally read through these documents with the participants and answered last minute questions. Again, in answering questions, the facilitator was careful to point participants to the training materials and not

provide any information that did not exist in these materials. Participants were then allowed to use all the training and experiment handouts during the experimental tasks.

13. Experimental assessment packets were distributed to the participants. Participants were instructed on the order in which they were to complete interpretation of the three GPMs.
    A. The order participants were assigned to complete their interpretations of the three types of BPI was counterbalanced to reduce learning order bias in the results. For example, approximately a third of the participants completed the experiment by interpreting the GPMs in the following order: (1) task-centric BPI, (2) resource-centric BPI, and finally (3) information-centric BPI. Approximately a third of the participants completed their experiment by interpreting the GPMs in this order: (1) resource-centric BPI, (2) information-centric BPI, and finally, (3) task-centric BPI. Approximately a third of the participants completed their experiment by interpreting the GPMs in this order: (1) information-centric BPI, (2) task-centric BPI, and finally, (3) resource-centric BPI.
    B. The order that the participants were presented the different types of BPI was assigned and counterbalanced to assure an almost equal number of participants per BPI order in each GPM Type.
14. The facilitator started all the participants at the same time. A stopwatch was used to keep track of the time on task.
15. After a participant completed the task accuracy questionnaires, data were collected in the following ways:
    A. When the participant said, “Stop,” then the time on task (in seconds) was recorded by the facilitator.
    B. The participant rated each of the dimensions of the NASA-TLX in relation to that specific type of BPI.
    C. The participant prepared him or herself for the next type of BPI, and notified the facilitator when they were ready to begin.
16. The facilitator looked at the stopwatch, told the participant to start their next GPM, and recorded the stopwatch time that the participant had begun interpretation of the next GPM.
17. Each participant completed their second BPI interpretation task according to number 15 above.
18. The facilitator started each participant on their third BPI interpretation task according to number 16 above.

19. Each participant completed their third BPI interpretation task according to number 15-A and 15-B above. Additionally, they completed:
    A. Fifteen NASA-TLX paired comparison ratings of the TLX subjective mental workload dimensions.
    B. The GPM self-efficacy questionnaire.
20. After completion of the experimental set of user comprehension tasks, the facilitator collected the assessment packets from each participant.
21. Experiment participants were then thanked and excused. They were told that the promised motivational rewards would be given to the winning participants after completion of the data analysis.
22. The facilitator completed notes on observations made during the experiment.

Table 3-5. Design Matrix for Experiment for Minimum Desired Number of Participants

		Task-Centric BPI (BPI_1)	Resource-Centric BPI (BPI_2)	Information-Centric BPI (BPI_3)
Industrial Engineering Expertise (UET_1)	UML (GPM_1)	< - - - -	n_{1-12}	- - - - >
	Metagraph (GPM_2)	< - - - -	n_{37-48}	- - - - >
Management Expertise (UET_2)	UML (GPM_1)	< - - - -	n_{13-24}	- - - - >
	Metagraph (GPM_2)	< - - - -	n_{49-60}	- - - - >
Computer Science Expertise (UET_3)	UML (GPM_1)	< - - - -	n_{25-36}	- - - - >
	Metagraph (GPM_2)	< - - - -	n_{61-72}	- - - - >

UET_i=type of User Educational Training
GPM_i=type of Graphical Process Modeling Technique
BPI_i=type of Business Process Information

n_i = ith participant

3.6 EXPERIMENTAL DESIGN

Data were collected using a 2 (type of GPM) x 3 (type of UET) x 3 (type of BPI) factorial design, with repeated measures on the third variable (BPI Type), and analyzed using three-way mixed MANOVAs that included two between-subjects variables (GPM Type and UET Type) and one within-subjects variable (BPI Type). In addition, the following variables were statistically controlled as covariates using MANOVAs for moderating effects of general cognitive abilities (GCA), attentional abilities, extroversion-introversion cognitive style, and perceptual cognitive style (i.e., sensing-intuition).

3.6.1 A Priori Determination of Statistical Power and Sample Size

Determining the appropriate statistical power, sample size, and Effect Size (ES) was difficult due to the fact that this form of GPM user comprehension research has not been performed, the multivariate nature of the data, and practical issues involved in running large numbers of participants through this experiment. No analysis results from past literature were found that could be used to determine the ES and total sample size for the multivariate data assessed in this experiment. This is because the instruments used in this experiment have either not been used in GPM user comprehension research or were developed specifically for this experiment so there is no past power or ES results available (as in the case of the questionnaires assessing task accuracy). In addition to past research, pilot study data is often used to calculate a prior statistical power and sample size. However, the pilot study in this study revealed that the experiment, as originally designed, was too difficult and took so long to complete that it created unnecessary mental fatigue in the participants. This was an unexpected result and, consequently, the actual experiment was redesigned. Time constraints for experiment data collection did not allow for a second pilot study. Academic course instructors were understandably reluctant to require students to participate and made it difficult to recruit large enough numbers of students to participate in the experiment in a timely fashion (ultimately creating time constraints on the completion of data collection). Thus, it was necessary to rely on statistical charts and estimates to determine a priori power level and sample size for this experiment. Consequently, after redesigning the experiment, the very limited pilot study did not produce enough data to determine an appropriate apriori ES or power level to estimate sample size. Therefore, an a priori power analysis was conducted using recommendations from statistical literature (Lipsey, 1990; Winer, Brown, & Michels, 1991).

A limited review of statistical literature revealed lack of recommendations for determining power in multivariate data. The power, ES, and sample size was determined using a two-tailed α-level of 0.05 based on instructions and Figure 2.1 from Lipsey (1990). A medium ES = 0.50 and a minimum of $n = 72$ participants generates an acceptable power level (1-β) of approximately 0.84 (Lipsey, 1990, p. 44). This figure assists in the determination of power levels and sample sizes for one-way ANOVAs was suggested as appropriate (Lipsey, 1990) because individual ANOVAs are the basis of MANOVAs. Table 3-5 shows the design matrix based on the minimum target number of participants per cell determined by a priori power analysis. Each of the six treatment cells in the experimental design was assigned a minimum of twelve students to produce sufficient power to detect a medium result. Table 3-6 shows the degrees of freedom computations for this experiment based on a minimum of 12 participants per treatment cell.

Table 3-6. Degrees of Freedom for Minimum Desired Number of Participants

Sources of Variation	**df**	**df***
Between Subjects	abn-1	(2)(3)(12)-1 = 71
A = type of Graphical Process Model (GPM)	a-1	2-1 = 1
B = type of Tacit PM Knowledge (TK)	b-1	3-1 = 2
AB	(a-1)(b-1)	(2-1)(3-1) = 2
Subjects between groups (error between)	ab(n-1)	(2)(3)(12-1) = 66
Within Subjects	abn(c-1)	(2)(3)(12)(3-1) = 144
C = type of Explicit BPM Task Information	c-1	3-1 = 2
AC	(a-1)(c-1)	(2-1)(3-1) = 2
BC	(b-1)(c-1)	(3-1)(3-1) = 4
ABC	(a-1)(b-1)(c-1)	(2-1)(3-1)(3-1) = 4
C x Subjects within groups (error within)	ab(n-1)(c-1)	(2)(3)(12-1)(3-1) = 132
Overall	abcn-1	(2)(3)(3)(12)-1 = 215

*a=2, b=3, c=3, n=12

3.6.2 Estimated Degrees of Freedom and Resulting Sample Sizes

However, due to the nature of the experimental procedures (see Section 3.5 above) and the schedules of the participants, the actual experiment did not produce an equal number of participants across treatment cells. A total of eighty-seven students from two universities participated in the experiment, including twenty-four (24) IE students, thirty-five (35) MGT students, and twenty-eight (28) CS students representing the independent variable, the type of UET. The number of participants using each type of GPM also were not equal. Of the IE students, twelve students completed the experiment using metagraphs and twelve students used UML diagrams. Of the MGT students, seventeen used metagraphs and the other eighteen used UML diagrams. Of the CS students who participated, twelve used metagraphs and sixteen used UML diagrams. All eighty-seven (87) participants completed each of the three conditions of the within-subjects independent variable type of BPI.

3.7 DATA ANALYSES TO TEST HYPOTHESES

The statistical methods used to analyze the data were different depending on the type of test and the specific hypotheses being tested. The dataset was multivariate in nature, because the three independent variables used the same set of participants to assess four different dependent variables (Rencher, 2001). This fact alone required multivariate statistical analyses to verify assumptions of multivariate normality, to test for preservation of the experiment-wise error rate in future univariate analyses, evaluate the independence of measures of the dependent variables, test scale reliability, evaluate the cognitive style distributions between groups, and test for homogeneity of variance and covariance. Therefore, several preliminary analyses were performed to test the underlying assumptions that permit parametric statistical analyses of this dataset. The methodologies required and the results of these preliminary analyses are reported in Appendices M and N. The preliminary analyses did not reveal any results that negatively impacted the statistical testing of these hypotheses.

Analyses to test the hypotheses of this experiment required several analytic methods, including correlations, factor analyses, and three-way, mixed multivariate analyses of variance (MANOVAs) and multivariate analyses of covariance (MANCOVAs). The following sections discuss the specific analyses used to test each of the hypotheses in this study.

3.7.1 Hypothesis 1 Analyses – Impacts of the Type of Graphical Process Model

Hypothesis 1, and associated sub-hypotheses, state that the type of GPM significantly affect participants' task performance (i.e., accuracy and timeliness), self-efficacy, and subjective mental workload. The between-subjects portion of a three-way mixed MANOVA was used to test this hypothesis. The direction of these statistical results were illustrated using box-plots for the dependent variables accuracy, timeliness, subjective mental workload, and GPM self-efficacy. (See Section 4.4.1 for these results.)

3.7.2 Hypothesis 2 Analyses – Impacts of the Type of Business Process Information

Hypothesis 2, and its sub-hypotheses, state that the type of BPI significantly affects participants' task performance (both accuracy and timeliness) and subjective mental workload. Self-efficacy data were not included in Hypothesis 2 because it was evaluated between-subjects (i.e., once by each participant at the end of the entire experiment) compared to other dependent variables that were evaluated within-subjects after each BPI Type. The within-subjects portion of a three-way mixed MANOVA was used to test this hypothesis. Tests of within-subjects simple contrasts (using both first and last methodologies) were used to indicate both direction and significance between the different types of BPI: task-centric, resource-centric, and information-centric BPI. The direction of these statistical results were illustrated using box-plots for the dependent variables accuracy, timeliness, and subjective mental workload. (See Section 4.4.2 for these results.)

3.7.3 Hypothesis 3 Analyses – Impacts of the Type of User Educational Training

Hypothesis 3, and associated sub-hypotheses, states that the type of User Educational Training of participants significantly affect participants' task performance (i.e., accuracy and timeliness), self-efficacy, and subjective mental workload. The between-subjects portion of a three-way mixed MANOVA was used to test this hypothesis. The direction of these statistical results were illustrated using box-plots for the dependent variables accuracy, timeliness, and subjective mental workload. Additionally, planned comparisons using simple contrast methodologies were used to indicate both direction and significance between the different types of UET: IE, MGT, and CS. (See Section 4.4.3 for these results.)

3.7.4 Hypothesis 4 Analyses – Subjective Mental Workload Correlations with Task Performance

Hypothesis 4, and associated sub-hypotheses, state that participants' task performance is correlated with subjective reports of mental workload. NASA TLX mental workload was assessed within-subject three times per participants – at the same point in the experiment as accuracy and timeliness. Because TLX mental workload was measured within-subjects, three TLX mental workload scores were calculated for each participant: one for task, resource, and information-centric BPIs. Then, by applying TLX paired comparison weightings, three TLX mental workload scores were calculated for each participant (for a total n = 261 data points) (Hart & Staveland, 1988b) (see Appendix L.5). Pearson's correlations were used to test these hypotheses relating subjective mental workload to accuracy and time. In addition, plots of cubic polynomial equations and the statistical significance of the curve fit lines were used to evaluate the negative quadratic, inverted-U inverse relationship specified by the Yerkes-Dodson law. (See Section 4.4.4 for these results.)

3.7.5 Hypothesis 5 Analyses – Subjective Mental Workload Correlation with Self-Efficacy

Hypothesis 5 states that GPM self-efficacy is negatively correlated with the subjective mental workload participants experience during task performance. Self-efficacy was measured between subjects using nine separate questions and an overall score per participant was averaged from participant's responses to these questions (see Section 4.3.4 for details). An overall TLX mental workload score for each participant (n = 87) was created by averaging the three ratings of each TLX dimension and then the TLX paired comparison ratings were applied. Pearson's correlations were used to test this hypothesis. Additionally, a factor analysis of between-subjects self-efficacy assessments and evaluations of TLX mental workload were performed to evaluate the associations between these variables. (See Section 4.4.5 for these results.)

3.7.6 Hypothesis 6 Analyses – Cognitive Style and Subjective Mental Workload

Hypothesis 6 states that participants' cognitive styles of extraversion-introversion and sensing-intuition, as assessed by the Myers-Briggs Type Indicator (MBTI), significantly affects the subjective mental workload participants experience during task performance. Pearson's correlations were used to test this hypothesis; additionally, tests of these MBTI cognitive styles were evaluated as covariates using both the between-subjects and within-subjects sections of a MANCOVA. (See Section 4.4.6 for these results.)

3.7.7 Hypothesis 7 Analyses – General Cognitive Abilities and Subjective Mental Workload

Hypothesis 7 states that participants' general cognitive abilities, as assessed by the WPT, significantly affect the subjective mental workload they experience during task performance. Pearson's correlations were used to test this hypothesis. Additionally, participants' General Cognitive Abilities scores (using WPT scores) were tested as covariates in both the between-subjects and within-subjects portions of a MANCOVA. (See Section 4.4.7 for these results.)

3.7.8 Hypothesis 8 Analyses – Attentional Abilities and Subjective Mental Workload

Hypothesis 8 states that participants' attentional abilities, as assessed by the DAPI, significantly affect the subjective mental workload they experience during task performance. Pearson's correlations were used to test the relationship between evaluations of TLX mental workload and DAPI assessments of four attentional abilities. Four MANCOVAs testing each of the four DAPI constructs as covariates were also used to test these hypotheses. (See Section 4.4.8 for these results.)

3.8 PREMISES

Several premises are fundamental to the design and accomplishment of this study as outlined here. The following sections outline these fundamental premises.

3.8.1 A Lab Experiment is More Appropriate than Field Research to Test these Hypotheses

Because of the abundance of prior related literature but empirical research was limited in studying BPM Systems, a lab experiment was selected a logical starting point to establish an empirical baseline for comparison in future research. Agarwal et al. (1999, p. 542) states that:

> "… experiments are a preferred research strategy when the cumulative body of knowledge related to a specific phenomenon is limited. It increases the internal validity of the study, albeit at the expense of some realism. Experimental findings can then be used to refine existing theory or develop new theory to be tested in the field."

However, a laboratory experimental research strategy is often criticized because of various threats to validity. Despite methodological drawbacks, the BPM System and GPM user comprehension literature can benefit from this study as it can be used to refine and extend the research model for future experimental research and in future field studies.

3.8.2 University Students are Suitable Participants for this Study

Besides providing a measure of control for tacit BPM knowledge (see Section 3.10.2.1), students were appropriate for this research because the GPMs used in this study are not yet widely used by BPM managers. Practitioners that use BPM Systems are novices when it comes to interpreting metagraphs and UML diagrams. Although UML diagrams are becoming the defacto standard for information system developers (Basu & Blanning, 2000; Vernadat, 2002), the literature does not report UML diagrams as being used extensively by managers in BPM Systems. The literature only reports UML diagrams as proposed extensions for BPM system development (Eriksson & Penker, 2000; Vernadat, 2002). In like manner, metagraphs have been proposed, but not utilized, as yet, in BPM Systems (Basu & Blanning, 2000). Therefore, students are suitable substitutes for BPM managers because they are also novices in understanding how to use and interpret these types of GPMs.

3.8.3 Boundaries of the Cognitive System Extends Beyond the Individual

This research also rests on the premise that the boundaries of a cognitive system can be extended to include cognitive resources external to the participants as well as individual cognitive differences that exist within the minds of the participants (Hollan, Hutchins, & Kirsh, 2000; Nardi, 1998) (see Section 2.5). This means it is appropriate to operationalize these elements as impacting GPM user comprehension.

3.9 THREATS TO VALIDITY

A lab experiment was selected as the most appropriate strategy for studying GPM user comprehension in the context of BPM and BPM Systems. However, an experimental research strategy is also often criticized for threats to internal and statistical validity, in addition to low generalizability. For example, Jarvenpaa, Dickson, and DeSanctis (1985) describe the lack of an underlying theory, the proliferation of measurement instruments, inappropriate research designs, and a diversity of experimental tasks as some of the weaknesses often found in experimental lab research. The following sections briefly discuss the potential threats to validity and how the experimental methodology in this dissertation addresses these threats.

3.9.1 Threats to Internal Validity

There were several possible threats to internal validity that needed to be addressed in this study, for example, training effects, task order, participant assignment to treatment groups, treatment date and time, lab condition, and proliferation of instruments.

3.9.1.1 Bias Due to Training Effects

Participants' lack of experience with a given GPM modeling technique may affect the internal validity of this research due to learning effects (Pedhazur & Schmelkin, 1991). This means that the results for each experimental task may be biased due to a learning curve during the within-subjects portions of the experimental tasks or due to participant differences in learning during training. The students did not have experience interpreting the GPMs or answering the questionnaires that ask them to interpret each type of BPI. Thus, novice participants' performance may be due more to what they learned from interpreting the prior type of BPI than their ability to interpret the current BPI. Or, differences in what participants gain out of training may affect GPM user comprehension outcomes. These issues can make it difficult to separate the learning effects from the actual task performance effects.

To address this issue, a training task and training procedure was designed to give participants experience with every GPM symbol, question, and assessment instrument they would see during the actual experiment. All participants were given the same verbal and written instructions and allowed to practice interpreting all the BPI and GPM symbols. Participants were given examples of all types of questions, asked to figure out the answers, and checked their answers on the back of the questionnaires. Participants were also allowed to use the training handouts during the experiment. This strategy helped to minimize the extraneous effects due to learning bias.

Originally, participants were to be given three simple GPM models to interpret and get 100% correct during the training phase before being allowed to proceed to the experiment. However, during the pilot study, this approach provide impractical. It took participants too long to complete the training. Also, since participants completed the training at different times, management of the participants in the treatment groups was too difficult. Therefore, the training phase was changed to reflect the process described in the previous paragraph and Section 3.5. Consequently, a limitation of this experiment is that there is no data that demonstrate all participants have the same minimum level of training.

3.9.1.2 Bias Due to Task Order Effects

The order that the experimental tasks was presented to participants can create bias in these data (Pedhazur & Schmelkin, 1991; Winer et al., 1991). To address this issue, the order that the BPM tasks were presented to participants were counterbalanced reduce order effects (as discussed in Section 3.5 number 13). A pilot study was also conducted that assessed potential threats to validity due to order effects and to ensure that the materials were administered without variability between the treatment groups.(see Appendix G and H for pilot study details).

3.9.1.3 Bias Due to Assignment of Participants to Treatment Groups

These results may be suffer from bias created by participants' not being assigned to treatment groups in a way that balanced their cognitive styles, cognitive abilities, or tacit knowledge (Pedhazur & Schmelkin, 1991; Winer et al., 1991). For example, if too many participants from a single academic major or possessing similar cognitive styles were assigned to one treatment group, the results would likely be biased towards that specific cognitive ability or cognitive style. Consequently, the statistical analyses may show a significant effect due to cognitive styles or cognitive abilities of the participants when, in fact, the result was due to another variable.

The ability to recruit participants with a balance of cognitive styles was not possible in this experiment. In the real-world, individuals self-select to their particular field of study, which causes a bias toward a particular profile of cognitive styles (Kroeger, Thuesen, & Rutledge, 2002). Additionally, since the participation was both voluntary or required, and treatment group scheduling did not lend itself to counterbalancing cognitive styles within groups, there was no way to control for participant cognitive styles in this experiment. The cognitive styles of participants within treatment groups may have caused problems with external validity because it was impossible to completely randomize the assignment of participants to treatment groups.

This experiment was designed with interventions to help reduce or account for this bias. First, participants were recruited based on a self-selected types of user educational training. The cognitive styles of participants may reflect similar cognitive styles of BPM managers that obtain degrees from the same academic field. It is hoped that this provided a measure of external validity and reflects a representative sample of their counterpart BPM practitioners. However, specific cognitive style research have not been conducted on BPM practitioners, so there are no studies to validate this supposition.

Second, participants cognitive styles and cognitive abilities were assessed and their impacts evaluated in hypotheses and post-hoc analyses. Third, the participants' prior experience with GPMs, modeling software, and BPM were assessed and evaluated, as well as the academic courses that students that have taken that relate to GPM user comprehension (see Appendices L.1 or L.2). These three strategies should give an understanding of the cognitive style and prior experience profiles of the participants to determine if the treatment group assignment caused biased results due to their cognitive styles, cognitive abilities, and tacit knowledge. (See Appendix O results of exploratory analyses results related to these variables.)

3.9.1.4 Bias Due to Treatment Date and Time

The date, time of day, or location could bias participants' results (particularly timeliness) (Pedhazur & Schmelkin, 1991). For example, people might have performed better if the experimental task was scheduled in the morning when they were rested as opposed to the end of the day when they were tired. To address this issue, treatment times were scheduled, as far as possible, in the later afternoon or evenings. Also, the date and time of the experiment was tracked for possible analysis as a blocking variable.

3.9.1.5 Bias Due to Lab Conditions

Differences in lab conditions and environments could bias the results (Pedhazur & Schmelkin, 1991; Winer et al., 1991). Due to participants coming from different universities and different academic majors, the experiment needed to be conducted in different rooms and locations. The design of the experiment itself helped control for this bias. Due to the fact that the GPMs were wall mounted and the assessments were on paper, the experiment was easily portable. The requirements for the experiment were that the GPMs could be mounted on walls in a classroom that allowed participants enough room to comfortably view the GPMs while standing. Also, desks and clipboards were made available so that participants could either sit or stand comfortably completing the assessment instruments. This design allowed for comparable lab conditions across lab experiment locations.

3.9.1.6 Proliferation of Instrumentation

Threats to internal validity can also be due to the proliferation of assessment instruments in an experiment (Jarvenpaa et al., 1985). For example, participants may be asked to complete so many assessment instruments that they become mentally fatigued and do not concentrate on what is being assessed. Also, the variety of assessment instruments may produce different types of data (e.g., categorical, interval, ordinal, or continuous) that cannot be easily or justifiably compared or statistically analyzed.

Two methodological design choices were made to address these issues. First, the instruments used in this research were designed to gather, as far as possible, continuous data from well-documented, validated, and widely-used instruments. For example, the continuous data collected included accuracy (percent correct), time (in seconds), NASA TLX subjective mental workload dimension scores (using a continuous scale in millimeters), the WPT score (numerical), and the MBTI dimension scores (numerical). Only the DAPI and the GPM self-efficacy assessments used likert-type scales.

Second, the number of assessment instruments that participants had to fill out at one time were minimized to reduce mental fatigue. For example, MBTI, demographics, and DAPI assessments were filled out by participants on their own time and were brought to the experiment already completed. Task accuracy questionnaires were filled out during the experiment and NASA-TLX dimensions were able to be quickly assessed after task accuracy questionnaires were completed. The end of the experiment was the only time that participants had to fill out multiple assessments: the last TLX dimension assessment, the paired comparisons, and the GPM self-efficacy questionnaire. Even if they were fatigued, these three assessments were so dissimilar that participants had to exert a measure of concentration to complete them. The self-efficacy instrument could be the most vulnerable to instrument proliferation issues as it was easy for participants to take lightly, because it was the last instrument they filled out in the entire experiment.

3.9.2 Threats to External Validity

Lab experiments in the classical scientific tradition suffer from threats to external validity (Kuutti, 1995; Pedhazur & Schmelkin, 1991). As a result, this lab study could have suffered from several types of threats to external validity as it relates to real-world BPM contexts (Pedhazur & Schmelkin, 1991; Winer et al., 1991), including using students as substitutes for BPM managers, external validity of real-world tasks, and student participant motivation.

3.9.2.1 Using Students as Substitutes for BPM Practitioners

The primary threat to external validity was that this study uses students to represent real-world managers with BPM expertise. In real-world BPM contexts, even general domain knowledge is based on experience over time in one or more specific contexts. Student participants did not have real-world BPM System experience. The risk is that results obtained from these students might not be applicable to BPM System practitioners.

However, if real-world BPM managers were used in this experiment instead of students, the amount and type of UET could not be easily controlled for in an experiment. Variations in tacit BPM knowledge in real-world managers is difficult to control, since their knowledge is usually specific to a given organization, business process, and affected by other factors, such as, age, years of experience in the company, or particular job responsibilities. This reality would likely confound the results if real-world BPM managers were participants in this experiment.

Students provide a measure of control for tacit BPM knowledge, operationalized in this study as UET. Students within a specific academic major were likely to have a similar level of educational training (although individual grades may vary), because they were required to take same major courses with similar course content. These similar educational experiences give students similar levels of tacit knowledge and experience related to BPM and the GPMs used in this study. Also, because students were self-selecting to their professional pursuits and academic majors, they are more likely to possess cognitive abilities and cognitive styles similar to BPM practitioners with the same educational training and who also self-selected to their particular jobs and academic education.

Students were not asked to perform BPM tasks that require actual BPM expertise. Instead, students were asked to interpret general types of BPI portrayed in the GPMs. Because specific BPM tasks were not the focus of this study and held constant in this experiment, differences in tacit BPM knowledge of participants were conceptualized as user educational training. It is assumed that the cognitive processes are similar for students as well as BPM managers as they interpret BPI portrayed from GPMs. Thus, students were believed to be good substitutes for BPM practitioners.

Furthermore, BPM Systems and these types of GPMs are not yet widely used by BPM practitioners. It was highly unlikely that BPM IT managers, process managers, management executives, and other middle managers would have any experience with these GPMs. Since practitioners would likely be novices in using these GPMs, research using university students would provide an indicator of how easily these GPMs can be understood. Therefore, students serve as the best possible surrogates for BPM practitioners and should provide a measure of external validity to real-world contexts that BPM practitioners could not provide because of the wide range of BPM contexts.

3.9.2.2 Lack of External Validity to Real World BPM Tasks

Lab experiments are criticized for being unrealistic when results are extrapolated to real-world tasks. Experimental tasks in the context of BPM Systems are even more difficult to create, because so many BPM tasks are unique to an organization, their business processes, and the required BPI.

These issues were addressed in this research in two ways. First, this experiment only required participants to understand and interpret BPI. This experiment did not require participants to apply this knowledge to a specific BPM decision-making context. As a result, GPM user comprehension is likely a similar cognitive activity for the experiment participants and BPM practitioners. These strategies should help these results be relatively generalizeable to the real world.

Second, using a real-world BPM task would provide a level of external validity of the results. The GPM user comprehension tasks in this study were modeled using a bank loan process that is similar across many financial organizations. Also, participants were not required to understand the business process to interpret the GPMs. Answers to questions used generic reference labels. Participants were provided with legends describing what the reference labels meant in relation to the bank loan process to help the interpretation of the GPMs. Thus, the experimental tasks in this research should provide a degree of external validity greater than many other lab experiments.

3.9.2.3 Motivation of Student Participants

Another issue is that students in lab experiments are usually not motivated to perform tasks in the same way as real-world managers, thus decreasing external validity. Interventions were needed to motivate students to both participate and to optimize their individual performance on the experimental tasks as per motivational literature (Campbell, Dunnette, Lawler, & Weick, 1970; Hertzberg, 1968; Klein, 1982).

Regarding students' motivation to participate, CS and MGT students volunteered without additional motivators for the experiment. IE students were required by their professor to participate and given points toward their course grade for participation. At the small U.S. university in Hawaii, MGT and CS students received an additional motivation to participate, pizza and soda, because not enough students volunteered initially. This incentive was not offered to CS, IE, or MGT students that volunteered at the large southeastern U.S. university.

Regarding students' motivation to optimize their performance, the motivation was the same for all students. The students were told that the top performing student in each academic major would be given a $100 gift certificate to the retailer of their choice. The top overall performer in the experiment would be given a $200 gift certificate. Although based on prior research, these two categories of motivation did not directly correlate to real-world practitioner motivations. This is a drawback of lab studies, regardless of whether students or practitioners are used as participants.

3.9.3 Threats to Statistical Validity

Threats to statistical validity in this study included multivariate data analyzed using univariate statistics and statistical power related to the sample size (Pedhazur & Schmelkin, 1991; Winer et al., 1991).

3.9.3.1 Multivariate Data Analyzed with Univariate Statistics

The greatest threat to statistical validity is the improper analysis and interpretation of the multivariate data by the misapplication of univariate statistics. Multivariate data require preliminary statistical tests be passed before the data can be analyzed to test hypotheses (Rencher, 2001). When preliminary multivariate hypothesis tests are conducted, the results and conclusions can be statistically supportable. Without passing preliminary multivariate tests of independence, there is no way to be sure the experiment-wise error-rate is preserved in further univariate analyses. (For a more detailed discussion and results pertaining to this topic, see Appendices M and N.)

3.9.3.2 Sample Size and Statistical Power

Another potential problem with statistical validity is that there might not be enough statistical power to detect differences in the results. Statistical power was calculated based on several factors: level of significance, effect size, sample size, and the degrees of freedom for the F-ratios (Winer et al., 1991, p. 126). The factor most under control of the researcher was sample size. The power, ES, and sample size was determined using a two-tailed α-level of 0.05 based on instructions and Figure 2.1 from Lipsey (1990). A medium ES = 0.50 and a minimum of n = 72 participants generates an acceptable power level (1-β) of approximately 0.84 (Lipsey, 1990, p. 44). Therefore, a minimum of twelve participants in each of the six treatment cells (for a total n = 72 participants) was deemed appropriate to provide statistical power sufficient to detect medium ES in the results (see Tables 3-5 and 3-6).

In summary, the research methodology used in this dissertation addresses the common problems in experimental research (Jarvenpaa et al., 1985). Consequently, the lab experiment methodology used in this study is expected to provide a sufficient level of internal, external, and statistical validity. The next chapter presents the data, results, and analyses produced by these research methods.

C h a p t e r F o u r

CHAPTER 4 – EXPERIMENTAL RESULTS

This chapter summarizes the experiment and reports its results. The descriptive statistics are presented in Section 4.1. Section 4.2 describes the results of each of the dependent and moderating variables. Section 4.3 discusses the results of preliminary analyses. Results from testing each of the hypotheses are presented in Section 4.4. Finally, Section 4.5 summarizes the overall results of the experiment.

4.1 DESCRIPTIVE STATISTICS

As described in chapter 3, the resulting multivariate data were based on an experimental design that combined three independent variables: two between-subjects variables (the type of Graphical Process Model [GPM] and the type of User Educational Training [UET]) and one within-subjects variable (the type of Business Process Information [BPI]). The following two subsections describe the dataset and demographic variables pertinent to this study.

4.1.1 Dataset Characteristics

There were a total of 87 students from two universities who participated in the experiment. Table 4-1 provides a breakdown of the participants according to several categorical variables pertinent to this study. Due to student participation in the study being primarily voluntary (except for the industrial engineering students), the number of participants were not equal across groups representing two of the three independent variables. There were a total of 24 industrial engineering (IE) majors, 35 business management (MGT) majors, and 28 computer science (CS) majors that participated in the experiment as representatives for the independent variable, the type of User Educational Training (UET_{1-3}). The number of participants representing groups who used each type of Graphical Process Models (GPM_{1-2}) were also not equal. Of the 24 IE students, 12 students completed the experiment using metagraphs and 12 students used UML diagrams. Of the MGT students, 18 used UML diagrams and the other 17 used metagraphs in the experiment. CS students participated with 12 using metagraphs and 16 using UML diagrams. All 87 participants completed each of the three conditions of the within-subjects independent variable type of Business Process Information (BPI_{1-3}).

Table 4-1. Demographics of Participants (n = 87).

Type of *User Educational Training*	**Type of *Graphical Process Model***	**Type of *Business Process Information***	**University Attending**		**Gender**		**Learned English as 1st Language**		**Age**	
(UET_{1-3})	(GPM_{1-2})	(BPI_{1-3})*	A	B	Male	Female	Yes	No	Mean	Std. Dev.
Industrial Engineering (IE) (UET_1)	UML (GPM_1)	12	12	0	8	4	7	5	21.83	1.08
	Metagraph (GPM_2)	12	12	0	7	5	10	2	22.00	2.22
	UET_1 Totals	24	24	0	15	9	17	7	21.92	1.69
Management (MGT) (UET_2)	UML (GPM_1)	18	8	10	12	6	12	6	23.17	2.83
	Metagraph (GPM_2)	17	5	12	11	6	13	4	24.00	3.14
	UET_2 Totals	35	13	22	23	12	25	10	23.57	2.97
Computer Science (CS) (UET_3)	UML (GPM_1)	16	11	5	12	4	13	3	21.94	2.18
	Metagraph (GPM_2)	12	7	5	12	0	8	4	22.25	2.09
	UET_3 Totals	28	18	10	24	4	21	7	22.07	2.48
	Experiment Totals	87	45	32	62	25	63	24	22.63	2.61

*All Participants interpreted all three types of BPI portrayed by a GPM:

- BPI_1 = Task-Centric BPI
- BPI_2 = Resource-Centric BPI
- BPI_3 = Information-Centric BPI

Total n = 87

4.1.2 Participant Demographics

Table 4-1 also shows the breakdown of the results of categorical variables representing the university, gender, first language, and age of the participants. Complete data from 87 students were used in this experiment. The average age of the participants was 22.63 years (SD = 2.61). There were a total of 62 men (average age, M = 23.15, SD = 2.80) and 25 women (average age, M = 21.36, SD = 1.41) that participated, 38% of the IE, 34% of the MGT, and 14% of the CS majors being women. Of all the participants, 24 of the 87 participants did not learn English as their first or native language. The representation of non-native English speakers in each of the three educational groups was almost evenly spread between 25% and 30%. Forty-five (45) participants were from University A with the other 32 participants coming from University B. It is important to note that all 24 IE students that took part in this experiment came from University A, because university B did not have an industrial engineering program. Also, it was very difficult to recruit MGT students from university A to participate in this experiment while university B participants were more willing to participate. As a consequence, more MGT students participated from university A than university B.

4.1.3 Summarizing the Dataset

In summary, the dataset of 87 participants was multivariate by definition, since the same dataset of three independent variables was used to analyze the results of four dependent variables. Cell sizes for two of the between-subject independent variables were unequal, but each contained a minimum complete treatment cell size of at least 12 participants. There seemed to be a fairly balanced representation of men to women (except from CS students), and there appeared to be a relatively equal balance of native to non-native English speakers across groups. There was not a equal percentage of women in CS between participant experimental groups from university A and B.

Preliminary analyses were conducted to assure the data was analyzed and interpreted properly. Subsequent data analyses testing the hypotheses in this study describes the data representing each variable, takes into account the unequal cell sizes, and the multivariate nature of the data.

Table 4-2. Cell numbers, means, and standard deviations for task accuracy in percent correct (*n* = 87)..

Dependent Variable: Accuracy (Percent Correct)

Type of GPM	**Type of User Educational Training**	**Type of Business Process Information**	**n**	**Mean**	**Std. Deviation**
UML Diagrams	IE: Industrial Engineering	Task-centric	12	59.38	12.07
		Resource-centric	12	63.33	18.75
		Information-centric	12	57.14	19.26
		Total	36	59.95	16.72
	MGT: Management	Task-centric	18	63.19	15.14
		Resource-centric	18	51.11	18.44
		Information-centric	18	55.56	20.14
		Total	54	56.62	18.38
	CS: Computer Science	Task-centric	16	62.50	16.46
		Resource-centric	16	58.75	23.63
		Information-centric	16	64.29	18.07
		Total	48	61.85	19.35
	Total	Task-centric	46	61.96	14.66
		Resource-centric	46	56.96	20.64
		Information-centric	46	59.01	19.19
		Total	138	59.31	18.33
Metagraphs	IE: Industrial Engineering	Task-centric	12	82.29	9.91
		Resource-centric	12	83.33	14.36
		Information-centric	12	77.38	18.73
		Total	36	81.00	14.59
	MGT: Management	Task-centric	17	75.00	11.69
		Resource-centric	17	70.59	21.35
		Information-centric	17	65.55	17.54
		Total	51	70.38	17.42
	CS: Computer Science	Task-centric	12	80.21	9.91
		Resource-centric	12	70.00	23.36
		Information-centric	12	71.43	18.27
		Total	36	73.88	18.12
	Total	Task-centric	41	78.66	10.91
		Resource-centric	41	74.15	20.61
		Information-centric	41	70.73	18.34
		Total	123	74.51	17.30
Total	IE: Industrial Engineering	Task-centric	24	70.83	15.93
		Resource-centric	24	73.33	19.26
		Information-centric	24	67.26	21.26
		Total	72	70.48	18.85
	MGT: Management	Task-centric	35	68.93	14.66
		Resource-centric	35	60.57	21.96
		Information-centric	35	60.41	19.32
		Total	105	63.30	19.13
	CS: Computer Science	Task-centric	28	70.09	16.44
		Resource-centric	28	63.57	23.76
		Information-centric	28	67.35	18.18
		Total	84	67.00	19.65
	Total	Task-centric	87	69.83	15.43
		Resource-centric	87	65.06	22.25
		Information-centric	87	64.53	19.59
		Total	261	66.47	19.37

4.2 Descriptions of Individual Variable Results

The following section reports basic statistics for each dependent and moderating variable used in this experiment in relation to the independent variables. The default level of significance used in this study was $p \leq 0.05$. In addition, several analyses used estimated marginal means due to unbalanced group sizes.

4.2.1 Dependent Variable: *Accuracy*

Task accuracy was measured by the percent of correct answers to questionnaires about participants' interpretation of eight task-centric, five resource-centric, and seven information-centric BPI questions (see Appendix L.3 for the task accuracy questionnaire). Table 4-2 lists the cell numbers, means, and standard deviations for the accuracy results related to the three independent variables. Eighty-seven (87) participants were measured three times during the experiment (i.e., after interpreting each of the types of BPI), hence, producing a total of 261 degrees of freedom. Table 4-3 and 4-4 shows the relevant sections of results for accuracy from the between and within portions of the repeated measures MANOVA (reported in Tables 4-26 and 4-29).

Table 4-3. Relevant MANOVA results describing between-subject main effects and interactions for task accuracy (see Table 4-26) ($n = 87$).

Dependent Variable: *Accuracy* (Percent Correct)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
GPM Type	15420.835	1	15420.83	41.56	**.000*** **
UET Type	2208.76	2	1104.38	2.98	.057†
GPM Type X UET Type	877.04	2	438.52	1.18	.312
Error	30053.89	81	371.04		

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Table 4-4. Relevant MANOVA results describing within-subject main effects and interactions for task accuracy (see Table 4-28) (n = 87).

Dependent Variable: *Accuracy* (Percent Correct)

Source	**Sphericity Correction**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
BPI Type	Huynh-Feldt	1293.52	1.93	670.14	2.29	.107
BPI Type X GPM Type	Huynh-Feldt	318.63	1.93	165.07	.56	.564
BPI Type X UET Type	Huynh-Feldt	1175.30	3.86	304.45	1.04	.387
BPI Type X GPM Type X UET Type	Huynh-Feldt	509.69	3.86	132.03	.45	.765
Error (BPI Type)	Huynh-Feldt	45765.93	156.35	292.72		

$^{\dagger}p < 0.10$ $\quad *p < 0.05$ $\quad **p < 0.01$ $\quad ***p < 0.001$

a Computed using alpha = 0.05

The results from Table 4-3 show , at the level of the whole individual, that there was a significant effect of GPM type on task accuracy, $F(1,81)=41.562$, $p = 0.000$. There was no significant effect of the type of UET on task accuracy at the $p = 0.05$ level of significance, $F(1,81)=2.98$, $p = 0.057$. Within-subjects, the type of BPI was not significant below $p < 0.05$ even when corrections were made for sphericity (see Table 4-4). These results are illustrated below in Figures 4-1, 4-2, and 4-3.

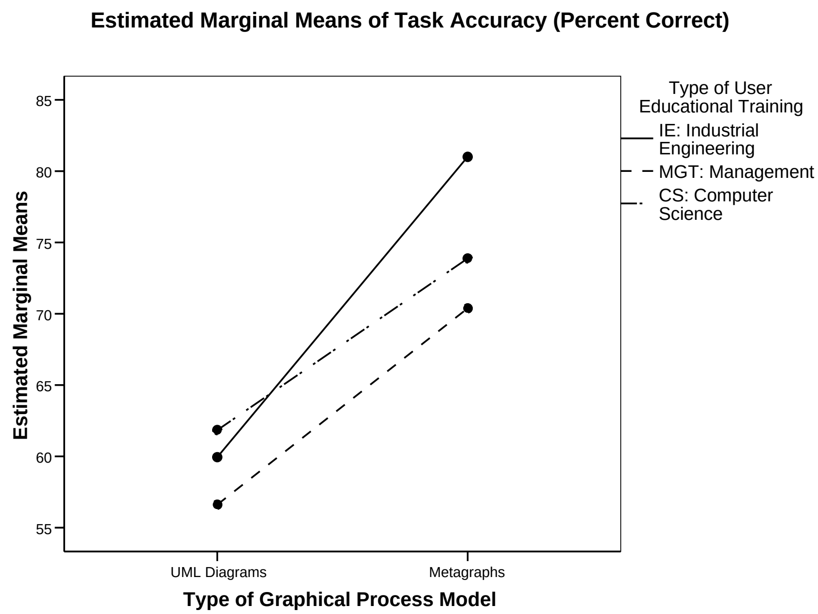


Figure 4-1. The mean accuracy for UML diagram users was lower than Metagraph users across all types of User Educational Training.

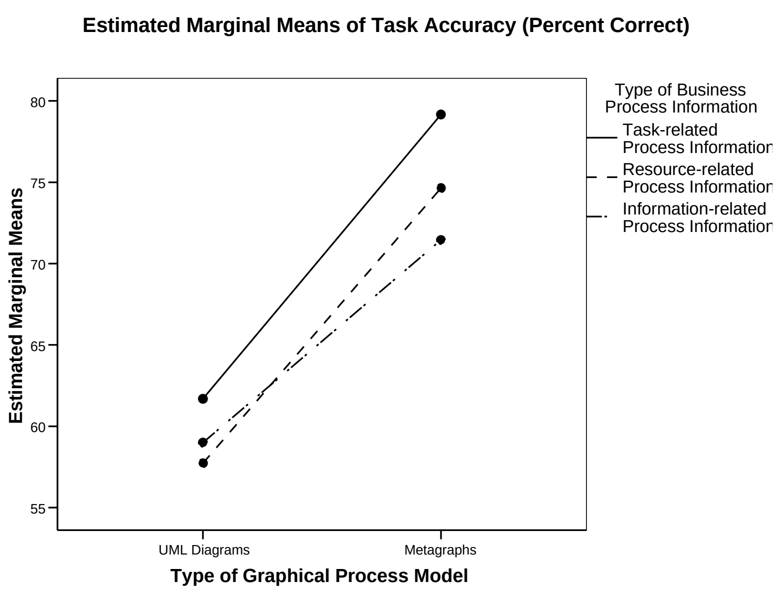


Figure 4-2. The mean accuracy for UML diagram users was lower than Metagraph users across all types of Business Process Information.

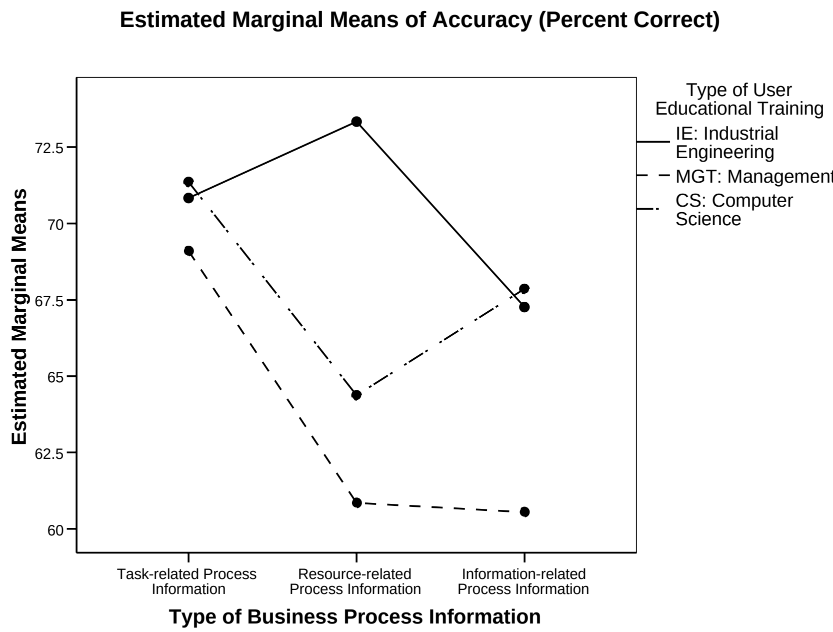


Figure 4-3. The type of User Educational Training appears to influence accuracy results as well as the type of Business Process Information.

Figures 4-1 and 4-2 show the strong effect of the type of GPM overshadowing the impacts of the type of UET and the type of BPI. Figure 4-3 shows differences, although not statistically significant below $p < 0.05$, in accuracy due to both the type of UET and the types of BPI .

4.2.2 Dependent Variable: *Timeliness*

Timeliness was measured by evaluating the time that participants took to complete the task, resource, and information-centric BPI questionnaires (in seconds). In this study, low timeliness was interpreted as taking a long time to finish the questionnaires. Conversely, high timeliness was interpreted as shorter amounts of time taken to finish experiment questionnaires. Timeliness was measured at the same three times as the accuracy measures. Table 4-5 lists the cell numbers, means, and standard deviations for the timeliness results related to the three independent variables. Tables 4-6 and 4-7 show the relevant MANOVA sections for the timeliness results.

Table 4-5. Cell numbers, means, and standard deviations for task timeliness (*n* = 87).

Dependent Variable: *Timeliness* (Seconds)

Type of GPM	**Type of User Educational Training**	**Type of Business Process Information**	**n**	**Mean**	**Std. Deviation**
UML Diagrams	IE: Industrial Engineering	Task-centric	12	315.58	107.96
		Resource-centric	12	355.33	157.83
		Information-centric	12	352.58	160.83
		Total	36	341.17	141.28
	MGT: Management	Task-centric	18	308.67	90.86
		Resource-centric	18	342.22	83.87
		Information-centric	18	398.11	96.39
		Total	54	349.67	96.29
	CS: Computer Science	Task-centric	16	273.19	42.75
		Resource-centric	16	332.63	78.29
		Information-centric	16	375.56	97.55
		Total	48	327.13	85.88
	Total	Task-centric	46	298.13	83.21
		Resource-centric	46	342.30	104.25
		Information-centric	46	378.39	115.50
		Total	138	339.61	106.36
Metagraphs	IE: Industrial Engineering	Task-centric	12	205.75	46.42
		Resource-centric	12	209.00	45.55
		Information-centric	12	263.83	82.70
		Total	36	226.19	64.88
	MGT: Management	Task-centric	17	255.59	98.72
		Resource-centric	17	259.00	82.30
		Information-centric	17	319.18	104.97
		Total	51	277.92	98.40
	CS: Computer Science	Task-centric	12	248.75	50.99
		Resource-centric	12	320.42	165.10
		Information-centric	12	315.25	142.12
		Total	36	294.81	129.72
	Total	Task-centric	41	239.00	75.38
		Resource-centric	41	262.34	112.45
		Information-centric	41	301.83	111.62
		Total	123	267.72	103.79
Total	IE: Industrial Engineering	Task-centric	24	260.67	98.75
		Resource-centric	24	282.17	135.99
		Information-centric	24	308.21	133.03
		Total	72	283.68	123.56
	MGT: Management	Task-centric	35	282.89	97.15
		Resource-centric	35	301.80	92.12
		Information-centric	35	359.77	106.93
		Total	105	314.82	103.33
	CS: Computer Science	Task-centric	28	262.71	47.18
		Resource-centric	28	327.39	120.62
		Information-centric	28	349.71	120.16
		Total	84	313.27	107.38
	Total	Task-centric	87	270.26	84.54
		Resource-centric	87	304.62	114.81
		Information-centric	87	342.31	119.39
		Total	261	305.73	110.94

The MANOVA results listed in Table 4-6 (from the relevant sections of Table 4-26) show, at the level of the whole individual, there was a significant effect of the type of GPM on task timeliness, $F(1,81)=17.51$, $p = 0.000$. The effects of the type of UET on task timeliness was not statistically significant. Within-subjects, there was a significant effect of BPI type on task timeliness, $F(1,81)=17.94$, $p = 0.000$ (see Table 4-7). These differences are illustrated in Figures 4-4, 4-5, and 4-6 below.

Table 4-6. Relevant MANOVA results describing between-subject main effects and interactions for task timeliness ($n = 87$).

Dependent Variable: *Timeliness* (in seconds)

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
GPM Type	337171.15	1	337171.15	17.51	**.000*** **
UET Type	43710.18	2	21855.09	1.14	.327
GPM Type X UET Type	65593.62	2	32796.81	1.70	.189
Error	1559935.88	81	19258.47		

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Figures 4-4 and 4-5 show that users of metagraphs took significantly less time (i.e., greater timeliness) compared to users of UML Diagrams. Figure 4-6 also illustrates the slight interaction between the type of GPM and the type of UET. CS participants took the least amount of time using UML diagrams, but took the most amount of time when using metagraphs compared to the other two categories of UET. Figure 4-6 shows differences for timeliness results between different types of BPI. Task-centric BPI was interpreted in the least amount of time (more timely) compared to information-centric BPI that was interpreted in the largest amount of time (less timely) across all types of UET.

Table 4-7. Relevant MANOVA results describing within-subject main effects and interactions for timeliness (n = 87).

Dependent Variable: *Timeliness* (in seconds)

Source		**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
BPI Type	Sphericity Assumed	203676.36	2	101838.18	17.94	**.000*** **
BPI Type X GPM Type	Sphericity Assumed	3750.26	2	1875.13	.33	.719
BPI Type X UET Type	Sphericity Assumed	28679.85	4	7169.96	1.26	.287
BPI Type X GPM Type X UET Type	Sphericity Assumed	19068.67	4	4767.17	.84	.502
Error (BPI Type)	Sphericity Assumed	919765.56	162	5677.56		

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$
a Computed using alpha = 0.05

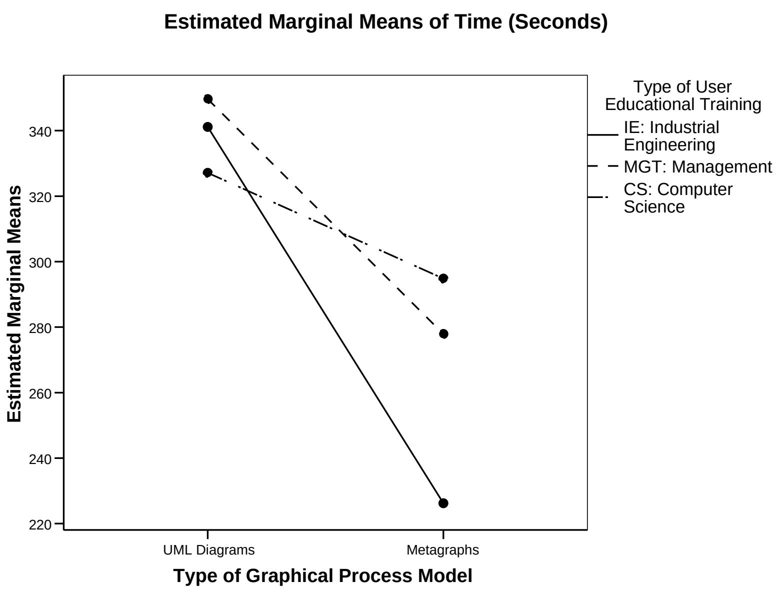


Figure 4-4. The type of Graphical Process Model appears to significantly influence timeliness results along with small interaction due to the type of User Educational Training.

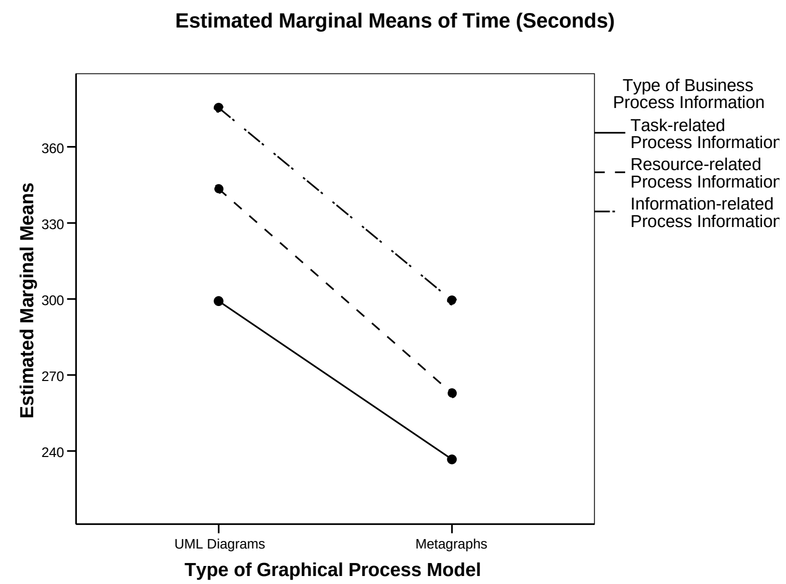


Figure 4-5. The type of Graphical Process Model appears to influence timeliness results in relation to the type of Business Process Information.

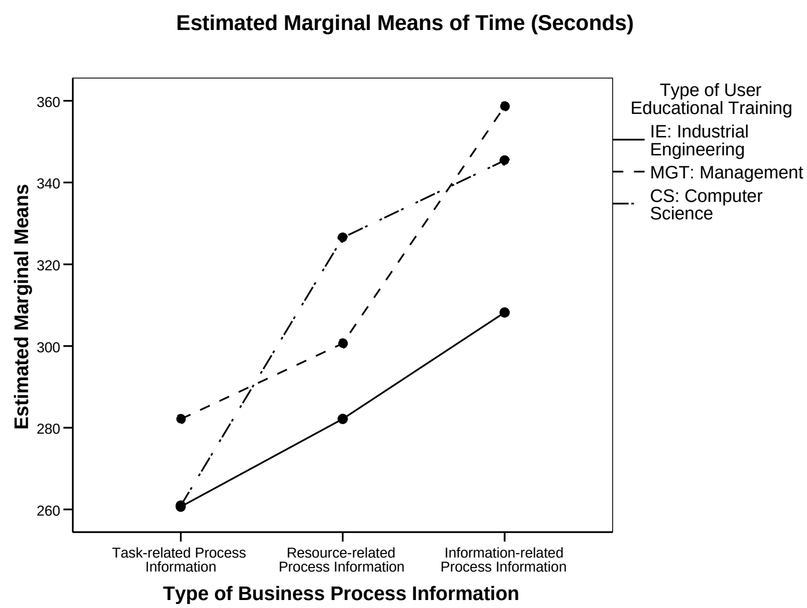


Figure 4-6. The type of Business Process Information appears to influence timeliness results with a small interaction due to the type of User Educational Training.

4.2.3 Dependent Variable: Subjective *Mental Workload*

Table 4-8 lists the cell numbers, means, and standard deviations for the NASA TLX subjective mental workload results related to the three independent variables. Tables 4-9 and 4-10 list the between and within-subject repeated measures MANOVA results. Table 4-9 shows a significant effect of the type of UET on subjective mental workload, $F(1,81)=3.31$, $p = 0.042$. The type of GPM was not statistically significant below $p < 0.05$, $F(1,81)=3.45$, $p = 0.067$. Table 4-10 shows a within-subjects effect of the type of BPI on subjective mental workload, $F(2,162)=5.19$, $p = 0.007$, as well as for the interaction between the type of BPI and the type of UET on subjective mental workload, $F(4,162)=3.26$, $p = 0.013$. These differences and interactions are illustrated in Figures 4-7, 4-8, and 4-9 below.

Table 4-8. Cell sizes, means, and standard deviations for NASA TLX assessments of subjective mental workload (n = 87).

Dependent Variable: NASA TLX *Mental Workload*

Type of GPM	Type of User Educational Training	Type of Business Process Information	n	Mean	Std. Deviation
UML Diagrams	IE: Industrial Engineering	Task-centric BPI	12	67.34	18.14
		Resource-centric BPI	12	75.36	17.50
		Information-centric BPI	12	68.77	15.49
		Total	36	70.49	16.96
	MGT: Management	Task-centric BPI	18	72.88	13.82
		Resource-centric BPI	18	73.50	12.21
		Information-centric BPI	18	77.25	13.00
		Total	54	74.54	12.93
	CS: Computer Science	Task-centric BPI	16	56.80	21.62
		Resource-centric BPI	16	63.93	19.38
		Information-centric BPI	16	58.73	21.42
		Total	48	59.82	20.61
	Total	Task-centric BPI	46	65.84	18.92
		Resource-centric BPI	46	70.65	16.78
		Information-centric BPI	46	68.60	18.44
		Total	138	68.36	18.05
Metagraphs	IE: Industrial Engineering	Task-centric BPI	12	58.85	10.81
		Resource-centric BPI	12	58.92	12.73
		Information-centric BPI	12	63.63	11.29
		Total	36	60.47	11.53
	MGT: Management	Task-centric BPI	17	59.44	14.00
		Resource-centric BPI	17	63.99	18.29
		Information-centric BPI	17	72.96	12.30
		Total	51	65.46	15.82
	CS: Computer Science	Task-centric BPI	12	61.76	9.28
		Resource-centric BPI	12	66.10	10.16
		Information-centric BPI	12	60.41	15.88
		Total	36	62.76	12.04

Type of GPM	Type of User Educational Training	Type of Business Process Information	n	Mean	Std. Deviation
	Total	Task-centric BPI	41	59.94	11.65
		Resource-centric BPI	41	63.12	14.67
		Information-centric BPI	41	66.56	14.01
		Total	123	63.21	13.66
Total	IE: Industrial Engineering	Task-centric BPI	24	63.10	15.24
		Resource-centric BPI	24	67.14	17.16
		Information-centric BPI	24	66.20	13.51
		Total	72	65.48	15.26
	MGT: Management	Task-centric BPI	35	66.34	15.31
		Resource-centric BPI	35	68.88	15.98
		Information-centric BPI	35	75.16	12.66
		Total	105	70.13	15.05
	CS: Computer Science	Task-centric BPI	28	58.92	17.35
		Resource-centric BPI	28	64.86	15.87
		Information-centric BPI	28	59.45	18.93
		Total	84	61.08	17.43
	Total	Task-centric BPI	87	63.06	16.10
		Resource-centric BPI	87	67.11	16.18
		Information-centric BPI	87	67.63	16.44
		Total	261	65.93	16.31

Table 4-9. Relevant MANOVA results describing between-subject main effects and interactions for subjective mental workload ($n = 87$).

Dependent Variable: NASA TLX *Mental Workload*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
GPM Type	1837.91	1	1837.91	3.45	.067†
UET Type	3525.18	2	1762.59	3.31	**.042***
GPM Type X UET Type	2169.93	2	1084.96	2.04	.137
Error	1559935.88	81	19258.47		

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Table 4-10. Relevant MANOVA results describing within-subject main effects and interactions for subjective mental workload ($n = 87$).

Dependent Variable: NASA TLX *Mental Workload*

Source		**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
BPI Type	Sphericity Assumed	954.32	2	477.16	5.19	**.007****
BPI Type X GPM Type	Sphericity Assumed	303.17	2	151.59	1.65	.196
BPI Type X UET Type	Sphericity Assumed	1198.06	4	299.52	3.26	**.013***
BPI Type X GPM Type X UET Type	Sphericity Assumed	520.37	4	130.09	1.42	.231
Error (BPI Type)	Sphericity Assumed	14898.61	162	91.97		

$^{\dagger}p < 0.10$ $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$

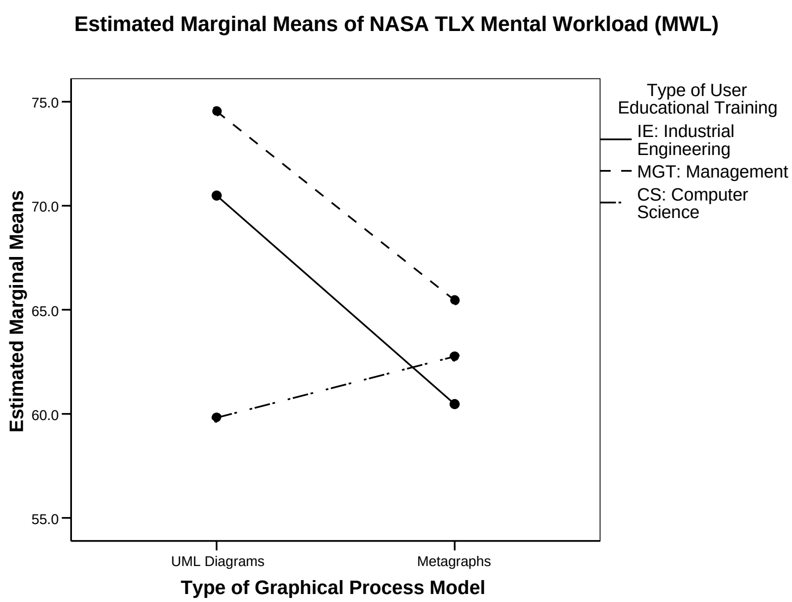


Figure 4-7. Subjective *mental workload* shows a difference between metagraphs and UML diagrams as well as between types of User Educational Training.

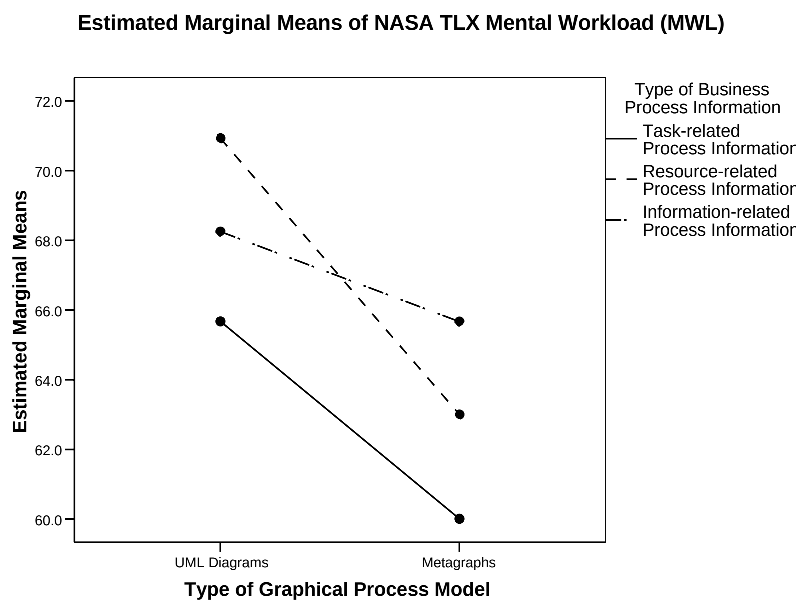


Figure 4-8. Subjective mental workload shows a difference between metagraphs and UML diagrams as well as slight between types of Business Process Information.

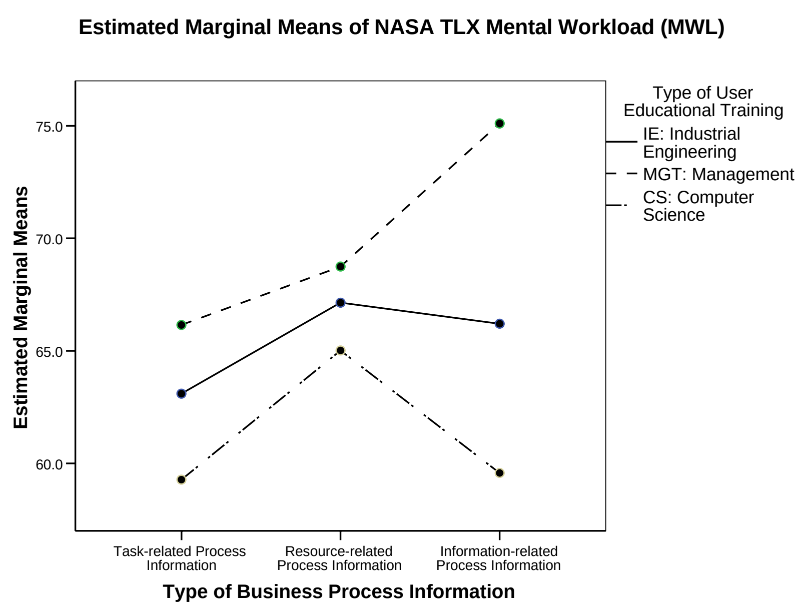


Figure 4-9. Subjective mental workload shows a difference between the types of Business Process Information as well as between types of User Educational Training.

Figures 4-7 and 4-9 illustrate the effect of the type of UET of participants on subjective mental workload. MGT students seem to consistently report higher TLX mental workload and CS students report lower TLX mental workload. Figures 4-8 and 4-9 illustrate the effect of the type of BPI. From these results it is clear that task-centric BPI related to the least subjective mental workload in the participants. Figure 4-9 also illustrates the interaction between the type of BPI and the type of UET. Task and resource-centric BPI results were consistently grouped, but information-centric BPI created much lower subjective mental workload in CS students and much higher subjective mental workload in MGT students.

The following three tables provide descriptive statistics and correlations of the six constructs of TLX mental workload. Table 4-11 cell numbers, means, and standard deviations. Table 4-12 lists descriptive statistics for participant weightings of the constructs.

Table 4-11. Cell sizes, means, and standard deviations for participants' ratings of the six constructs making up for the NASA TLX mental workload scores (*n* = 87).

Dependent Variable: NASA TLX *Mental Workload* (MWL)

NASA TLX Mental Workload Constructs	**n**	**Mean**	**Std. Deviation**
Mental Demand	261	71.08	23.28
Physical Demand	261	16.59	19.44
Temporal Demand	261	65.66	26.07
Perception of Performance	261	47.49	21.85
Mental Effort	261	73.95	23.38
Frustration	261	54.03	30.99
NASA TLX Mental Workload	261	65.93	16.31

Table 4-12. Descriptive information for participant weightings created by pairwise comparisons between the six NASA TLX mental workload constructs (*n* = 87).

		Mental Demand Weights	**Physical Demand Weights**	**Temporal Demand Weights**	**Performance Weight**	**Mental Effort Weights**	**Frustration Weights**
n	Valid	87	87	87	87	87	87
	Missing	0	0	0	0	0	0
Mean		3.71	.32	2.74	2.90	2.98	2.36
Median		4.00	.00	3.00	3.00	3.00	2.00
Mode		5	0	1	3	4	1
Std. Deviation		1.19	.72	1.53	1.18	1.25	1.65
Range		5	3	5	5	4	5

a Multiple modes exist. The smallest value is shown

Table 4-13 shows how the TLX mental workload constructs are correlated to each other and to the final, weighted TLX scores. It appears from Table 4-13 that the calculated TLX mental workload scores for individual participants were significantly and positively correlated with four of the six constructs: mental demand, $r(261) > 0.75$, $p < 0.01$, temporal demand, $r(261) > 0.64$, $p < 0.01$, mental effort, $r(261) > 0.65$, $p < 0.01$, and frustration, $r(261) > 0.68$, $p < 0.01$. Also, mental demand was significantly and positively correlated with mental effort, $r(261) = 0.55$, $p < 0.01$. Although other correlations were statistically significant, the highest amount of correlation was below $r(261) < 0.39$ and therefore, is difficult to interpret its importance. These correlations suggest that an underlying factor or factors in the data. Further exploratory analysis explored this issue (see Appendix O).

Table 4-13. Correlation matrix of the six constructs making up NASA TLX in relation to the associated NASA TLX mental workload scores (n = 261).

NASA TLX *Mental Workload* Construct	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
(1) Mental Demand	.10	.37**	-.10	**.55****	.36**	**.75****
(2) Physical Demand	1	.21**	.01	.08	.13*	.18**
(3) Temporal Demand		1	-.04	.38**	.38**	**.64****
(4) Perception of Performance			1	-.30**	.23**	.18**
(5) Mental Effort				1	.25**	**.65****
(6) Frustration					1	**.68****
(7) NASA TLX Mental Workload						1

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

4.2.4 Dependent Variable: *Self-Efficacy*

In contrast to accuracy, timeliness, and subjective mental workload, the three within-subjects dependent variables described above, self-efficacy was evaluated only one time per participant and was, thus, a between-subjects variable. Self-efficacy was assessed after completion of the entire experiment by participants' responses to nine questions that evaluate different conditions related to their self-confidence in completing the experimental task. An overall score per participant was averaged from participant's responses to these questions. Therefore, its results were analyzed using a separate ANOVA. (Note that the type of BPI was a within-subjects variable and therefore, was not included in this analysis.)

Tables 4-14 reports demographic information for the self-efficacy questions and the overall average. It showed that participants felt the most confident about questions 5, 6, 7, 8, and 9. They were least confident on questions 1 and 2. This appeared consistent, because questions 1 and 3 were similar to questions 5, 6, and 9, but were phrased oppositely.

Table 4-14. Cell sizes, Means, and standard deviations for the nine self-efficacy questions and the average of these questions (ordinal scale 1 to 10).

	n	**Mean**	**Std. Deviation**	**Minimum** (No Confidence)	**Maximum** (Highly Confident)
Self-Efficacy Question 1: If Alone & No One Was Available to Help	87	4.16	3.08	0	10
Self-Efficacy Question 2: If Never Used MG or UML Diagrams Before	87	3.41	2.75	0	10
Self-Efficacy Question 3: If Had Only the Training Handouts for Reference	87	5.55	2.42	0	10
Self-Efficacy Question 4: If Had Seen Others Using MG or UML Diagrams	87	5.79	2.72	0	10
Self-Efficacy Question 5: If Could Call on Someone for Help	87	7.64	2.27	0	10
Self-Efficacy Question 6: If Someone Helped You Get Started	87	7.25	2.31	0	10
Self-Efficacy Question 7: If Had a lot of Time	87	7.69	2.47	0	10
Self-Efficacy Question 8: If Had Training Handouts	87	6.10	2.53	0	10
Self-Efficacy Question 9: If Used MG or UML Diagrams on Similar Tasks	87	7.43	2.37	0	10
Average Individual *Self-Efficacy* Score	87	6.11	1.87	--	--

Table 4-15. Correlations of the nine self-efficacy questions and the overall participant averages (n = 87).

Dependent Variable: *Self-Efficacy* Questions

	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Self-Efficacy-Question 1: If Alone & No One Was Available to Help	**.66****	**.52****	**.52****	.38**	.27**	.33**	**.58****	.26**	**.71****
(2) Self-Efficacy-Question 2: If Never Used MG or UML Diagrams Before	1	**.57****	**.52****	.33**	.32**	.19**	**.51****	.31**	**.69****
(3) Self-Efficacy-Question 3: If Had Only the Training Handouts for Reference		1	**.57****	**.47****	**.49****	.34**	**.62****	**.49****	**.77****
(4) Self-Efficacy-Question 4: If Had Seen Others Using MG or UML Diagrams			1	**.67****	**.59****	**.49****	**.48****	**.52****	**.81****
(5) Self-Efficacy-Question 5: If Could Call on Someone for Help				1	**.76****	**.56****	**.51****	**.45****	**.76****
(6) Self-Efficacy-Question 6: If Someone Helped You Get Started					1	**.51****	**.51****	**.65****	**.75****
(7) Self-Efficacy-Question 7: If Had a lot of Time						1	.41**	**.59****	**.66****
(8) Self-Efficacy-Question 8: If Had Training Handouts							1	**.52****	**.78****
(9) Self-Efficacy-Question 9: If Used MG or UML Diagrams on Similar Tasks								1	**.71****
(10) Average Self Efficacy Score									1

** Correlation is significant at the p = 0.01 level (2-tailed).

Table 4-15 shows the correlation matrix of the nine self-efficacy questions and participant average self-efficacy scores. Many of the nine questions were highly positively correlated at the $p < 0.01$ level of significance. These results suggest an underlying factor or factors driving the self-efficacy results.

Exploratory analysis revealed two clear underlying factors. The first factor in Table O-7 includes most self-efficacy questions associated with receiving help from others to interpret GPMs. The second factor associated questions with the user being alone when interpreting GPMs. These results suggest participants self-efficacy is greatly influenced by whether their receive help from others when comprehending these GPMs (see Appendix O.10).

Table 4-16 reports results of a between-subjects ANOVA of average self-efficacy scores. There was a significant effect of the type of GPM on average self-efficacy, $F(1,86)=6.09$, $p = 0.016$. There was not a significant effect of the type of UET on average self-efficacy, $F(2,86)=2.28$, $p = 0.107$. No interactions were statistically significant.

Table 4-16. Two-way, between-subject ANOVA results for average self-efficacy showing the type of GPM and the type of User Educational Training as significant ($n = 87$).

Dependent Variable: Average *Self Efficacy* Score

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	39.906(a)	5	7.98	2.45	.040
Intercept	3231.435	1	3231.44	993.67	.000
GPM Type	19.785	1	19.79	6.08	**.016***
UET Type	14.810	2	7.41	2.28	.109
GPM Type X UET Type	2.970	2	1.49	.46	.635
Error	263.413	81	3.25		
Total	3556.469	87			
Corrected Total	303.320	86			

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$
a R Squared = 0.248 (Adjusted R Squared = 0.126)

Figure 4-10 shows the breakdown of the self-efficacy average scores by the type of GPM and the type of UET of the participants. Although similar to results for metagraph participants, there seemed to be a difference between average self-efficacy results for users of UML diagrams with different types of UET.

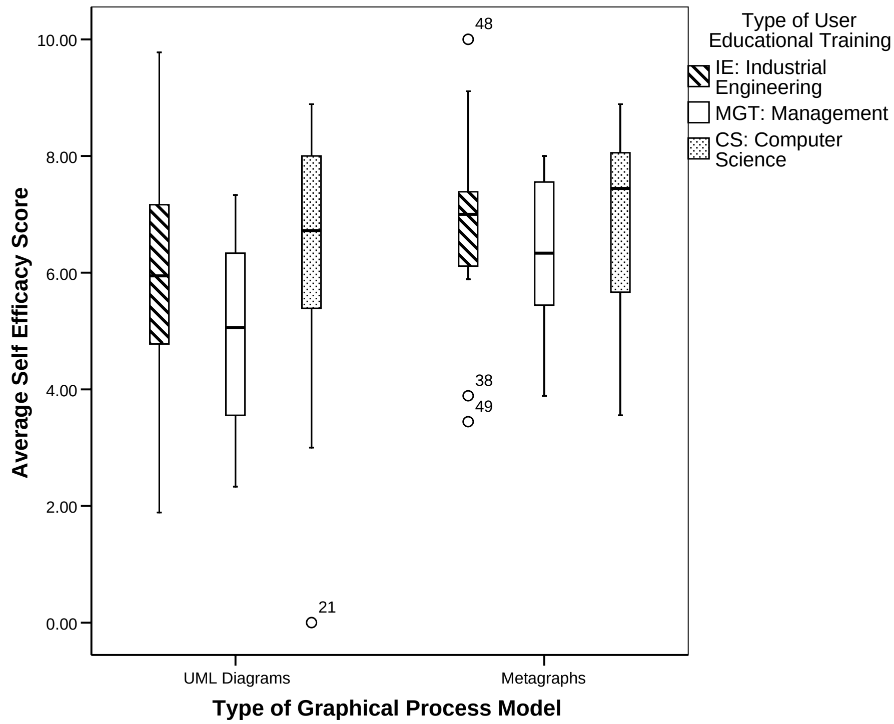


Figure 4-10. Self-efficacy scores showing box plots for each type of User Educational Training graphed by the type of GPM.

The following three sections describe variables hypothesized as moderating the relationship between the independent and dependent variables during GPM user comprehension. These potential moderators included participants' cognitive styles (measured by the Myers-Briggs Type Indicator (MBTI)), general cognitive abilities (measured by the Wonderlic Personnel Test (WPT)), and attentional abilities (assessed by the Differential Attentional Processes Inventory (DAPI)).

4.2.5 Moderating Variable: *Cognitive Styles* (MBTI)

The MBTI was used to assess two types of cognitive styles of the participants: (1) extraversion vs. introversion and (2) sensing vs. intuition. In this experiment, continuous scores for each participant were calculated for both MBTI extrovert-introvert and sensing-intuition dimensions of cognitive styles. A positive number described the reported strength of MBTI extrovert as well as sensing cognitive styles. A negative number described the reported strength of MBTI introvert or intuitive cognitive styles. These cognitive styles were random variables and organized in Table 4-17 according to the between-subject independent variables used in this study.

Table 4-17. Counts of the MBTI Cognitive Styles of the participants grouped by the between-subject independent variables (*n* = 87).

Moderating Variable: *Cognitive Styles* (MBTI)

Type of GPM	***Type of User Educational Training***	**MBTI Extrovert (E) Count**	**MBTI Introvert (I) Count**	**MBTI Sensor (S) Count**	**MBTI Intuitive (N) Count**
UML Diagrams	IE: Industrial Engineering	7	5	9	3
	MGT: Management	10	8	11	7
	CS: Computer Science	9	7	7	9
	Total	26	20	27	19
Metagraphs	IE: Industrial Engineering	8	4	5	7
	MGT: Management	7	10	12	5
	CS: Computer Science	5	7	9	3
	Totals	20	21	26	15
Experiment Totals	*n* = 87	46	41	53	34

Table 4-17 gives an overview of the distribution of the participants' evaluations of extroversion, introversion, sensing, and intuition, as well as balances of participants across both the type of GPM and the type of UET. Table 4-17 shows the MBTI scores of the participants that were slightly introverted (M = -2.43, SD = 27.30, n = 87) and slightly sensing (M = 6.66, SD = 23.23, n = 87). The number of IE students using UML diagrams that were sensors (9) vs. intuitives (3) was quite different from those using metagraphs (5 sensors vs. 7 intuitives). IE students reported a similar balance of extroverts vs. introverts using UML (7 vs. 5) vs. metagraphs (8 vs. 4), but there was a difference between the balance of sensors (UML 9 vs. metagraphs 5) vs. intuitives (UML 3 vs. metagraph 7). MGT students reported a difference between extroverts (10) vs. introverts (8) that used UML diagrams vs. metagraphs (7 vs. 10). MGT sensors vs. intuitives were similar for both groups of participants using different type of GPMs (UML – 11 vs. 12, metagraphs 7 vs. 5).

CS students reported different distributions of extroverts (9 using UML diagrams vs. 5 using metagraphs); while there were seven (7) introverts for both types of GPMs. CS sensors vs. intuitives were quite different for the two types of GPMs: sensors using UML diagrams (7) vs. metagraphs (9), and intuitives using UML diagrams (9) vs. metagraphs (3). There was a discrepancy between CS students using UML vs. metagraphs both on the extraversion vs. introversion and sensing vs. intuition cognitive styles.

Additionally, there was a difference in the number of participants with extraversion vs. introversion cognitive styles who used UML diagrams (26 vs. 20) vs. metagraphs (20 vs. 21). Figures 4-11 and 4-12 further illustrate these distributions and statistics.

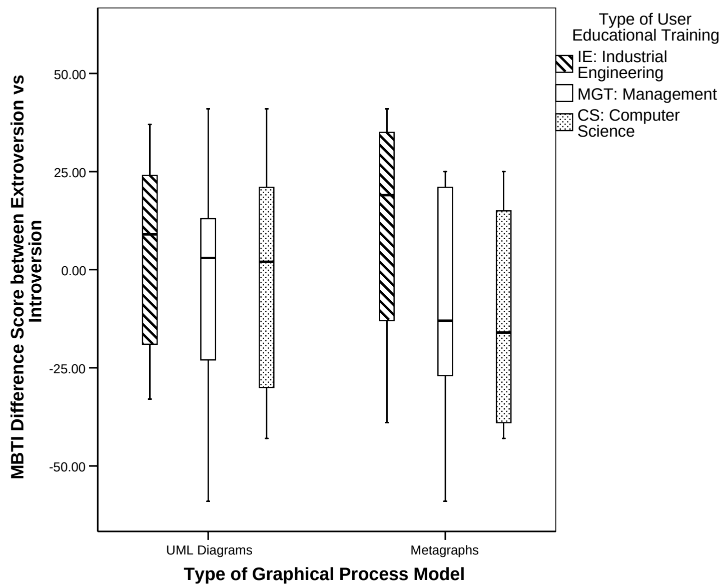


Figure 4-11. Box plots of continuous extrovert to introvert scores (+ scores = Extroverted tendencies; - scores = Introverted tendencies). by the type of GPM and type of UET.

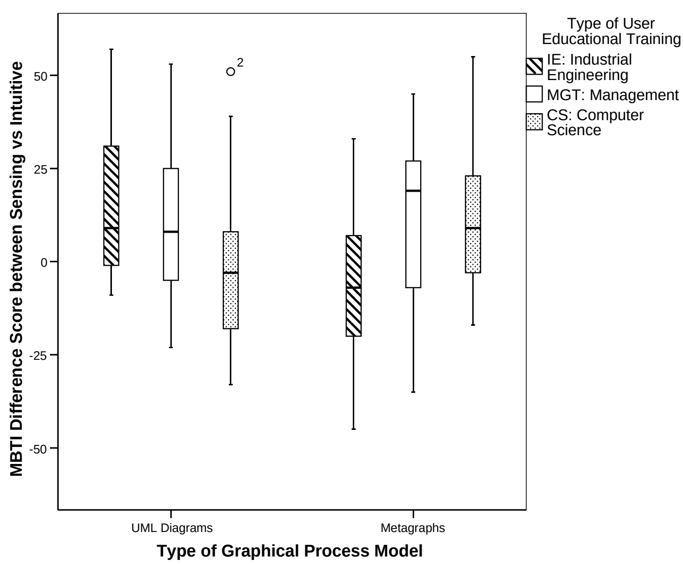


Figure 4-12. Box plots of continuous sensing to intuitive scores (+ scores = Sensing tendencies; - scores = Intuitive tendencies). by the type of GPM and type of UET.

Table 4-18. One-way ANOVA of the MBTI Cognitive Styles of the participants in context of the type of GPM (n = 87).

Factor: Type of GPM		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
MBTI Difference Score between *Extroversion vs. Introversion*	Between Groups	198.29	1	198.29	.26	.609
	Within Groups	63904.98	85	751.82		
	Total	64103.26	86			
MBTI Difference Score between *Sensing vs. Intuitive*	Between Groups	52.89	1	52.89	.10	.756
	Within Groups	46356.76	85	545.37		
	Total	46409.66	86			

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Table 4-19. One-way ANOVA of the MBTI Cognitive Styles of the participants in context of the type of User Educational Training (n = 87).

Factor: Type of User Educational Training		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
MBTI Difference Score between *Extroversion vs. Introversion*	Between Groups	2979.95	2	1489.98	2.05	.135
	Within Groups	61123.31	84	727.66		
	Total	64103.26	86			
MBTI Difference Score between *Sensing vs. Intuitive*	Between Groups	688.14	2	344.07	.63	.534
	Within Groups	45721.52	84	544.30		
	Total	46409.66	86			

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

Tables 4-18 and 4-19 describe the results of one-way ANOVAs comparing MBTI extrovert-introvert and sensing-intuition scores, respectively, to potential groups for the type of GPM and type of UET. These tables showed no statistically significant differences for either cognitive style on the treatment groups representing GPM type and UET type.

4.2.6 Moderating Variable: *General Cognitive Abilities* (WPT scores)

General Cognitive Abilities was evaluated in this experiment by the WPT. The WPT scores were hypothesized to effect the subjective mental workload a participant experiences in this study. Tables 4-20 and 4-21 show descriptive statistics and ANOVAs that break down WPT scores according to both the type of GPM and the type of UET.

Table 4-20. Descriptive statistics for the WPT scores by the type of GPM used by participants (n = 87).

Moderating Variable: WPT Score

Type of Graphical Process Model	Type of User Educational Training	n	Mean	Std. Deviation
UML Diagrams	IE: Industrial Engineering	12	29.75	4.81
	MGT: Management	18	27.06	7.69
	CS: Computer Science	16	31.19	7.23
	Total	46	29.20	6.98
Metagraphs	IE: Industrial Engineering	12	30.83	4.84
	MGT: Management	17	25.94	5.01
	CS: Computer Science	12	29.50	6.75
	Total	41	28.41	5.81
Total	IE: Industrial Engineering	24	30.29	4.75
	MGT: Management	35	26.51	6.46
	CS: Computer Science	28	30.46	6.95
	Total	87	28.83	6.43

Table 4-21. Two-way, between-subjects ANOVA of the WPT scores for the type of GPM and the type of User Educational Training (n = 87).

Moderating Variable: WPT Scores

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	351.17(a)	5	70.24	1.78	.127
Intercept	71142.36	1	71142.36	1798.97	.000
GPM Type	6.92	1	6.92	.18	.677
UET Type	303.97	2	151.98	3.84	**.025***
GPM Type X UET Type	27.27	2	13.63	.35	.709
Error	3203.24	81	39.55		
Total	75854.00	87			
Corrected Total	3554.41	86			

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$
a R Squared = 0.099 (Adjusted R Squared = 0.043)

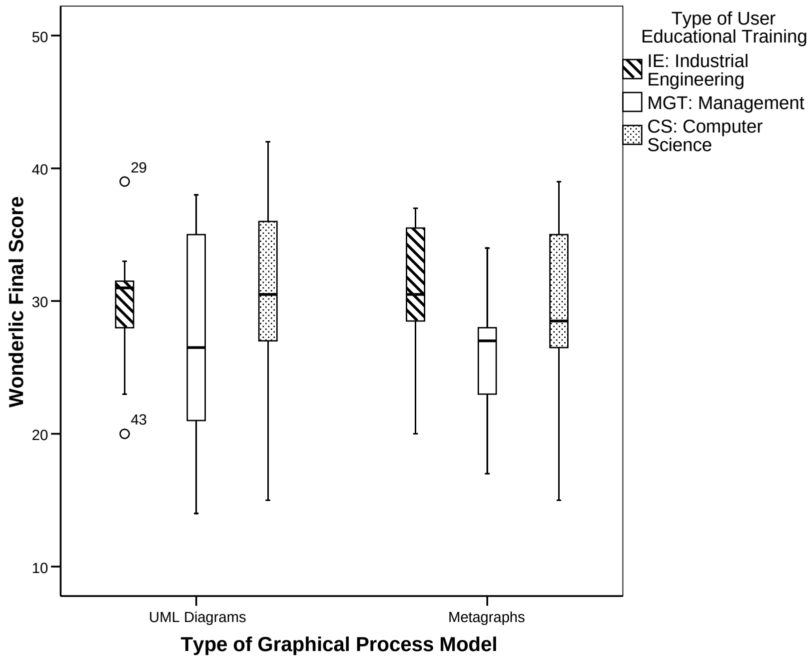


Figure 4-13. Distribution of WPT scores by the type of Graphical Process Model and type of User Educational Training.

Table 4-21 displays the results of ANOVAs showing no significant effect of GPM type on WPT scores. In contrast, it appeared that there was a significant effect of UET type on WPT scores, $F(2,86)=3.84$, $p = 0.025$. Although not statistically significant, Figure 4-13 shows that there was a larger range of scores of MGT students using UML diagrams than those using metagraphs.

4.2.7 Moderating Variable: *Attentional Abilities* (DAPI)

Attentional abilities permit people to keep their attention focused, to one extent or another, on the tasks at hand. In this experiment, these attentional abilities were evaluated by the Differential Attentional Processes Inventory (DAPI). The DAPI was made up of four separate constructs assessing moderate-focus attentional abilities, extreme-focus attentional abilities, the ability to focus attention during dual performance on a cognitive task and a physical task (dual cognitive-physical tasks), and the ability to focus attention during dual performance on two cognitive tasks (dual cognitive-physical tasks). These attentional abilities were hypothesized to effect the subjective mental workload a participant experiences in the performance of the experimental task.

Table 4-22 presents the statistical results describing the four DAPI constructs. Table 4-23 shows there was a significant, positive correlation between those Moderately-Focused attentional abilities and Dual Cognitive-Cognitive Tasks attentional abilities, $r(87)=0.61$, p (2-tailed) < 0.01 (see Table 4-23).

Table 4-22. Descriptive statistics of DAPI constructs ($n = 87$).

Moderating Variable: DAPI Constructs

Differential Attentional Processes Inventory (DAPI)	**n**	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
Moderately-Focused Attention	87	3.45	1.00	.88	5.50
Extremely-Focused Attention	87	2.68	.80	1.17	4.92
Dual Cognitive-Physical Tasks	87	4.14	.94	1.60	6.00
Dual Cognitive-Cognitive Tasks	87	2.34	1.11	.00	5.00

Table 4-23. Correlations of DAPI constructs ($n = 87$).

Moderating Variable: DAPI Constructs

	(2)	(3)	(4)
(1) DAPI - Moderate-Focus	-.03	.35**	**.61****
(2) DAPI - Extreme-Focus	1	-.10	.09
(3) DAPI - Dual Cognitive-Physical Tasks Focus		1	.38**
(4) DAPI - Dual Cognitive-Cognitive Tasks Focus			1

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

** Correlation is significant at the 0.01 level (2-tailed).

Figure 4-14 and Table 4-24 show that, both practically and statistically, there was no significant difference between the attentional abilities of participants on GPM type.

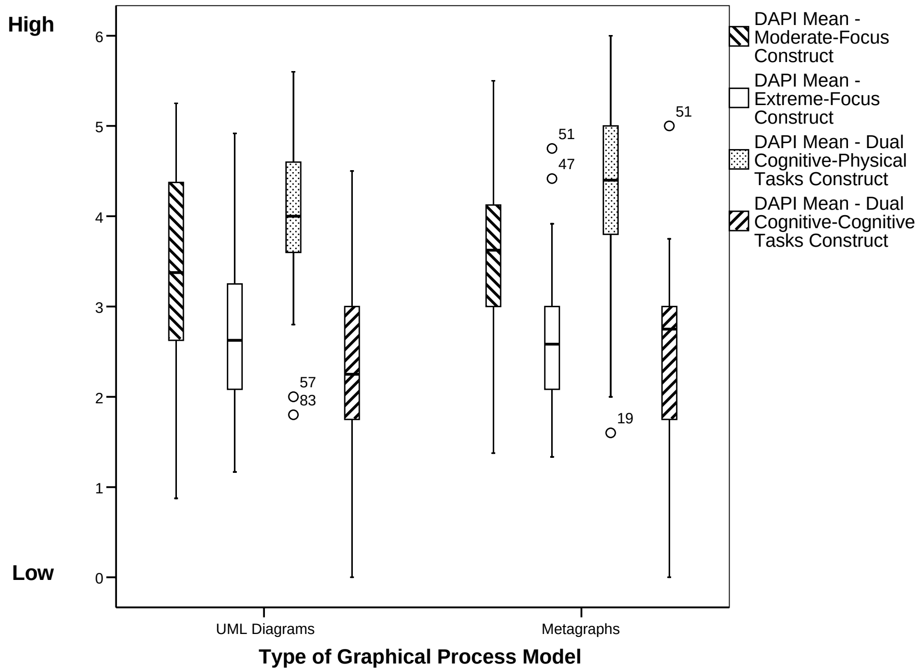


Figure 4-14. Distribution of DAPI construct scores according to the type of Graphical Process Model.

Table 4-24. One-way ANOVAs showing no statistical difference exist of DAPI attentional abilities between-subjects existed between groups that used different types of GPMs (n = 87).

Moderating Variable: DAPI Constructs

Factor: Type of GPM		**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
DAPI Moderately-Focused Attention	Between Groups	.30	1	.30	.30	.587
	Within Groups	86.40	85	1.02		
	Total	86.70	86			
DAPI Extremely-Focused Attention	Between Groups	.15	1	.15	.23	.635
	Within Groups	55.35	85	.65		
	Total	55.50	86			
DAPI Dual Cognitive-Physical Tasks	Between Groups	1.18	1	1.18	1.34	.251
	Within Groups	75.27	85	.89		
	Total	76.46	86			
DAPI Dual Cognitive-Cognitive Tasks	Between Groups	.52	1	.52	.42	.520
	Within Groups	106.38	85	1.25		
	Total	106.91	86			

$^{\dagger}p < 0.10$ $*p < 0.05$ $**p < 0.01$ $***p < 0.001$

Figure 4-15 and Table 4-25 show the attentional abilities differences between participants in relation to the three types of UET of the participants. There was little difference between the participants with different educational training on three of the four DAPI constructs. There was only a significant effect of Moderately-Focused attentional abilities on groups representing the types of User Educational Training, $F(2,86)=4.62$, $p = 0.012$. Figure 4-15 shows that CS students possess significantly higher Moderately-Focused attentional abilities than IE or MGT students.

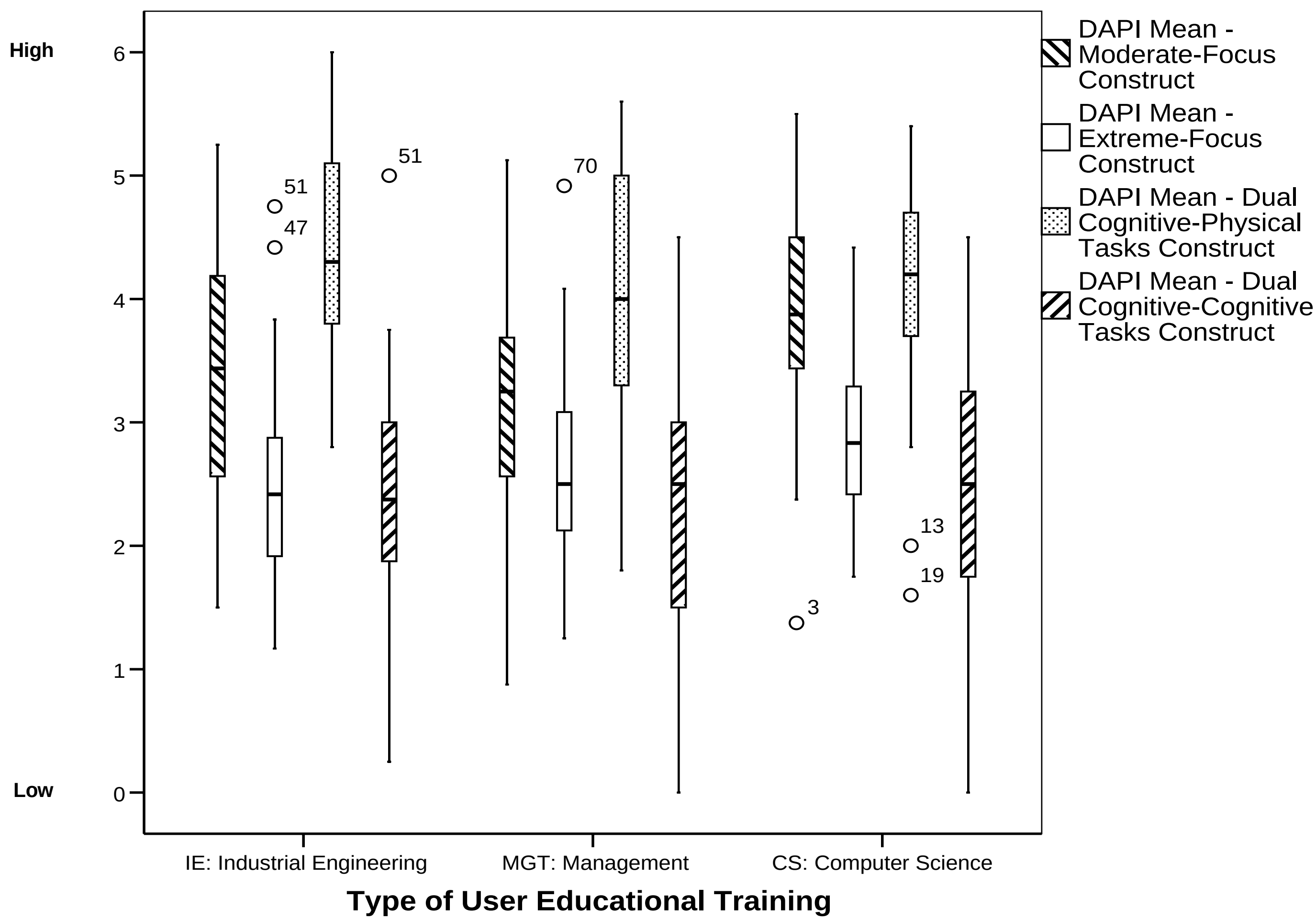


Figure 4-15. Distribution of DAPI construct scores by the type of User Educational Training.

Table 4-25. One-way ANOVAs showing only participants with DAPI moderately-focused attentional abilities differed statistically between groups of different types of User Educational Training (n = 87).

Moderating Variable: DAPI Constructs

Factor: Type of User Educational Training		Sum of Squares	df	Mean Square	F	Sig.
DAPI Moderately-Focused Attention	Between Groups	8.60	2	4.30	4.62	**.012***
	Within Groups	78.10	84	.93		
	Total	86.70	86			
DAPI Extremely-Focused Attention	Between Groups	1.53	2	.77	1.19	.309
	Within Groups	53.97	84	.64		
	Total	55.50	86			
DAPI Dual Cognitive-Physical Tasks	Between Groups	3.44	2	1.72	1.98	.145
	Within Groups	73.01	84	.87		
	Total	76.46	86			
DAPI Dual Cognitive-Cognitive Tasks	Between Groups	1.82	2	.91	.73	.486
	Within Groups	105.08	84	1.25		
	Total	106.91	86			

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

4.3 PRELIMINARY ANALYSES OF THE DATASET

The preliminary analyses of the data are discussed (in Section 4.3 and Appendix N) before reporting the analysis results that test each of the research hypotheses (in Section 4.4). Preliminary analyses showed problems with observed power on several dependent variables. Further investigation revealed problems with the way the a priori power analysis was conducted. Consequently, post hoc power analyses were performed to identify whether the sample size and multivariate data associated with this experiment was sufficient to detect meaningful effects. Appendix N.2 describes details of problems in the a priori power analyses and multivariate post hoc power analyses (D'Amico, Neilands, & Zambarano, 2001; Faul, Erdfelder, Lang, & Buchner, In Press). Post hoc power analyses revealed that the experiment was powerful enough to detect large effects ($ES \leq 0.40$) (Jacob Cohen, 1988; J. Cohen, 1992), using ANOVAs and MANOVAs across all dependent variables assessing each independent variable at $(1-\beta) \geq 0.80$ at $\alpha = 0.05$. Future research should increase the sample size of the treatment groups to be capable of detecting medium or smaller effect sizes, but statistically significant results from this experiment show large effects in the data.

Appendix N describes results of preliminary analyses of the data set. The preliminary analyses showed that the four parametric assumptions were upheld for most of the dataset. Also, DAPI constructs were sufficiently reliable and could be used in future analyses. Where there appeared to be a problem with accuracy sphericity, a statistical correction was made that allowed statistically justifiable interpretation of the results. Some questions remain about the normality of timeliness results, yet the difference was arguable. Thus, it was determined that further analyses testing the experimental hypotheses and conducting exploratory analyses was reasonable.

4.4 Results Testing Research Hypotheses

This section describes the results testing the hypotheses of this experiment. Results testing Hypotheses 1-3, addressing impacts of the type of GPM, the type of BPI, and the type of UET, are presented in Sections 4.4.1-4.4.3, respectively. Results of hypotheses describing the relationships between subjective mental workload and outcomes of user comprehension are presented in Sections 4.4.4-4.4.5. Lastly, results of Hypotheses testing the moderating variables – extroversion-introversion, sensing-intuition, general cognitive abilities, and attentional abilities – are presented in Sections 4.4.6-4.4.8.

Table 4-26. Repeated measures, between-subject MANOVA results testing Hypotheses 1 and 3 (n = 87).

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Accuracy	1145197.31	1	1145197.31	3086.49	.000
	Time	23198976.21	1	23198976.21	1204.61	.000
	Mental Workload	1088364.98	1	1088364.98	2043.07	.000
GPM Type	Accuracy	15420.83	1	15420.83	41.56	**.000*** **
	Time	337171.15	1	337171.15	17.51	**.000*** **
	Mental Workload	1837.91	1	1837.91	3.45	.067†
UET Type	Accuracy	2208.76	2	1104.38	2.98	.057†
	Time	43710.18	2	21855.09	1.14	.327
	Mental Workload	3525.18	2	1762.59	3.31	**.042***
GPM Type X UET Type	Accuracy	877.04	2	438.52	1.18	.312
	Time	65593.62	2	32796.81	1.70	.189
	Mental Workload	2169.93	2	1084.96	2.04	.137
Error	Accuracy	30053.89	81	371.04		
	Time	1559935.88	81	19258.47		
	Mental Workload	43149.67	81	532.71		

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

a Computed using alpha = 0.05

4.4.1 Hypothesis 1 Results – Impacts of the *Type of Graphical Process Model*

Hypothesis 1, and associated sub-hypotheses, state that the type of GPM significantly affects participants' task performance (i.e., accuracy and timeliness), self-efficacy and subjective mental workload. Tables 4-16 and 4-26 show significant effects of the type of GPM on three of the four dependent variables: accuracy ($F(1,81)=41.56$, $p = 0.000$), time ($F(1,81)=17.51$, $p = 0.000$), and average self-efficacy ($F(1,81)=6.08$, $p = 0.016$). There was not a significant effect of GPM type on subjective mental workload, $F(1,81)=3.45$, $p = 0.067$. No interactions were significant. The direction of these statistical results are illustrated in Figures 4-16 through 4-19.

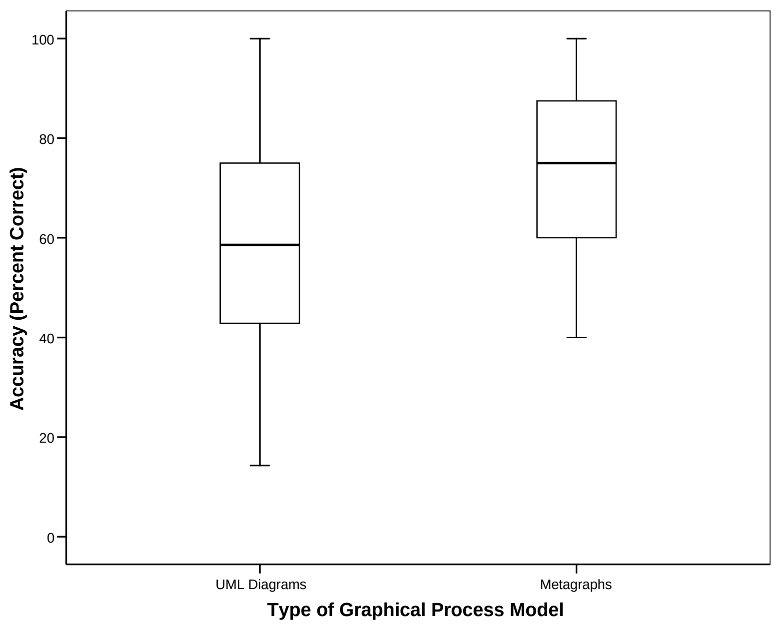


Figure 4-16. Box-plot showing users of metagraphs produced higher accuracy results compared to users of UML diagrams.

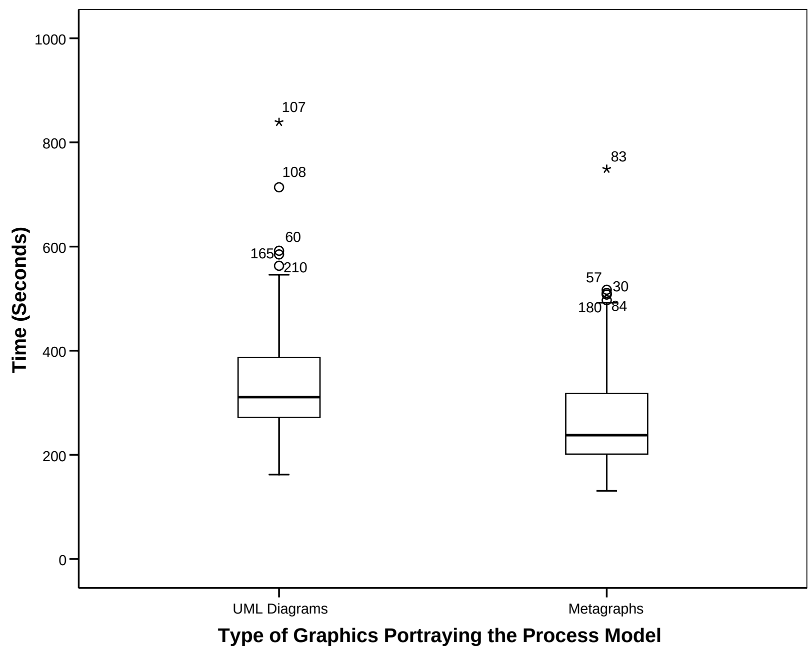


Figure 4-17. Box-plot showing users of metagraphs spending lower time on task (i.e., higher timeliness) compared to users of UML diagrams.

As a group, users interpreted metagraphs more accurately than UML diagrams rejecting Hypothesis 1.1 and supporting its opposite (Figure 4-16). Similarly, metagraph users completed their experimental tasks in less time (i.e., higher timeliness) compared to the users of UML diagrams (Figure 4-17), not supporting Hypothesis 1.2 and supporting its opposite.

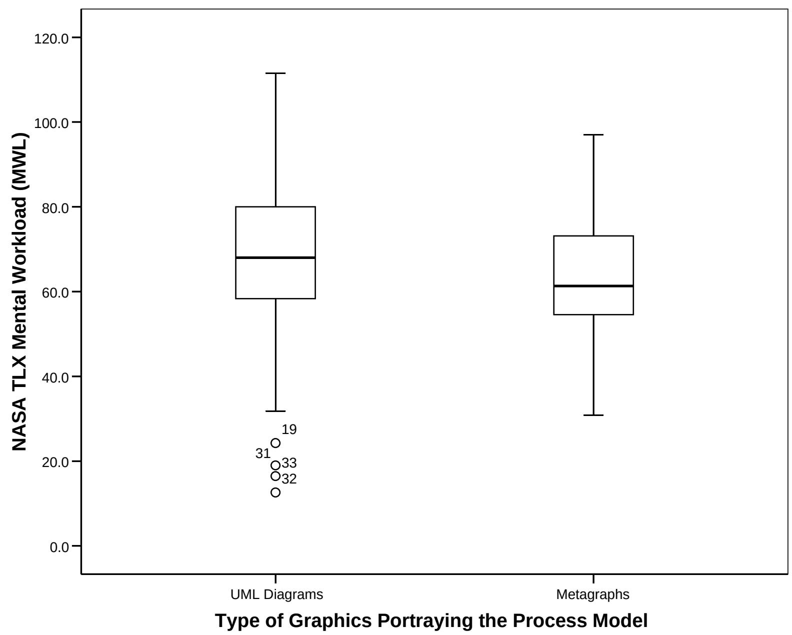


Figure 4-18. Box-plot showing metagraph users reported similar but slightly lower TLX subjective mental workload than users of UML diagrams.

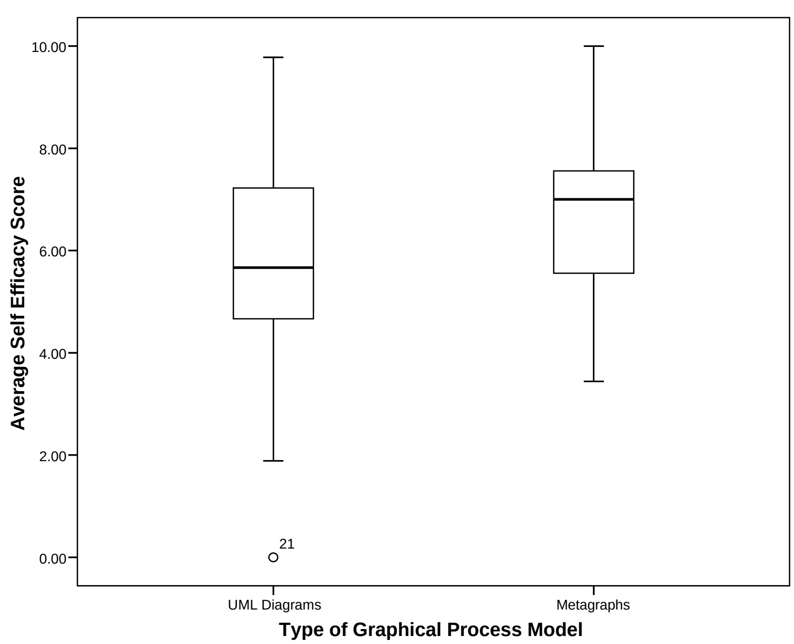


Figure 4-19. Box-plot showing metagraph users reported higher average self-efficacy than users of UML diagrams.

Self-reports of subjective mental workload and average self-efficacy illustrated similar results. Metagraph users reported lower and more concentrated subjective mental workload overall (Figure 4-18), but this result was not significant below $p = 0.05$ ($F(1,81)=3.45$, $p = 0.067$). As a consequence, Hypothesis 1.3 was also rejected and the alternate sub-hypotheses was supported. Figure 4-19 shows average self-efficacy of metagraph users was higher than users of UML diagrams. Hypothesis 1 was supported in that the type of GPM did significantly affect tack accuracy, timeliness, and self-efficacy, but did not significantly affect subjective mental workload (see Table 4-26). In fact, the alternate sub-hypotheses were supported: metagraphs produced more desirable accuracy, timeliness, and self-efficacy than UML diagrams. Also, an argument can be made that metagraphs produced less subjective mental workload in novice users than UML diagrams based on Figure 4-18. In summary, these results show that metagraphs produced more positive results in novice users than UML diagrams contrary to what was hypothesized based on the principle of Ontological Completeness.

Table 4-27. Summary of Hypothesis 1 Results

Research Question 1:	*How do different types of Graphical Process Model influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*	***Results***
Hypothesis 1:	H_1: The type of Graphical Process Model (GPM) will significantly affect participants' task performance (i.e., accuracy and timeliness), subjective mental workload and self-efficacy.	Supported
	1.1 Participants using *UML diagrams* will produce significantly higher *accuracy* than participants using *metagraphs*.	Not Supported (Opposite Hypothesis Supported)
	1.2 Participants using *UML diagrams* will produce significantly better *timeliness* time than participants using *metagraphs*.	Not Supported (Opposite Hypothesis Supported)
	1.3 Participants using *UML diagrams* will experience significantly lower *subjective mental workload* than participants using *metagraphs*.	Not Supported
	1.4 Participants using *UML diagrams* will experience significantly higher *self-efficacy* than participants using *metagraphs*.	Not Supported (Opposite Hypothesis Supported)

4.4.2 Hypothesis 2 Results – *Type of Business Process Information* Impacts

Hypothesis 2 and its sub-hypotheses states that the type of BPI significantly affect participants' task performance (both accuracy and timeliness) and subjective mental workload. Self-efficacy data was not included in Hypothesis 3, because it was evaluated between-subjects (i.e., once by each participant at the end of the entire experiment). Table 4-28 reports repeated measures that MANOVA results related to Hypotheses 2 in the context of sphericity assumptions and corrections. There were significant effects on BPI type on time, $F(2,162)=17.95$, $p = 0.000$, and subjective mental workload, $F(2,162)=5.19$, $p = 0.007$. There was also a significant effect of the interaction between the type of BPI and the type of UET on subjective mental workload, $F(2,162)=3.26$, $p = 0.013$. There was not a significant effect of BPI type on accuracy, $F(1.93,156.35)=2.29$, $p = 0.11$.

Table 4-28. Repeated measures, within-subjects MANOVA results for Hypothesis 2 testing the type of Business Process Information (n = 87).

Source	Measure	Sphericity	Type III Sum of Squares	df	Mean Square	F	Sig.
BPI Type	Accuracy	Huynh-Feldt	1293.52	1.93	670.14	2.29	.107
	Time	Sphericity Assumed	203676.36	2	101838.18	17.94	**.000*** **
	Mental Workload	Sphericity Assumed	954.32	2	477.16	5.19	**.007** **
BPI Type X GPM Type	Accuracy	Huynh-Feldt	318.63	1.93	165.07	.56	.564
	Time	Sphericity Assumed	3750.26	2	1875.13	.33	.719
	Mental Workload	Sphericity Assumed	303.17	2	151.59	1.65	.196
BPI Type X UET Type	Accuracy	Huynh-Feldt	1175.30	3.86	304.45	1.04	.387
	Time	Sphericity Assumed	28679.85	4	7169.96	1.26	.287
	Mental Workload	Sphericity Assumed	1198.06	4	299.52	3.26	**.013***
BPI Type X GPM Type X UET Type	Accuracy	Huynh-Feldt	509.69	3.86	132.03	.45	.765
	Time	Sphericity Assumed	19068.67	4	4767.17	.84	.502
	Mental Workload	Sphericity Assumed	520.37	4	130.10	1.42	.231
Error (BPI Type)	Accuracy	Huynh-Feldt	45765.93	156.35	292.72		
	Time	Sphericity Assumed	919765.56	162	5677.57		
	Mental Workload	Sphericity Assumed	14898.61	162	91.97		

$^{\dagger}p < 0.10$ $*p < 0.05$ $**p < 0.01$ $***p < 0.001$

Table 4-29 reports results of within-subjects contrasts (combined results of first and last simple contrast methods) for the BPI Type independent variable and an interaction shown to be significant. For the type of BPI, although overall accuracy was not statistically significant, there was a significant effect of BPI type on accuracy results for task-centric vs. information-centric BPI, $F(1,81)=6.02$, $p = 0.016$ (Figure 4-20 illustrates this result). Therefore, Hypothesis 2.1 was, partially supported but Hypotheses 2.4 and 2.7 were not supported.

Table 4-29. Partial results of tests of within-subjects simple contrasts (combined first and last) between conditions of the types of Business Process Information (n = 87).

Source	Measure	BPI Type	Type III Sum of Squares	df	Mean Square	F	Sig.
BPI Type	Accuracy	Resource vs. Task	1517.71	1	1517.71	2.54	.115
		Information vs. Task	2284.69	1	2284.69	6.02	**.016***
		Resource vs. Information	78.16	1	78.16	.11	.742
	Time	Resource vs. Task	104364.85	1	104364.85	11.52	**.001*****
		Information vs. Task	407331.99	1	407331.99	33.59	**.000*****
		Resource vs. Information	99332.23	1	99332.23	7.72	**.007****
	Mental Workload	Resource vs. Task	1433.81	1	1433.81	7.84	**.006****
		Information vs. Task	1429.13	1	1429.13	8.87	**.004****
		Resource vs. Information	.00	1	.00	.00	.997
BPI Type X UET Type	Accuracy	Resource vs. Task	1824.56	2	912.28	1.53	.223
		Information vs. Task	523.52	2	261.76	.69	.505
		Resource vs. Information	1177.82	2	588.91	.82	.444
	Time	Resource vs. Task	39469.67	2	19734.83	2.18	.120
		Information vs. Task	19223.87	2	9611.94	.79	.456
		Resource vs. Information	27345.10	2	13672.10	1.06	.351
	Mental Workload	Resource vs. Task	151.75	2	75.88	.42	.662
		Information vs. Task	1224.83	2	612.42	3.80	**.026***
		Resource vs. Information	2217.61	2	1108.81	5.34	**.007****
Error (BPI Type)	Accuracy	Resource vs. Task	48351.93	81	596.94		
		Information vs. Task	30741.57	81	379.53		
		Resource vs. Information	58204.28	81	718.57		
	Time	Resource vs. Task	734161.67	81	9063.72		
		Information vs. Task	982178.23	81	12125.66		
		Resource vs. Information	1042956.77	81	12876.01		
	Mental Workload	Resource vs. Task	14809.56	81	182.83		
		Information vs. Task	13051.64	81	161.13		
		Resource vs. Information	16834.64	81	207.84		

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

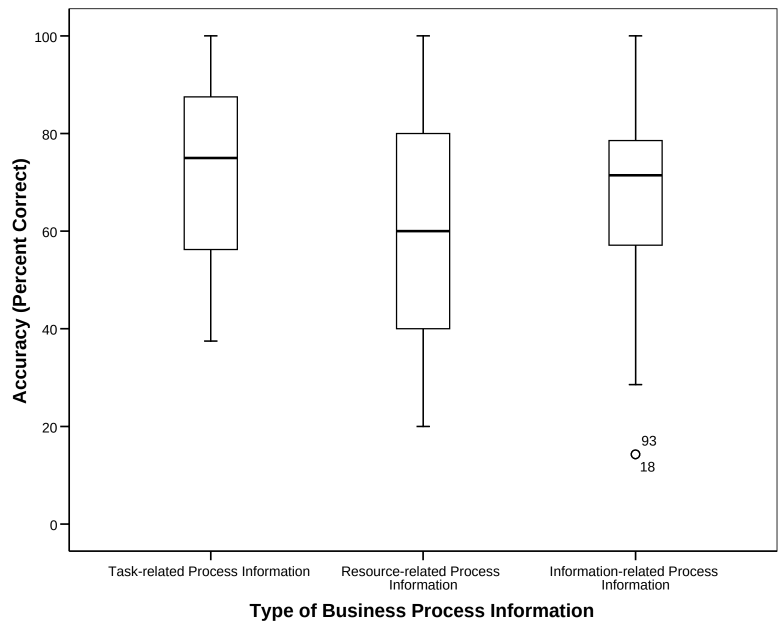


Figure 4-20. Graph showing the accuracy results of participants according to the different types of Business Process Information.

Table 4-29 show a significant effects of comparisons of BPI types on timeliness: between resource-centric and task-centric BPI, $F(2,81)=11.52$, $p = 0.001$, between resource-centric and information-centric BPI, $F(2,81)=7.72$, $p = 0.007$, as well as between the information-centric and task-centric BPI, $F(2,81)=33.59$, $p = 0.000$. Figure 4-21 shows that task-centric BPI took the least amount of time (i.e., highest timeliness) to interpret and information-centric BPI took the most amount of time to interpret (i.e., lowest timeliness). Therefore, Hypothesis 2.2 was supported. Hypothesis 2.5 was partially supported in that timeliness of interpretation of resource-centric BPI was significantly lower than for task-centric BPI, but it was not significantly different from information-centric BPI. Hypothesis 2.8 was not supported. In fact, the alternate sub-hypothesis was supported because information-centric BPI interpretations were less timely than resource-centric BPI interpretations.

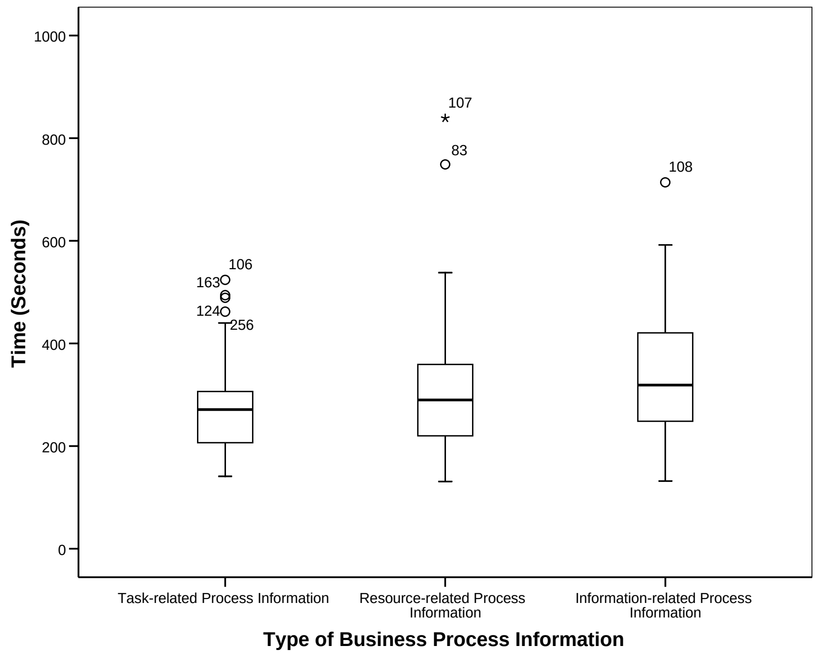


Figure 4-21. Graph showing the timeliness results of participants according to the different types of Business Process Information.

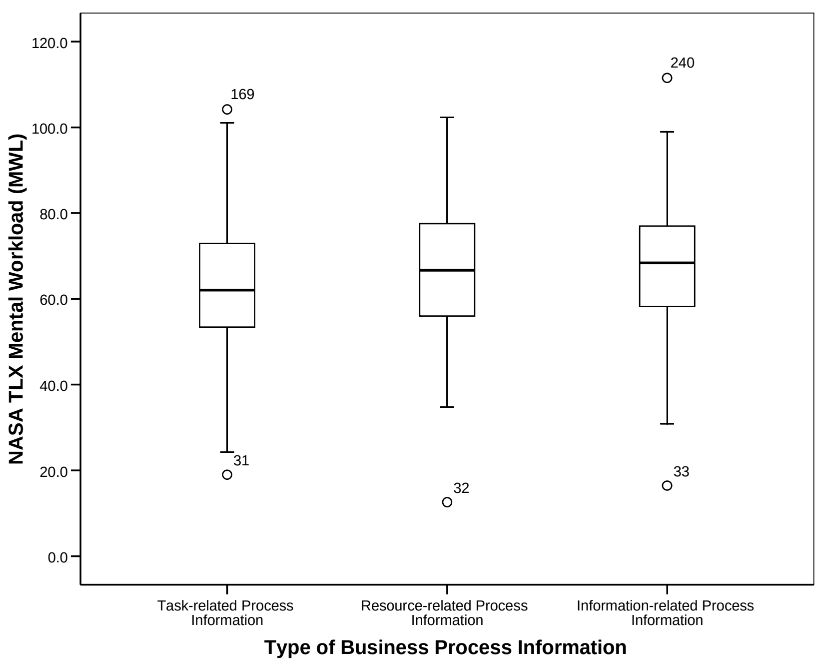


Figure 4-22. Graph showing the subjective mental workload results of participants according to the different types of Business Process Information.

There was no significant effect of BPI type on subjective mental workload by users of resource-centric and information-centric BPI, $F(1,81)=0.00$, $p = 0.997$. However, there were significant effects of differences between these two BPI types compared to users of task-centric BPI results on subjective mental workload, $F(1,81)=7.84$, $p = 0.006$ and $F(1,81)=8.87$, $p = 0.004$ respectively (see Table 4-29). Figure 4-22 shows that users of task-centric BPI reported less subjective mental workload than users of the other two BPI Types. There was not a significant difference between resource-centric and task-centric BPI on subjective mental workload, $F(2,81)=0.42$, $p = 0.662$. There was a significant effect between information-centric and task-centric BPI Types, $F(2,81)=3.80$, $p = 0.026$, and between resource-centric and information-centric BPI, $F(2,81)=5.34$, $p = 0.007$ on subjective mental workload. Therefore, Hypothesis 2.3 was supported. Hypothesis 2.6 was partially supported in that resource-centric users reported significantly higher subjective mental workload than task-centric BPI interpretations, but their results were not significantly different from information-centric BPI subjective mental workload results. Finally, Hypothesis 2.8 was not supported. The results for Hypothesis 3 and its sub-hypotheses are summarized in Table 4-30.

Table 4-30. Hypothesis 2 Results

Research Question 2:	*How do different types of Business Process Information influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*	***Results***
Hypothesis 2:	H_2: The type of Business Process Information will significantly affect participants' task performance (i.e., accuracy and timeliness), and subjective mental workload[1].	Partially Supported (*Timeliness & Mental Workload* only)
	2.1 Participants using GPMs portraying *task-centric BPI* will produce significantly higher *accuracy* results compared to resource- or information-centric *BPI*.	Partially Supported (> Information-centric BPI)
	2.2 Participants using GPMs portraying *task-centric BPI* will produce significantly better *timeliness* results compared to resource- or information-centric *BPI*.	Supported
	2.3 Participants using GPMs portraying *task-centric BPI* will experience significantly lower subjective *mental workload* compared to resource- or information-centric *BPI*.	Supported

[1] *Self-efficacy* was not measured within-subjects so it is not included in this hypothesis.

Research Question 2:	*How do different types of Business Process Information influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*	***Results***
	2.4 Participants using GPMs portraying *resource-centric BPI* will produce significantly lower *accuracy* compared to task- or information-centric *BPI*.	Not Supported
	2.5 Participants using GPMs portraying *resource-centric BPI* will produce significantly worse *timeliness* compared to task- or information-centric *BPI*.	Partially Supported (< Task-centric BPI)
	2.6 Participants using GPMs portraying *resource-centric BPI* will experience significantly higher subjective *mental workload* compared to task- or information-centric *BPI*.	Partially Supported (> Task-centric BPI)
	2.7 Participants using GPMs portraying *information-centric BPI* will produce significantly higher *accuracy* compared to resource-centric *BPI*.	Not Supported
	2.8 Participants using GPMs portraying *information-centric BPI* will produce significantly better *timeliness* compared to resource-centric *BPI*.	Not Supported (Opposite Supported)
	2.9 Participants using GPMs portraying *information-centric BPI* will experience significantly higher subjective *mental workload* compared to resource-centric *BPI*.	Not Supported

4.4.3 Hypothesis 3 Results – *Type of User Educational Training* Results

Hypothesis 3, and associated sub-hypotheses, predicted that the type of UET of participants will significantly affect participants' task performance (i.e., accuracy and timeliness), self-efficacy, and subjective mental workload. Tables 4-16 and 4-26 shows a significant effect of the type of UET on only one of the four dependent variables: TLX subjective mental workload, $F(2,81)=3.31$, $p = 0.042$. There was not a significant effect of UET type on accuracy, $F(2,81)=2.98$, $p = 0.057$, timeliness, $F(2,81)=1.14$, $p = 0.327$, and average self-efficacy, ($F(2,81)=2.28$, $p = 0.109$, below the default level of significance, $p < 0.05$. Therefore, Hypotheses 3.2, 3.6, and 3.10 were not supported.

Table 4-31. Results of Planned Comparisons using simple contrast methodologies which indicate direction and significance between the types of User Educational Training (n = 87).

Type of User Educational Training	Simple Contrasts*	Accuracy (Percent)	Time (Seconds)	NASA TLX Mental Workload	Average Self - Efficacy Score
IE vs. CS (a)	Contrast Estimate	2.61	-27.29	4.19	-.18
	Hypothesized Value	0	0	0	0
	Difference (Estimate - Hypothesized)	2.61	-27.29	4.19	-.18
	Std. Error	3.11	22.40	3.73	.50
	Sig.	.403	.227	.264	.721
MGT vs. IE (b)	Contrast Estimate	-6.98	30.11	4.52	-.74
	Hypothesized Value	0	0	0	0
	Difference (Estimate - Hypothesized)	-6.98	30.11	4.52	-.74
	Std. Error	2.95	21.24	3.53	.48
	Sig.	**.020***	.160	.204	.128
MGT vs. CS (a)	Contrast Estimate	-4.36	2.83	8.71	-.92
	Hypothesized Value	0	0	0	0
	Difference (Estimate - Hypothesized)	-4.36	2.83	8.71	-.92
	Std. Error	2.84	20.44	3.40	.46
	Sig.	.128	.890	**.012***	**.050***

$^{\dagger}p < 0.10$ $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$
a Reference category = 3
b Reference category = 1

The results of planned comparisons in Table 4-31 indicated that three significant differences exist between groups of the four dependent variables:

- There was significant effect between MGT and IE students on accuracy, p (one-tailed) = 0.020. Figure 4-23 shows MGT students produced less accurate results than IE students. Therefore, Hypothesis 3.9 was supported and Hypothesis 3.5 was only partially supported.
- There was a significant difference between MGT and CS students on subjective mental workload, p (one-tailed) = 0.013. Figure 4-24 shows that MGT students experienced more subjective mental workload than both CS and IE students (but the latter relationship was not statistically significant). Therefore, Hypotheses 3.3 and 3.7 were partially supported.
- There was a significant difference between MGT and CS students on average self-efficacy, p (one-tailed) = 0.050. Figure 4-25 showed MGT students experienced lower average self-

efficacy than both CS and IE students (but the latter relationship was not statistically significant). Therefore, Hypotheses 3.4 and 3.8 were partially supported.

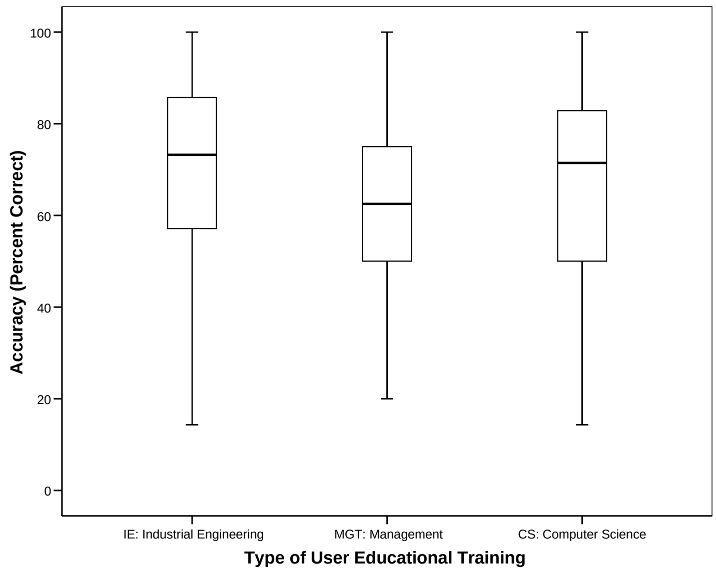


Figure 4-23. Graph showing the experimental task accuracy results of the participants by their different types of User Educational Training.

UET and timeliness-related sub-hypotheses were not supported. There were no significant differences between IE and CS students with respect to the dependent variables. Therefore, any hypothesis comparing IE and CS majors did not have statistical support.

In summary, there were significant differences due to the type of UET of participants, thus Hypothesis 3 was supported, although only partially. See Table 4-32 for specific outcomes of Hypothesis 3.

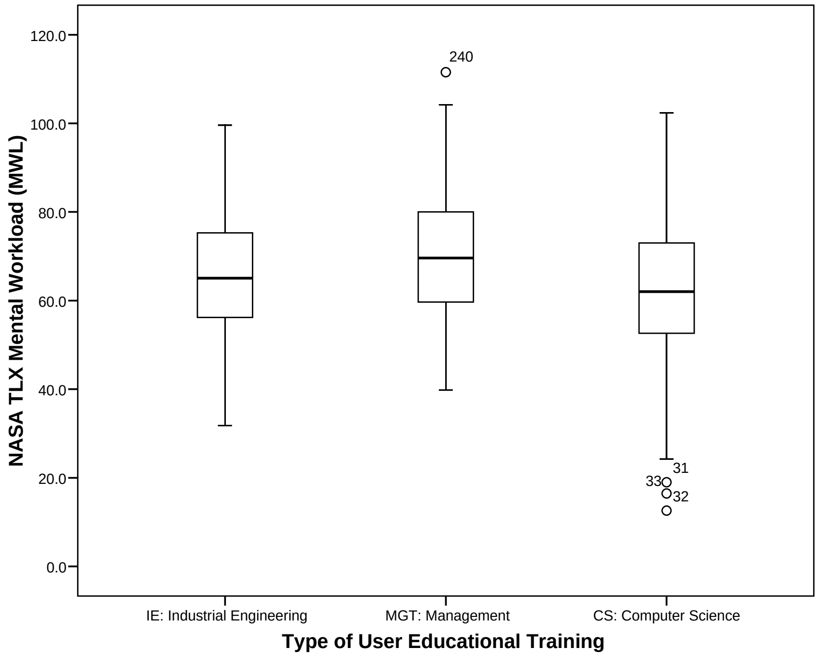


Figure 4-24. Graph showing the TLX subjective mental workload results of the participants by their different types of User Educational Training.

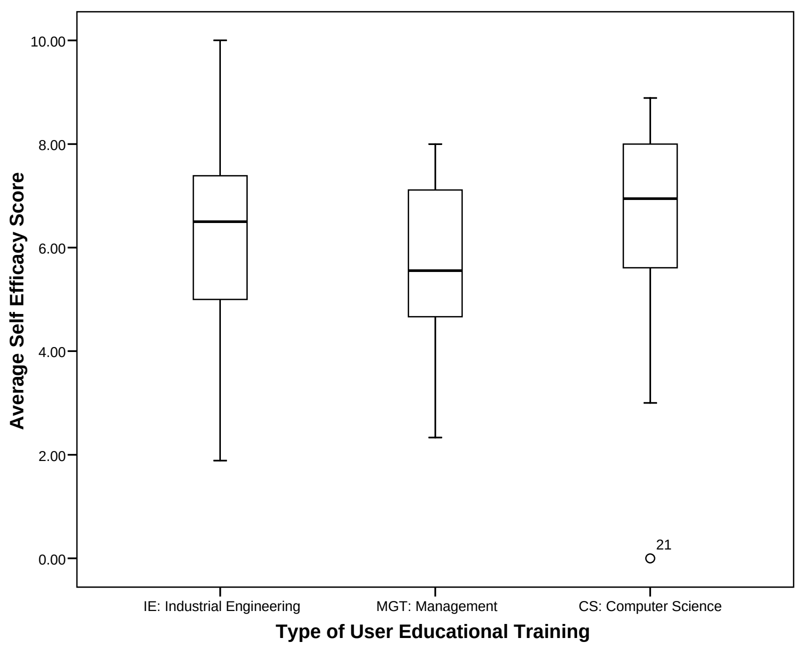


Figure 4-25. Graph showing the average self-efficacy results of the participants by their different types of User Educational Training.

Table 4-32. Hypothesis 3 Results

Research Question 3:	*How do different types of user educational training influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*	***Results***
Hypothesis 3:	H_3: The type of User Educational Training of participants will significantly affect participants' task performance (i.e., accuracy and timeliness), subjective mental workload and self-efficacy.	Partially Supported (except for Timeliness)
	3.1 *Computer science* majors will produce significantly higher *accuracy* compared to Industrial Engineering and Management majors.	Not Supported
	3.2 *Computer science* majors will produce significantly better *timeliness* compared to Industrial Engineering and Management majors.	Not Supported
	3.3 *Computer science* majors will experience significantly lower subjective *mental workload* compared to Industrial Engineering and Management majors.	Partially Supported (< Management Majors Only)
	3.4 *Computer science* majors will experience significantly higher *self-efficacy* compared to Industrial Engineering and Management majors.	Partially Supported (> Management Majors Only)
	3.5 *Management* majors will produce significantly lower *accuracy* compared to Industrial Engineering and Computer Science majors.	Partially Supported (< Industrial Engineering Majors Only)
	3.6 *Management* majors will produce significantly worse *timeliness* compared to Industrial Engineering and Computer Science majors.	Not Supported
	3.7 *Management* majors will experience significantly higher subjective *mental workload* compared to Industrial Engineering and Computer Science majors.	Partially Supported (> Computer Science Majors Only)
	3.8 *Management* majors will experience significantly lower *self-efficacy* compared to Industrial Engineering and Computer Science majors.	Partially Supported (< Computer Science Majors Only)
	3.9 *Industrial Engineering* majors will produce significantly higher *accuracy* compared to Management majors.	Supported
	3.10 *Industrial Engineering* majors will produce significantly better *timeliness* compared to Management majors.	Not Supported
	3.11 *Industrial Engineering* majors will experience significantly lower subjective *mental workload* compared to Management majors.	Not Supported
	3.12 *Industrial Engineering* majors will experience significantly higher *self-efficacy* compared to Management majors.	Not Supported

4.4.4 Hypothesis 4 Results – Subjective *Mental Workload* Correlations with *Performance*

Hypothesis 4, and associated sub-hypotheses, state that participants' task performance is correlated with subjective reports of mental workload according to the Yerkes-Dodson Law. TLX mental workload was evaluated three times per participant, at the same times as accuracy and timeliness. By applying TLX weightings, three TLX mental workload scores were calculated for each participant (n = 261). Pearson's correlation results testing these hypotheses between accuracy, time, and subjective mental workload are illustrated in Table 4-33. Although statistically significant, only small correlations exist between TLX mental workload and these variables: accuracy r (261) = - 0.25, p = 0.01 (2-tailed), and time r (261) = 0.22, p = 0.01 (2-tailed).

Table 4-33. Correlations between subjective mental workload and performance variables (n = 261).

	Accuracy (% Correct)	Time (Seconds)	NASA TLX Mental Workload
Accuracy (% Correct)	1	-.18**	-.25**
Time (Seconds)		1	.22**
NASA TLX Mental Workload			1

** Correlation is significant at the p < 0.01 level (2-tailed).

Figures 4-26 and 4-27 show the plots of cubic polynomial equations that evaluate the inverse relationship specified by the Yerkes-Dodson Law. Visually, there appears to be a slight inverse relationship between accuracy and TLX mental workload. After a certain point in Figure 4-26, subjective mental workload increases, accuracy tends to decrease. Figure 4-27 shows a similar relationship between timeliness and TLX mental workload; as TLX mental workload increases, the time on task increases until a certain point (i.e., timeliness decreases). Although the curve fit lines were statistically significant for both accuracy vs. mental workload (Figure 4-26, adjusted R^2 = 0.07, p = 0.000) and time vs. mental workload (Figure 4-27, adjusted R^2 = 0.06, p = 0.000), neither curve explained a large amount of variation in the data.

These figures seemed to visually support the sub-hypotheses, but statistically the results were not significant. Therefore, Hypothesis 4, and its associated sub-hypotheses, were not supported (see Table 4-34).

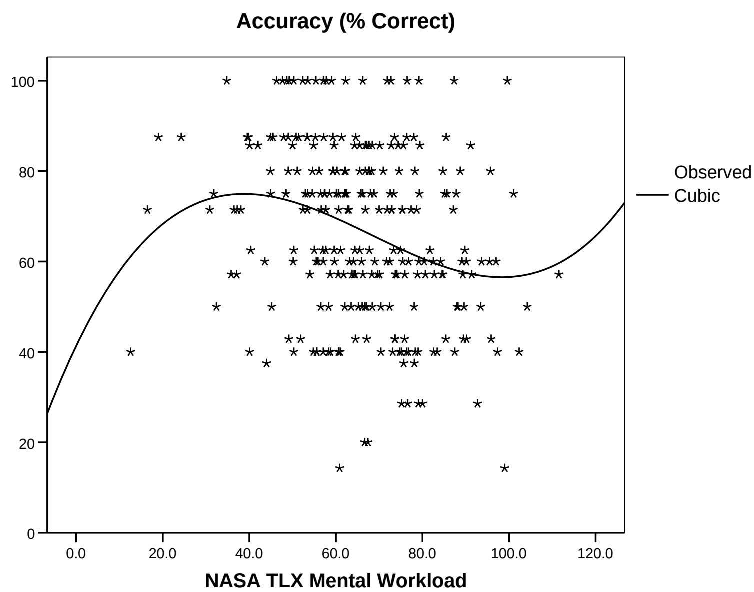


Figure 4-26. Trend line showing a slight inverse relationship between accuracy and subjective mental workload.

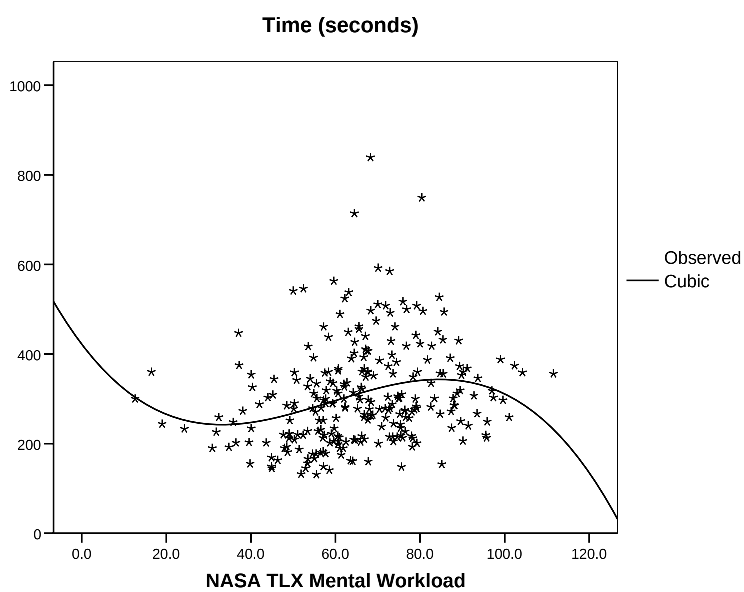


Figure 4-27. Trend line showing a slight inverse relationship between accuracy and subjective mental workload.

Table 4-34. Hypothesis 4 Results

Research Question 4:	*When interpreting graphical business process information, does the relationship between user subjective Mental Workload and Task Performance follow the Yerkes-Dodson Law (an inverted-U relationship)?*	***Results***
Hypothesis 4:	H_4: Participants' subjective mental workload will significantly affect task performance (i.e., task accuracy and timeliness) in inverted-U relationships (in accordance with the Yerkes-Dodson principle).	Not Supported
	4.1 Low subjective *mental workload* will be associated with low *accuracy*.	Not Supported
	4.2 Moderate subjective *mental workload* will be associated with high *accuracy*.	Not Supported
	4.3 High subjective *mental workload* will be associated with low *accuracy*.	Not Supported
	4.4 Low subjective *mental workload* will be associated with low *timeliness*.	Not Supported
	4.5 Moderate subjective *mental workload* will be associated with high *timeliness*.	Not Supported
	4.6 High subjective *mental workload* will be associated with low *timeliness*.	Not Supported

4.4.5 Hypothesis 5 Results – Subjective *Mental Workload* Correlation with *Self-Efficacy*

Hypothesis 5 states that self-efficacy is negatively correlated with the subjective mental workload participants experience during task performance. Self-efficacy was assessed at the end of the entire experiment by participant ratings of nine separate questions. Then, an overall average for self efficacy was calculated for each participant (n = 87). In addition, an overall TLX mental workload score was calculated by averaging each participants' three ratings of the six TLX dimensions (i.e., mental demand, physical demand, temporal demand, performance, effort, frustration) and then applying participants' overall TLX weightings to the average for each TLX dimension. In this way, an overall TLX mental workload score was calculated for each participant (n = 87).

Table 4-35. Correlations between-subjects relating TLX mental workload to average self-efficacy (n = 87).

	NASA TLX *Mental Workload* - Task-centric BPI	NASA TLX *Mental Workload* - Resource-centric BPI	NASA TLX *Mental Workload* - Information-centric BPI	Overall NASA TLX *Mental Workload*
Self-Efficacy Q1-If Alone & No One Was Available to Help	-.32**	-.38**	-.34**	-.40**
Self-Efficacy Q2-If Never Used MG or UML Diagrams Before	-.27*	-.30**	-.26*	-.32**
Self-Efficacy Q3-If Had Only the Training Handouts for Reference	-.21	-.21	-.32**	-.28**
Self-Efficacy Q4-If Had Seen Others Using MG or UML Diagrams	-.32**	-.29**	-.17	-.30**
Self-Efficacy Q5-If Could Call on Someone for Help	-.20	-.09	-.15	-.17
Self-Efficacy Q6-If Someone Helped You Get Started	-.32**	-.21	-.19	-.28**
Self-Efficacy Q7-If Had A lot of Time	-.22*	-.14	-.12	-.18
Self-Efficacy Q8-If Had Training Handouts 2	-.35**	-.26*	-.36**	-.37**
Self-Efficacy Q9-If Used MG or UML Diagrams on Similar Tasks	-.28**	-.19	-.18	-.25*
Average *Self Efficacy*	-.38**	-.32**	-.32**	-.39**

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$ (2-tailed)

Table 4-35 shows the correlations between the measures of TLX mental workload and self-efficacy. In addition, the overall average self-efficacy and TLX mental workload scores, the correlations between the average scores for each of the nine questions of self-efficacy, and the three TLX mental workload scores per participant are included in Table 4-35. Although many of these questions were significantly and negatively correlated, none were correlated above r (87) = - 0.40, p (2-tailed) < 0.01.

Exploratory factor analyses, that included TLX mental workload and the nine self-efficacy constructs, confirmed TLX mental workload as unrelated to self-efficacy (see Appendix O). The TLX mental workload constructs loaded on an entirely separate factor than the self-efficacy constructs that explained the least amount of variation (19.5%). The largest of the three factors, explaining 28.5% of the variation, loaded with all the positively worded self-efficacy questions. The second largest factor, explaining 23.0% of the variation, loaded with the negatively-worded and training materials-related self-efficacy questions. Therefore, Hypothesis 5 was not supported (see Table 4-36).

Table 4-36. Hypothesis 5 Results

Research Question 5:	*When interpreting graphical business process information, how does user subjective Mental Workload relate to their Self-Efficacy after task completion?*	**Result**
Hypothesis 5:	H_5: Participants' subjective mental workload will significantly and negatively affect self-efficacy results.	Not Supported

Table 4-37. Correlations between-subjects relating TLX mental workload to MBTI Cognitive Styles (n = 87).

		MBTI Difference Score between *Extroversion vs. Introversion*	MBTI Difference Score between *Sensing vs. Intuitive*
NASA TLX Mental Workload for interpreting Task-centric BPI	Pearson's Correlation	.08	.13
	Sig. (2-tailed)	.438	.245
	Sum of Squares and Cross-products	3181.41	4052.99
	Covariance	36.99	47.13
	n	87	87
NASA TLX Mental Workload for interpreting Resource-centric BPI	Pearson's Correlation	.10	.19
	Sig. (2-tailed)	.367	.075†
	Sum of Squares and Cross-products	3716.62	6199.82
	Covariance	43.22	72.09
	n	87	87
NASA TLX Mental Workload for interpreting Information-centric BPI	Pearson's Correlation	.02	.09
	Sig. (2-tailed)	.852	.386
	Sum of Squares and Cross-products	785.08	3091.17
	Covariance	9.13	35.94
	n	87	87
Overall NASA TLX Mental Workload	Pearson's Correlation	.08	.16
	Sig. (2-tailed)	.476	.144
	Sum of Squares and Cross-products	2561.04	4447.99
	Covariance	29.78	51.72
	n	87	87

$^{\dagger}p < 0.10$ $*p < 0.05$ $**p < 0.01$ $***p < 0.001$ (2-tailed)

4.4.6 Hypothesis 6 Results – *Cognitive Style* and Subjective *Mental Workload*

Hypothesis 6 states that participants' cognitive styles of extroversion vs. introversion and sensing vs. intuition (as assessed by the Myers-Briggs Type Indicator (MBTI)) significantly impacts the subjective mental workload participants experience during task performance. Table 4-37 shows that there was no significant correlation between subjective mental workload scores and extrovert-introvert or sensing-intuition scores. Tables 4-38 and 4-39 report the between and within-subject sections of the repeated measures MANCOVA results that portrayed extrovert-introvert and sensing-intuition covariation. These tables show there was not significant effect of the two MBTI cognitive styles on accuracy, timeliness, or subjective mental workload. Therefore, Hypothesis 6 and its sub-hypotheses were not supported (see Table 4-40).

Table 4-38. Tests of MBTI Cognitive Styles as covariates of between-subjects, MANCOVA (n = 87).

Source	**Measure**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
MBTI Difference Score between *Extroversion vs. Introversion*	Accuracy	55.02	1	55.02	.15	.703
	Time	51609.19	1	51609.19	2.74	.102
	Mental Workload	344.09	1	344.09	.64	.425
MBTI Difference Score between *Sensing vs. Intuitive*	Accuracy	10.93	1	10.93	.03	.865
	Time	73.46	1	73.46	.00	.951
	Mental Workload	311.21	1	311.21	.58	.448

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$ (2-tailed)

Table 4-39. Tests of MBTI Cognitive Styles as covariates of within-subjects, repeated measures MANCOVA (n = 87).

Source	**Measure**	**Sphericity Correction**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
BPI Type X MBTI EvsI Score	Accuracy	Huynh-Feldt	613.08	1.95	315.29	1.09	.339
	Time	Sphericity Assumed	4227.85	2	2113.92	.37	.692
	Mental Workload	Sphericity Assumed	76.00	2	38.00	.41	.664
BPI Type X MBTI SvsN Score	Accuracy	Huynh-Feldt	103.38	1.95	52.90	.18	.830
	Time	Sphericity Assumed	7911.62	2	3955.81	.69	.501
	Mental Workload	Sphericity Assumed	100.91	2	50.45	.55	.581

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$ (2-tailed)

Table 4-40. Hypothesis 6 Results

Research Question 6:	*How do user Cognitive Styles affect the subjective Mental Workload they experience when interpreting graphical business process information?*	**Result**
Hypothesis 6:	H_6: Participants' cognitive styles will significantly affect the subjective mental workload they experience during task performance.	Not Supported
	6.1 Participants' scoring high on the cognitive style of extroversion will experience significantly lower subjective mental workload than participants scoring high on introversion.	Not Supported
	6.2 Participants' scoring high on the cognitive style of sensing will experience significantly lower subjective mental workload than participants scoring high on intuition.	Not Supported

4.4.7 Hypothesis 7 Results – *General Cognitive Abilities* and Subjective *Mental Workload*

Hypothesis 7 proposes that a participants' general cognitive abilities, as assessed by the WPT significantly affects the subjective mental workload they experience during task performance. Table 4-41 shows no significantly large correlation between WPT scores and participants' overall subjective mental workload. For example, even though there was a significant, negative correlation between WPT scores and the subjective mental workload that participants reported when interpreting information-centric BPI, the correlation was low, $r\ (87) = -\ 0.21$, $p = 0.049$ (2-tailed).

Several interesting results were no hypothesized. Tables 4-42 and 4-43 report the between and within-subject sections of repeated measures MANCOVA results that included WPT scores as covariates. The between-subjects sections of a MANCOVA in Tables 4-42 show that WPT scores did not have a covariate effect on the relationships between GPM type and the dependent variables compared to Table 4-26). However, a significant covariate effect of WPT was observed on the effects of UET type on the dependent variables. When WPT was included in the analysis as a covariate, the effect of UET type on accuracy, $F(2,80)=1.32$, $p = 0.274$, and subjective mental workload, $F(2,80)=2.96$, $p = 0.057$, was no longer significant. Also, MANCOVA revealed a significant direct effect of WPT on task accuracy, $F(1,80)=10.90$, $p = 0.001$, that was not hypothesized.

Table 4-43 reports the within-subjects portion of this MANCOVA. When WPT scores were considered as covariates within-subjects, there is no longer a significant effect of the type of BPI on task timelines, $F(2,160)=1.11$, $p = 0.334$, and subjective mental workload, $F(2,160)=2.51$, $p = 0.085$ (compared to the MANOVA results in Table 4-28 that do not include WPT as a covariate).

Table 4-41. Correlations between-subjects relating TLX mental workload to General Cognitive Abilities (WPT) ($n = 87$).

		WPT Score
NASA TLX Mental Workload for interpreting Task-centric BPI	Pearson's Correlation	-.07
	Sig. (2-tailed)	.507
	Sum of Squares and Cross-products	-642.37
	Covariance	-7.47
	n	87
NASA TLX Mental Workload for interpreting Resource-centric BPI	Pearson's Correlation	.06†
	Sig. (2-tailed)	.575
	Sum of Squares and Cross-products	544.71
	Covariance	6.33
	n	87
NASA TLX Mental Workload for interpreting Information-centric BPI	Pearson's Correlation	-.21
	Sig. (2-tailed)	**.049***
	Sum of Squares and Cross-products	-1928.08
	Covariance	-22.42
	n	87
Overall NASA TLX Mental Workload	Pearson's Correlation	-.09
	Sig. (2-tailed)	.424
	Sum of Squares and Cross-products	-675.25
	Covariance	-7.85
	n	87

$^{\dagger}p < 0.10$ $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$ (2-tailed)

Table 4-42. MANCOVA between-subjects results that include the covariate General Cognitive Abilities (WPT scores) (n = 87).

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Accuracy	26699.66	1	26699.66	80.76	.000
	Time	1442806.07	1	1442806.07	76.06	.000
	Mental Workload	48019.89	1	48019.89	89.04	.000
WPT Scores	Accuracy	3604.48	1	3604.48	10.90	**.001*****
	Time	42386.35	1	42386.35	2.23	.139
	Mental Workload	6.99	1	6.99	.01	.910
GPM Type	Accuracy	16086.84	1	16086.84	48.66	**.000*****
	Time	347623.62	1	347623.62	18.33	**.000*****
	Mental Workload	1844.48	1	1844.48	3.42	.068†
UET Type	Accuracy	869.32	2	434.66	1.32	**.274**
	Time	32075.08	2	16037.54	.85	.433
	Mental Workload	3196.39	2	1598.19	2.96	**.057†**
GPM X UET Type	Accuracy	574.81	2	287.41	.87	.423
	Time	56340.11	2	28170.05	1.49	.233
	Mental Workload	2147.18	2	1073.59	1.99	.143
Error	Accuracy	26449.41	80	330.62		
	Time	1517549.53	80	18969.37		
	Mental Workload	43142.68	80	539.28		

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$ (2-tailed)

Table 4-43. MANCOVA tests of General Cognitive Abilities (WPT scores) as covariates (n = 87).

Source	Measure	Sphericity Correction	Type III Sum of Squares	df	Mean Square	F	Sig.
BPI Type	Accuracy	Huynh-Feldt	40.44	1.96	20.69	.07	.928
	Time	Sphericity Assumed	12684.09	2	6342.05	1.11	**.334**
	Mental Workload	Sphericity Assumed	452.19	2	226.09	2.51	**.085†**
BPI Type X WPT Score	Accuracy	Huynh-Feldt	1.44	1.96	.74	.00	.997
	Time	Sphericity Assumed	1719.30	2	859.65	.15	.861
	Mental Workload	Sphericity Assumed	464.15	2	232.08	2.57	**.080†**

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$ (2-tailed)

These results show that WPT scores had a significant effect, but small, on subjective mental workload; however, these results did not show a significant negative correlation. As a covariate, WPT did affect subjective mental workload in relation to UET type and BPI type. Therefore, Hypothesis 7 was partially supported (see Table 4-44). Other direct and covariate effects of WPT were discovered.

Table 4-44. Hypothesis 7 Results

Research Question 7:	*How do user General Cognitive Abilities affect the subjective Mental Workload they experience when interpreting graphical business process information?*	**Result**
Hypothesis 7:	H_7: Participants with high general cognitive abilities will experience significantly lower subjective mental workload.	Partially Supported (indirectly as a covariate)

4.4.8 Hypothesis 8 Results – *Attentional Abilities* and Subjective *Mental Workload*

Hypothesis 8 states that participants' attentional abilities, as assessed by the DAPI, significantly affects the subjective mental workload they experience during task performance. Table 4-45 shows the correlations between individual-level evaluations of DAPI constructs and subjective mental workload. Several negative and significant correlations existed, but the strength of these correlations was small (below r (87) < 0.40). The results from four MANCOVAs testing each of the four DAPI constructs are described below.

Table 4-45. Correlations between-subjects relating TLX mental workload to DAPI assessments of attentional abilities (n = 87).

	NASA TLX Mental Workload - Task-centric BPI	NASA TLX Mental Workload - Resource-centric BPI	NASA TLX Mental Workload - Information-centric BPI	Overall NASA TLX Mental Workload
DAPI Moderate-Focus	-.196	-.218*	-.267*	-.262*
DAPI Extreme-Focus	-.071	-.022	-.135	-.088
DAPI Dual Cognitive-Physical Tasks	-.269*	-.215*	-.235*	-.276**
DAPI Dual Cognitive-Cognitive Tasks	-.144	-.271*	-.214*	-.242*

†p < 0.10 *p < 0.05 **p < 0.01 ***p < 0.001

<u>DAPI Moderately-Focused Attention</u>: There was no direct significant effect of DAPI Moderately-Focused Attention on subjective mental workload, $F(1,80)=2.30$, $p = 0.134$. However, when taken as a covariate, there was no longer a significant effect of the type of UET on subjective mental workload, $F(1,80)=2.03$, $p = 0.139$, compared to when this covariate was not taken into account. This result was interesting because without including this construct covariate, there was a significant effect due to UET type on subjective mental workload (compare Table 4-26 to Table 4-46). No within-subjects covariate effects were found to be significant. Thus, Hypotheses 8.1 was partially supported, because DAPI Moderately-Focused attention indirectly affected subjective mental workload as a covariate. Additional results that were not hypothesized include a direct significant effect of DAPI Moderately-Focused Attention on the timeliness, $F(1,80)=5.79$, $p = 0.018$ (see Table 4-46).

<u>DAPI Extremely-Focused Attention</u>: There was no direct significant effect of DAPI Extremely-Focused Attention on subjective mental workload, $F(1,80)=0.55$, $p = 0.460$. However, when taken as a covariate, there was no longer a significant effect of the type of BPI on subjective mental workload, $F(2,80)=0.693$, $p = 0.502$, compared to when this covariate was not taken into account. The between-subjects MANCOVA remained approximately the same level of statistical significance with this covariate taken into account as compared to when it was not (compare Table 4-26 to Table 4-46). Thus, Hypotheses 8.2 was partially supported, because DAPI Extremely-Focused attention indirectly affected subjective mental workload as a covariate. Additional results that were not hypothesized include a direct significant effect of DAPI Moderately-Focused Attention on the timeliness, $F(1,80)=5.79$, $p = 0.018$. There was no longer a significant effect of the type of BPI on timeliness, $F(2,80)=1.466$, $p = 0.234$, compared to when this covariate was not taken into account (compare Table 4-28 to Table 4-47).

<u>DAPI Dual Cognitive-Physical Tasks Attention</u>: There was a direct significant effect of DAPI Dual Cognitive-Physical Tasks Attention on subjective mental workload, $F(1,80)=5.22$, $p = 0.025$ (Table 4-47). However, when taken as a covariate, there effect of the type of GPM on subjective mental workload was lowered significantly, $F(2,80)=2.55$, $p = 0.114$, compared to when this covariate was not taken into account. The effect of the BPI type on subjective mental workload was also no longer significant, $F(2,80)=0.06$, $p = 0.946$ (compare Table 4-28 to Table 4-47). Thus, Hypothesis 8.3 was supported. Additional results that were not hypothesized include a direct significant effect on timeliness, $F(1,80)=4.68$, $p = 0.034$ (Table 4-47). Also, there was no longer a significant effect of the type of BPI on timeliness,

$F(2,80)=4.31$, $p = 0.015$, compared to when this covariate was not taken into account (compare Table 4-28 to Table 4-47).

Table 4-46. Between-subject MANCOVA results evaluating the covariate DAPI Dual Cognitive-Physical Tasks ($n = 87$).

Source	**Measure**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Intercept	Accuracy	47022.43	1	47022.43	125.94	.000
	Time	1748175.71	1	1748175.71	94.90	.000
	Mental Workload	75343.68	1	75343.68	148.80	.000
DAPI Dual Cognitive-Physical Tasks	Accuracy	183.15	1	183.15	.49	.486
	Time	86183.24	1	86183.24	4.68	**.034***
	Mental Workload	2642.77	1	2642.77	5.22	**.025***
GPM Type	Accuracy	14742.99	1	14742.99	39.49	**.000*****
	Time	289696.49	1	289696.49	15.73	**.000*****
	Mental Workload	1290.69	1	1290.69	2.55	**.114**
UET Type	Accuracy	1897.10	2	948.55	2.54	.085†
	Time	20338.83	2	10169.41	.55	.578
	Mental Workload	3236.58	2	1618.29	3.20	**.046***
GPM Type X UET Type	Accuracy	795.77	2	397.88	1.07	.349
	Time	51345.36	2	25672.68	1.39	.254
	Mental Workload	1806.34	2	903.17	1.78	.175
Error	Accuracy	29870.74	80	373.38		
	Time	1473752.64	80	18421.91		
	Mental Workload	40506.90	80	506.34		

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$ (2-tailed)

Table 4-47. Partial within-subject MANCOVA results evaluating the covariate DAPI Dual Cognitive-Physical Tasks (n = 87).

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.
BPI Type	Accuracy	202.53	1.95	104.02	.36	**.694**
	Time	47849.72	2	23924.86	4.31	**.015***
	Mental Workload	10.30	2	5.15	.06	**.946**
BPI Type X DAPI Dual Cognitive-Physical Tasks Attention	Accuracy	445.91	1.95	229.02	.79	.454
	Time	32461.26	2	16230.63	2.93	.056†
	Mental Workload	45.73	2	22.87	.25	.782

†p < 0.10 *p < 0.05 **p < 0.01 ***p < 0.001 (2-tailed)

DAPI Dual Cognitive-Cognitive Tasks Attention: There was no direct significant effect of DAPI Dual Cognitive-Cognitive Tasks Attention on subjective mental workload, $F(1,80)=3.06$, $p = 0.084$. However, when taken as a covariate, there was no longer a significant effect of the type of UET on subjective mental workload, $F(2,80)=2.795$, $p = 0.067$, compared to when this covariate was not taken into account. Other between-subject results were approximately the same as Table 4-26. Hypothesis 8.4 was only partially supported (see Table 4-48).

Consequently, Hypothesis 8 was also only partially supported due to no few direct effects of attentional abilities on subjective mental workload. Yet, there were several covariate effects of attentional abilities on subjective mental workload.

Table 4-48. Hypothesis 8 Results

Research Question 8:	*How does user Attentional Abilities affect the subjective Mental Workload they experience when interpreting graphical business process information?*	**Result**
Hypothesis 8:	H_8: Participants scoring high on attentional abilities will experience significantly lower subjective mental workload during task performance.	Partially Supported (indirectly as a covariate)
	8.1 Participants' that score high on moderate-focus attentional abilities will experience significantly lower subjective mental workload.	Partially Supported (indirectly as a covariate)
	8.2 Participants' that score high on extreme-focus attentional abilities will experience significantly lower subjective mental workload.	Partially Supported (indirectly as a covariate)
	8.3 Participants' that score high on dual cognitive-physical task focus attentional abilities will experience significantly lower subjective mental workload.	Supported
	8.4 Participants' that score high on dual cognitive-cognitive task focus attentional abilities will experience significantly lower subjective mental workload.	Partially Supported (indirectly as a covariate)

Chapter 5 discusses implications of these results in context of the reference literature.

C h a p t e r   F i v e

CHAPTER 5 – DISCUSSION OF RESULTS

The implications of these results are discussed in this chapter. This chapter interprets the results of this experiment in the context of the research purpose and related literature, and presents discussion in the following sections:

Section 5.1: Effect of BPM Cognitive Resources on User Comprehension

Section 5.2: Effect of Individual Cognitive Differences on GPM User Comprehension

Section 5.3: The Relationship between Cognitive Resources and Individual Cognitive Differences on GPM User Comprehension

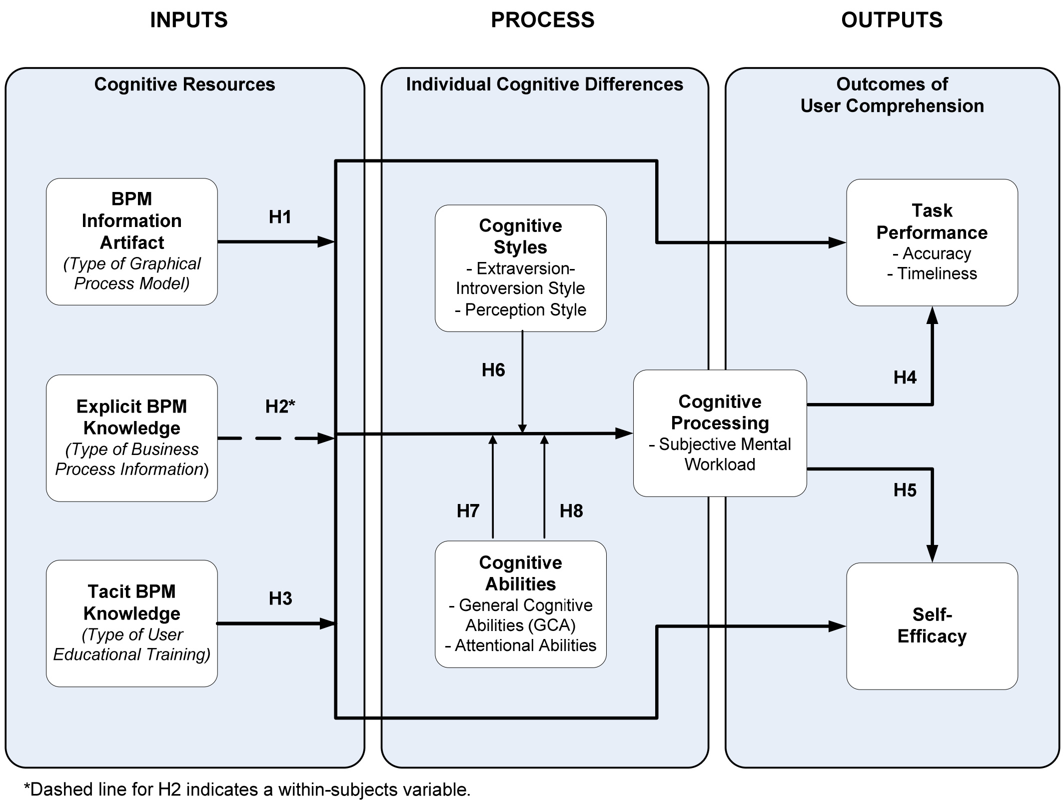


Figure 5-1. GPM user comprehension research model in the context of BPM Systems.

The purpose of this research was to study how BPM cognitive resources and individual cognitive differences affect outcomes of user comprehension in the context of BPM and BPM Systems. Figure 5-1 illustrates the operational research model, developed to answer the following research questions.

This experiment produced some interesting results showing that the type of Graphical Process Model (GPM) significantly affects the performance of participants – with metagraphs producing significantly more positive outcomes of GPM user comprehension. Under different conditions, both the type of User Educational Training (UET) and the type of Business Process Information (BPI) impacted different types of GPM user comprehension. Many of the hypotheses in this study were supported, but specific sub-hypotheses were reversed, only partially supported, or not supported. Exploratory analyses also revealed that the impact of the type of UET and the type of BPI on timeliness and subjective mental workload were more significantly influenced by the individual cognitive differences of general cognitive abilities (GCA) and attentional abilities. Also, many of the key demographics assessed in this study did not significantly affect user comprehension outcomes. This chapter discusses the following research questions (RQs):

RQ1: How do different types of GPM influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?

RQ2: How do different types of BPI influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?

RQ3: How do different types of user educational training influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?

RQ4: When interpreting graphical business process information, does the relationship between user subjective mental workload and task performance follow the Yerkes-Dodson Law (an inverted-U relationship)?

RQ5: When interpreting graphical business process information, how does user subjective mental workload relate to their self-efficacy after task completion?

RQ6: How do user cognitive styles affect the subjective mental workload they experience when interpreting graphical business process information?

RQ7: How do user general cognitive abilities affect the subjective mental workload they experience when interpreting graphical business process information?

RQ8: How do user attentional abilities affect the subjective mental workload they experience when interpreting graphical business process information?

5.1 Effect of BPM Cognitive Resources on User Comprehension

This section discusses the research questions and implications of the experiment results related to the three independent variables that operationalize the three BPM cognitive resources (see Figure 5-1): the type of BPM information artifact (represented by the variable type of GPM), the type of tacit BPM knowledge (represented by the type of UET), and the type of explicit BPM knowledge (represented by the type of BPI).

5.1.1 Type of Graphical Process Model and GPM User Comprehension

Research Question 1: *How do different types of GPM influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*

A primary goal of this study is to investigate which type of GPM is most easily comprehended by novice users. Basu and Blanning (2000) suggest that metagraphs can be easier to comprehend because there are only a few symbols used to model multiple types of business processes and BPI; compared to UML diagrams which use different sets of graphical symbols and grammars to model each different type of BPI. Contrary to Basu and Blanning's proposition, the principle of Ontological Completeness suggests that, once users are trained on the symbols, UML diagrams are easier to interpret than metagraphs because of the one-to-one relationship between the UML symbol and its meaning in the real-world. Because metagraphs use the same small set of symbols to represent multiple real-world BPM meanings, the principle of Ontological Completeness states that metagraphs should cause construct overload and less desirable user comprehension outcomes (Wand & Weber, 1993). The results of this experiment provided clear evidence of the effect of GPM type on user comprehension.

Type of GPM significantly affects every dependent variable studied in this experiment. What is surprising is the direction of these results. Contrary to what is hypothesized, outcomes for metagraph users are significantly more positive than for UML users for every dependent variable: accuracy ($p = 0.00$), timeliness ($p = 0.00$), subjective mental workload ($p = 0.07$), and self-efficacy ($p = 0.02$). All of the sub-hypotheses are rejected, and the opposite of each sub-hypothesis is supported. Therefore, the principle of Ontological Completeness (Wand & Weber, 1993) is not supported, and the supposition put forth by Basu and Blanning (2000) is supported in this experiment. However, there may be several other issues that provide a different explanation for these results.

There are several potential explanations for this outcome. First, the principle of Ontological Completeness is incorrect or valid in only certain circumstances. Second, it is possible that the nature of the experiment itself did not appropriately reflect or test the true meaning of the principle. Third, the level of complexity of the business processes being modeled, in combination with the modeling rules of a specific GPM, impacted user comprehension more than the principle of Ontological Completeness. Finally, there could be a novice vs. expert learning curve between the two GPM types that mitigate the application of this principle. The following paragraphs discuss these explanations in more detail.

5.1.1.1 Principle of Ontological Completeness is Potentially Incorrect

The first and most obvious explanation for these results is that the principle of Ontological Completeness is incorrect. Users were able to interpret the meanings and relationships between the symbols in a more accurate and timely fashion using metagraphs as opposed to UML diagrams. According to the principle of Ontological Completeness, this result should not have happened, and therefore, it is possible that this theoretical principle is incorrect. It is also possible that Ontological Completeness is only valid under specific task conditions, and this bank loan process is not one of those conditions. Further empirical research is needed to discover the limitations of this principle. However, there could be several other explanations for this result that may describe boundary conditions for the application of the principle of Ontological Completeness.

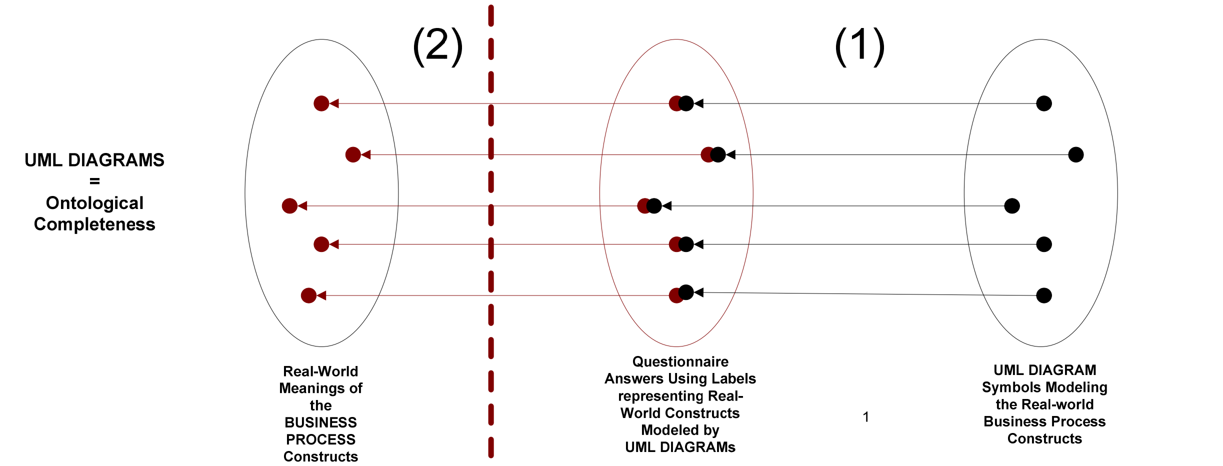
5.1.1.2 What is Specifically Meant by 'Ontological Completeness'

An alternate explanation for these results may be that the participants were not required by the experiment to translate the labels on the GPM symbols into their real-world meanings. During the pilot study and the experiment, participants did not appear to take time to study and understand what the GPM symbols represented in relation to the real-world loan application process being modeled. Participants were verbally instructed in the meanings of the GPM labels, given a handout listing the meanings of GPM symbols and labels, and provided with legends on each GPM diagram explaining the real-world meanings of the GPM labels.

Due to the training, the participants knew that their performance was based on both the timeliness and accuracy of their interpretations and not on their understanding the real-world meanings of the GPM symbols. The questionnaires themselves did not require participants to translate the GPM symbol labels into their real-world meanings. The answers to the multiple choice questionnaires used the GPM label references and not what the real-world loan application process terminology (see Appendix L.3 for examples of the questionnaires). Therefore, participants' seldom appeared to take the time to look up the real-world business process meanings of the labels and symbols when considering how to answer the questions.

There were two important reasons for formatting the GPMs and the questionnaires in this way. First, space requirements did not permit the use of the real-world terminology of the loan process on or next to the corresponding symbols on the GPMs. This approach was attempted on prototype GPM diagrams, but the addition of the terms made the GPMs appear overly cluttered and confusing when participants tried to identify which label went with which symbol. Consequently, in order to make each GPM as neat and organized as possible, shorter, more generic reference labels were substituted for the real-world terms on the GPMs and a legend explaining the real-world meaning of each reference label was added to each GPM (e.g., T1 = Task 1 = Calculate clients' credit rating) (see Appendices C and D for examples of the legends on the GPMs).

The second reason the GPMs were laid out this way was because the cluttered layout of GPMs using the real-world terminologies appeared to add an extra level of complexity and comprehension that seemed to distort the user comprehension outcomes. If participant questionnaires had included answers containing the real-world terminology of the bank loan application process, user comprehension would consist of two levels of interpretation: from the GPM symbols to the reference labels (see [1] on Figure 5-2) and then from the reference labels to their real-world meanings (see [2] on Figure 5-2). It was feared that asking users to translate from (1) to (2) would add an extra level of user cognition that could distort user comprehension outcomes. This is because it would be unclear if users' accuracy and timeliness results were due to differences between user comprehension during translation between the GPMs symbols and their reference labels ([1] on Figure 5-2), or during translation between the GPM reference labels and their real-world bank loan process meanings ([2] on Figure 5-2), or (3) both.



***(The experiment only required participants to interpret the symbol labels *(dashed line)* and not the meanings of the labels in the real-world.**

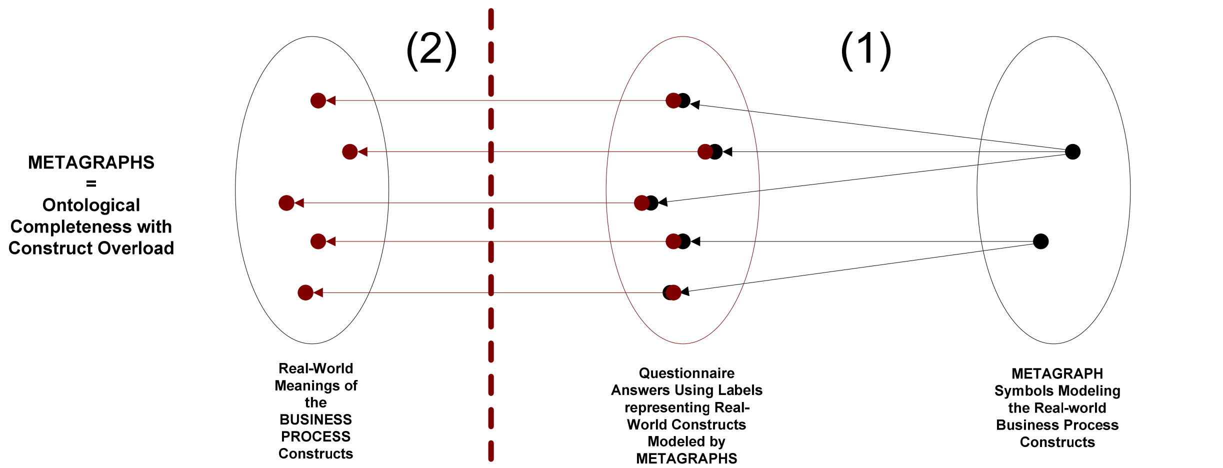


Figure 5-2. This study evaluates user comprehension of Metagraph and UML Diagram constructs only (to the right of the dashed line); not their interpretation back to real-world constructs (across the dashed line)[1].

Since this is apparently the first GPM user comprehension study in the context of BPM Systems, and it appears to be the first study testing the principle of Ontological Completeness in the context of BPM, it was determined that this experiment would be best served by assessing participants' direct interpretations of the labels on the GPMs. Consequently, the experiment questionnaires were purposely designed to use the GPM labels in the answers to minimize the effects of extraneous cognitive variables on GPM user comprehension (see [1] on Figure 5-2). Future experiments can build on these results to study the whether

[5-1] Currently seeking permission to user, although this is my own figure, the symbols are from Wand and Weber (1993).

the principle of Ontological Completeness related to interpreting real-world BPM terminology in the user comprehension of GPMs.

Do these results actually represent "Ontological Completeness"? Does the principle of Ontological Completeness mean (1) it should only be applied to interpreting GPM symbols to their real-world meanings, or (2) should it be applied at each intermediate level of interpretation between the GPM symbols, to their labels, and finally, to their real-world meanings? In describing the justification for the principle of Ontological Completeness, Wand and Webber are clear in stating that 'completeness' means that a graphical grammar (e.g., a GPM) must contain "constructs that enable it to model any real-world phenomenon in which a user is interested" (Wand & Weber, 1993, p. 220). On the other hand, they also state that there are multiple translations that must be made between multiple grammars, scripts, and constructs to achieve a complete model of the real-world. For example, they discuss how users must interpret and translate between the real-world data being modeled, the data flow diagrams, and the program scripts that are written for a database system (Wand & Weber, 1993, p. 223-228).

If the principle of Ontological Completeness is to be interpreted broadly as applying only to the relationships between the GPM symbols and their real-world meanings, then these results did not reject this principle, because this experiment did not require users to interpret GPM symbols back to their real-world meanings. On the other hand, if the principle is to be interpreted more narrowly as applying to each level of translation, then the principle of Ontological Completeness is clearly not supported by these results, because participants' were able to comprehend metagraphs more easily and with more positive outcomes than participants using UML diagrams. At a minimum, the results of this study suggest the possibility that boundary conditions exist for when the principle of Ontological Completeness is valid and how it should be applied. Consequently, further research is required to identify these conditions and define the principle more explicitly, so that it could be applied properly in empirical research.

5.1.1.3 Principle of Ontological Completeness and Participant Motivation

Building on the previous point, a third reason that these results do not support the principle of Ontological Completeness could be participant motivation. Students' performance was motivated by the potential reward and to finish the experiment as soon as possible in order to move on to other tasks in their lives. Students knew they would not have to complete any other tasks with the information they interpreted.

Therefore, despite the training and handouts, participants in the experiment generally did not appear to be interested in learning what the symbols on the GPMs mean.

In the real-world, it is anticipated that users would be just as motivated to finish BPI interpretation as quickly as possible, but for different reasons. Real-world BPM managers know they will need to use in the future the BPI they interpret. Consequently, they would be more interested in understanding the real-world meanings of the diagrams.

If participants were not motivated to comprehend the real-world meanings, has the principle of Ontological Completeness really been tested, or has it only partially been tested? This issue of participant motivation might create a problem with external validity of these results. Thus, the principle of Ontological Completeness should not yet be rejected based on these results. Further research is needed to understand participant motivations for interpretation before rejecting this principle.

5.1.1.4 Level of Complexity and GPM user Comprehension

Because this was the first empirical GPM user comprehension experiment in this context, the level of complexity of the business processes used in the experiment was held constant to allow the direct comparison of the outcomes across different types of GPMs. The level of complexity was controlled in this study by modeling the same business processes in both metagraph and UML diagram formats. Adjustments were made to the level of complexity of the experiment based on the pilot study (see Appendices C, D, E, and F for GPMs illustrating the levels of complexity).

However, the pilot study revealed that the level of complexity of the business process that was modeled may be more predictive of GPM user comprehension than the principle of Ontological Completeness. The pilot study used more complex business processes in the experiment portion of the study. Metagraphs were considerably more difficult to label, lay out, and comprehend compared to UML diagrams. During the pilot study, participants reported metagraphs became a great deal more difficult to comprehend as (1) the number of components increased between the training and the experimental GPMs and (2) as the number of tasks and information components grew large as a small set of resources remained constant (e.g., Figure 5-3). Additionally, when metagraphs became more complex, they were reported to be harder to comprehend because they are circular by nature. As a result, following the connecting lines between components and interpreting the meanings of their labels became hard to interpret (see Figure 5-3).

UML diagrams also became complex, large, and difficult to lay out as the number of components of the business process increased, particularly the activity diagram (e.g., Figure 5-4). However, observations and anecdotal evidence from the pilot study suggested that UML diagrams were easier to interpret than metagraphs as the level of complexity increased, because they were laid out in a more linear fashion compared to metagraphs. Consequently, pilot study participants preferred to interpret UML diagrams, despite the empirical results (see Figure 5-4).

It is possible that the level of complexity of the business process might determine user comprehension outcomes, and may have little or nothing to do with the principle of Ontological Completeness. No empirical literature was found that either supported or rejected these observations about the complexity of UML diagrams vs. metagraphs. Basu and Blanning (2000) assert only that metagraphs are easier to comprehend due to the smaller number of symbols needed to model all different BPI compared to UML diagrams. One reason for this lack of discussion comparing complexity between GPM types is because modeling and control of these business processes is a complex, organizational task that is often nonroutine, difficult, dynamic, and context specific (Kirsch, 1996; Weske, van der Aalst, & Verbeek, 2004). This makes comparisons to other research in information systems, HCI, cognitive ergonomics and BPM Systems literature difficult. Therefore, level of complexity issues in GPM modeling are important to be included and controlled for as an independent variable in future GPM user comprehension research.

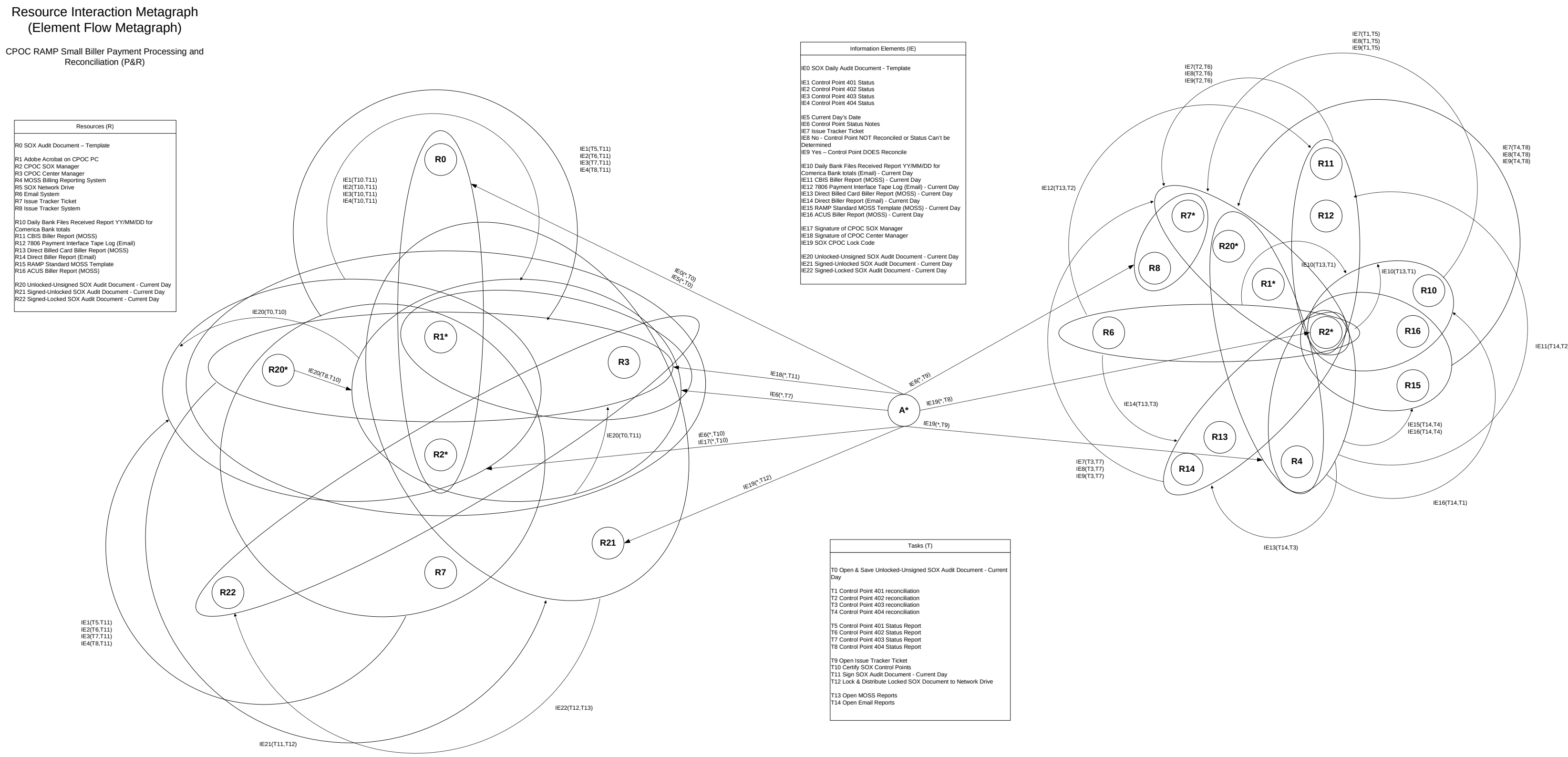


Figure 5-3. Example of how metagraph complexity increases as the number of components increases or one component is central to multiple components.

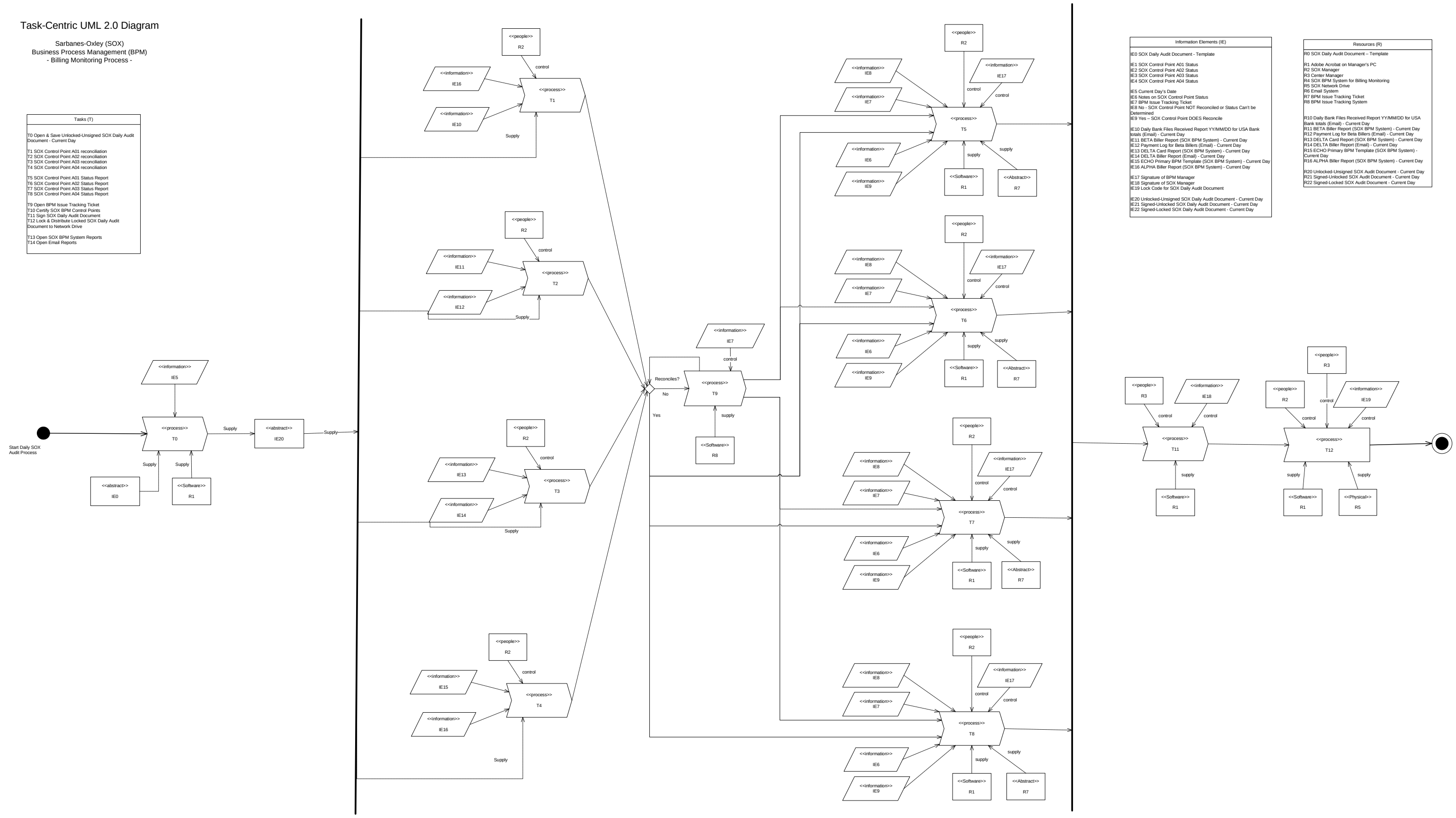


Figure 5-4. Example of how UML activity diagram complexity increases as the number of components increases and resources and information elements are added.

5.1.1.5 Novice vs. Expert Impact on Interpretation of GPMs

A final alternative explanation for these results is that the nature of the experiment itself may not have provided sufficient training time for participants to become educated in the GPMs to properly test the principle of Ontological Completeness. This experiment was set up with the intention of testing novice GPM users that possess little or no experience with interpreting these graph theory formalisms. This was because most BPM System users likely will possess little or no experience interpreting these GPMs on a regular basis. Additionally, this study tested whether novice GPM users with a variety of tacit BPM knowledge could easily comprehend BPI portrayed by these GPMs. If easy user comprehension is possible, the use of these GPMs could improve collaboration among business process managers, BPM decision-making, and the effectiveness of information systems supporting BPM.

In agreement with past literature (Basu & Blanning, 2000; Gou, Huang, Liu, & Li, 2003), during the training phase of the experiment, it was observed that the diversity of UML symbols and their meanings created a far greater learning curve for novice users than was needed by metagraphs users. The experimental results revealed that it took more time for users to be able to comfortably interpret UML diagrams compared to metagraphs.

How 'novice' should a BPM manager be to properly test the principle of Ontological Completeness or to comprehend these GPMs? Literature is nonexistent that describes how much training and experience users should receive to be considered either 'novice" or "expert" in interpretation of metagraphs or UML diagrams. Related literature, such as operations research and the psychology of programming literature, has explored various ways to determine if someone is an expert or not. For example, Shanteau, Weiss, Thomas, & Pounds (2002) proposed the use of the Cochran-Weiss-Shanteau survey instrument in the absence of a "gold standard" for determining expertise in specific domains. In contrast, Winslow (1996) reviewed research related to determining the characteristics of novice vs. expert programmers. However, no research is found to provide specific guidance for this study. Research that combines development of specific GPM expertise characteristics and instruments might be of value in the future, once novice GPM user comprehension is better understood.

In summary, the type of GPM makes a clear difference in GPM user comprehension. Contrary to hypotheses based on the principle of Ontological Completeness, metagraph users produced more desirable results than UML users. However, based on these results, before the principle of Ontological Completeness needs to be further understood it can be discounted. Several other issues should be taken into account, including user motivation, the complexity of the business process being modeled, what specifically determines Ontological Completeness, and what minimal amount of training is valid to still consider someone a ”novice” GPM user.

5.1.2 Type of Business Process Information and GPM User Comprehension

Research Question 2: *How do different types of BPI influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*

5.1.2.1 Explicit BPM Knowledge: Impacts of Different Types of Business Process Information

A variety of research suggests that the type of BPI affects participants' task performance (Basu & Blanning, 2000; Vessey, 1991; Zhang, 1996b). However, the results related to BPI Type were mixed. The hypothesis that the type of BPI significantly affects GPM user comprehension outcomes was only partially supported. Task-centric BPI was more easily interpreted across all types of GPMs and all types of UET. Contrary to sub-hypotheses, resource-centric BPI was the second most easily comprehended.

5.1.2.2 The Limitations of Literature Attempting to Explain Explicit BPM Knowledge Results

Past research provided little guidance to explain these results. The Cognitive Fit perspective (Giordano, 2002; Vessey, 1991) suggests different BPI types are better suited for producing different user comprehension outcomes. For example, user comprehension outcomes for task-centric BPI seemed to produce a better cognitive "fit" in terms of timeliness and subjective mental workload results. Also, it was close to being the best cognitive "fit" for producing the most desirable accuracy results. In contrast. information-centric related BPI is the worst cognitive "fit" in terms of timeliness. However, the cognitive fit model fell short in helping explain these results, because it does not specify why these different types of BPI produced the best or worst "fit" or what are the characteristics of a better or worse "fit".

In similar fashion, Relational Information Display (RID) research suggests that the information perceived (i.e., comprehended) from the GPM should exactly match the information required for user comprehension task performance (Zhang, 1996a, 1997). Therefore, the RID perspective suggests that the reason for the poor information-related BPI results was that there was a poor match between the way the information- centric BPI was portrayed and what information was required by the information-centric BPI portion of the user comprehension task. However, RID literature still does not help explain why there was a good or poor match between the different types of BPI and the user comprehension task nor what are the characteristics of good or poor RID match.

None of the past literature reviewed for this study helped explain these results. The cognitive fit and RID perspectives are too general to explain these results. Neither theoretical approach can take into account other variables that impacted user comprehension, such as past expertise, training, or the cognitive styles of the participants. The best explanation for BPI results appear to be the principle of Ontological Completeness, which would suggest that there are problems with the way individual GPM symbols represent their real-world meanings. However, the principle of Ontological Completeness is not supported in this study. Therefore, future research is needed to understand why different types of BPI affected user comprehension, or is there are variables that combine with BPI Type to produce these results.

5.1.3 Type of User Educational Training and GPM user Comprehension

Research Question 3: *How do different types of user educational training influence user task performance, subjective mental workload, and self-efficacy when interpreting graphical business process information?*

5.1.3.1 Tacit BPM Knowledge: Impacts of Different Types of User Educational Training

The results showed the influence of different types of UET to be mixed. The hypothesis that the type of UET significantly affects GPM user comprehension was only partially supported. No type of UET was shown to be better or worse than any other type of UET across all four of the dependent variables. Additionally, the lack of any statistically significant interaction means that neither type of GPM was easier or more difficult to interpret for any type of UET.

There were differences between two of the types of UET on one or more of the dependent variables, but not across all of them. IE students were significantly more accurate in their user comprehension than either CS or MGT students. This was probably due to the fact that IE students have been trained in modeling and interpreting business processes (using both formal and informal techniques). CS tacit knowledge did not appear to help them as much as IE tacit knowledge. This was possibly because CS students, as a group, were not well trained in object-oriented systems development that could have helped them interpret UML diagrams and possibly even metagraphs (Agarwal, De, & Sinha, 1999; Agarwal, Sinha, & Tanniru, 1996). Thus, they did not appear to perceive the object-oriented relationships in the GPMs. Instead, CS students interpreted the diagrams from a process-oriented perspective, but they did not seem to be as familiar with this perspective as IE students. As anticipated, CS students reported significantly less subjective mental workload and higher average self-efficacy than MGT majors. In complementary fashion, MGT students reported significantly higher subjective mental workload and lower average self-efficacy, but only compared to CS students. Additionally, supplemental exploratory analyses did not contribute to explaining differences between participants and their user comprehension performance (see Appendix O). There were no significant differences in outcomes between students from different universities across different types of UET. There were some minor but statistically insignificant differences between students who did or did not learn English as their first language in user comprehension accuracy and self-efficacy.

5.1.3.2 Discussion of the Literature Attempting to Explain Tacit BPM Knowledge Results

Tacit BPM knowledge related to GPM user comprehension has not been studied experimentally, so no direct comparisons could not be made to past literature to help interpret these results. In general, prior educational training or experience is expected to create mental models or schema that individuals use when performing a new task (Cannon-Bowers & Salas, 2001; Salas & Cannon-Bowers, 2001). The participants in this study unconsciously used their cognitive schemas and mental models to interpret GPMs portraying the different types of BPI. Unfortunately, no single type of UET gave participants the cognitive schemas and mental models that allowed them to perform better than other participants' UET across all dependent variables. There are at least four possibilities:

1. None of the academic disciplines prepared students sufficiently to produce mental models that affect GPM user comprehension outcomes that were better than another discipline. Or, all three of the academic disciplines prepared students equally well.
2. Participant motivation in the lab experiment made a significant difference in UET results. In this study, IE students were required to participate by their course instructor. Instructors of both MGT and CS students from both universities did not want to require them to participate so these students volunteered. Even though results identifying specific types of UET were not clearly significant across all dependent variables, there was no way to distinguish between how

much of their IE, MGT, and CS performance were due to motivation to participate vs. their educational training and experience.

3. Wand and Weber (1993, p. 372) propose that GPM techniques could mitigate expert-novice differences in user comprehension. If true, then the GPMs themselves may mitigate UET and tacit BPM knowledge differences in user comprehension.
4. UET alone did not explain differences in GPM user comprehension. Other variables combined with UET to affect user comprehension outcomes.

Research is needed that addresses ways to identify and assess expert-novice tacit BPM knowledge differences in future empirical GPM comprehension research. Also, issues related to participant motivation in lab and field studies need to be overtly considered in future empirical research. The following sections discuss the joint impact of variables that may interact with tacit knowledge to affect GPM user comprehension.

5.1.4 Joint Effects of BPM Cognitive Resources on GPM User Comprehension

Since no one variable was able to explain all user comprehension outcomes, could these results be explained by jointly considering the impacts of the three BPM cognitive resources? By taking a joint view of how BPM cognitive resources affect user comprehension, these results seem to validate Wand and Webers' (1993, p 372) assertion that GPM techniques may be able to mitigate differences the type of BPI as well as expert-novice differences (i.e., types of UET). While there were significant differences between users with regard to different types of UET and types of BPI, these differences were overshadowed by the fact that metagraph user comprehension was clearly superior to UML user comprehension. Users of metagraphs performed significantly better across every dependent variable: accuracy, timeliness, subjective mental workload, and average self-efficacy. There was no type of UET that proved more "expert" across all types of BPI nor were able to perform better across all dependent variables. Accordingly, it seemed GPM Type might be able to mitigate explicit BPM knowledge and novice-expert tacit BPM knowledge differences, supporting the assertion by Wand and Weber (1993, p 372). This study presents sufficient evidence to justify further research to confirm their proposition and these results.

5.2 Effect of Individual Cognitive Differences on GPM User Comprehension

The following sections briefly discuss the effects of cognitive differences between individuals on GPM user comprehension in the context of related literature.

5.2.1 Subjective Mental Workload and the Yerkes-Dodson Law

Research Question 4: *When interpreting graphical business process information, does the relationship between user subjective mental workload and task performance follow the Yerkes-Dodson Law (an inverted-U relationship)?*

This research question builds on the Yerkes-Dodson law, which asserts an inverted-U relationship between performance and mental workload (see Figure 2-12 in Chapter 2). As a consequence, results of both measures of task performance in this study, accuracy and timeliness, were hypothesized to produce an inverted-U relationship when graphed against NASA-TLX assessments of subjective mental workload. Although cubic trend lines resulted in what appears to be inverted-Us and were found to be statistically significant, they explained only a small amount of variation in both the accuracy or timeliness results. Consequently, these results did not support the Yerkes-Dodson relationship (see Section 4.4.4).

Additionally, a global finding of this experiment was that there was no significant statistical relationship between TLX mental workload and task performance measures. The individual NASA-TLX constructs also did not correlate highly with task performance. This result was in line with Rose et al.'s (2002) study of vigilance tasks[2] and subjective mental workload, which conclude that subjective mental workload and task performance do not always relate to one another (a finding which is also supported by the other researchers they cite). However, Fisher and Ford (1998) found TLX mental workload and its constructs as strong predictors of time on task and learner outcomes (such as accuracy). Rubio et al. (2004) evaluated the methodological and psychometric properties of three different types of subjective mental workload instruments and found TLX mental workload to have acceptable correlations ($r > 0.65$) with their two measures of task performance: time and accuracy. In fact, they concluded by recommending the NASA-TLX be used when the goal is to predict performance, as was hypothesized in this experiment. Therefore, the results of this experiment seem to contradict the majority of research that demonstrated high correlations between TLX mental workload and task performance.

[5-2] A "vigilance task" is a task that requires sustained, concentrated attention over time to complete (Rose et al., 2002).

There are at least three possible explanations for the lack of support for the Yerkes-Dodson law that are found in related literature:

1. The Yerkes-Dodson law is simplistic and empirically unreliable.
2. Task difficulty is often overlooked in Yerkes-Dodson literature.
3. Task-specific mental workload 'signatures' might exist and be a more accurate conceptualization than an inverted-U relationship.

5.2.1.1 The Yerkes-Dodson Law: Simplistic and Empirically Unreliable

The lack of support for the Yerkes-Dodson law is not entirely unexpected. Research tracing the history of the Yerkes-Dodson law from its inception in 1908 until the present, summarized the findings in this way (Teigen, 1994, p. 543):

> "These reanalyses underscore the discrepancy between the schematic, idealized textbook presentations of the [Yerkes-Dodson] 'law', and its more messy empirical and historical basis."

Teigen's (1994) historical analysis of the Yerkes-Dodson law found that Yerkes and Dodson's original research had been adapted over the last century to fit the needs of various researchers and often disregard or ignore the fundamental constructs that Yerkes and Dodson studied. Most alterations and adaptations of Yerkes-Dodsons' work has been to both the meanings of the variables they studied and to the exclusion of task difficulty. As a result, the so-called Yerkes-Dodson, inverted-U relationship has come to be more of a simplified tool for communicating psychological relationships than an empirically verifiable psychological "law" (Teigen, 1994).

Therefore, empirical research has not reliably supported the Yerkes-Dodson law. For example, a study by Hanoch and Vitouch (2004) used the Yerkes-Dodson law to empirically investigate the relationship between the quantity of information available, emotional arousal (i.e., stress), and task performance. They concluded that emotional arousal should not be conceptualized as a unidimensional concept, and that the Yerkes-Dodson law is too simplistic to account for the various cognitive functions and emotional conditions affecting task performance.

Thus, past literature suggests that the lack of empirical support for the Yerkes-Dodson law found in this experiment may be due to the fact that relating a single score for TLX mental workload[3] and a single score for task performance is too simplistic to yield empirically reliable results. Consequently, analyzing the relationship between mental workload and task performance should be broken down into more specific psychological constructs. Yet, there is little evidence to suggest that this adjustment would create an inverted-U relationship.

5.2.1.2 Task Difficulty is Inherent in the Original the Yerkes-Dodson Research

Yerkes and Dodsons' original work included task difficulty in their study of the arousal-performance relationship (Broadhurst, 1959; Teigen, 1994; Winton, 1987). Task difficulty was controlled in this experiment by modeling the same BPI from the same business process to compare different types of GPMs. Because task difficulty was not assessed directly, it is difficult to say if the task was too simple or too complex for individual participants.

There are at least two ways that task difficulty might account for the lack of support for the Yerkes-Dodson relationship in these results: the quantity of information and the type of GPM. Hanoch and Vitouchs' (2004) study increased the difficulty of the tasks by increasing the availability of information to perform their task. They found that having more information available to complete a task is preferable to having less information even if some information is irrelevant to the task.

A second way task difficulty may explain these results is that metagraph characterizations of the business process might simplify the GPM user comprehension task. Similar to Hanoch and Vitouchs' (2004) study, the quantity of information available in the metagraphs in this experiment could have made it easier to interpret metagraphs compared to UML diagrams. UML users experienced more information overload and higher subjective mental workload than metagraph users. Figure 2-12 in Chapter 2 illustrates why metagraphs users performed better than UML diagram users based on Klein (1982, p. 126). Even though they experienced high amounts of subjective mental workload, metagraph users were able to achieve higher levels of performance because metagraph comprehension tasks were perceived as simpler to interpret compared to UML diagrams (see the *simple task* diagram in Figure 2-12). On the other hand, UML diagrams are only able to achieve lower levels of performance compared to metagraph users because a UML

[5-3] A TLX *mental workload* score is a composite of six different constructs adjusted for pairwise comparisons between these constructs (Hart & Staveland, 1988a, 1988b).

diagram was perceived as harder for their novice users to interpret (see the *difficult task* diagram in Figure 2-12).

Prior literature shows mental workload is expected to be higher at the beginning of a task or when there is an expectation of short time frame to complete the task (i.e., high temporal demand) because mental workload wanes during task performance over time (Rose et al., 2002). It is possible that UML diagrams made user comprehension so difficult that participants' mental effort waned more quickly than metagraph users who perceived the task as not as difficult. Concurrently, participants using UML may have felt an increase in temporal demand and inadvertently excluded relevant information necessary for high GPM user comprehension task performance. Therefore, the inherent differences between metagraphs and UML diagrams may have created task difficulty in this experiment.

The difference between the training and experimental GPM user comprehension tasks might have been a third way task difficulty could have affected these results. The experimental task GPMs were far more complex than the training task GPMs because they portrayed a larger quantity of information (Hanoch & Vitouch, 2004). The subsequent increase in mental workload during the experiment task (compared to the training task) may have caused participants to exclude relevant information (Easterbrook, 1959; Teigen, 1994).

In summary, task complexity might have had an important impact on GPM user comprehension of BPI, despite attempting to control for it. Future research is needed to explore these issues.

5.2.1.3 GPM user Comprehension Mental "Signatures"

Another explanation for the lack of relationship between subjective mental workload and task performance in this experiment may be several underlying psychological issues affecting participants. Exploratory factor analysis revealed three underlying factors explaining variation in the TLX mental workload scores (see Table 5-1 and Appendix O.1). These three factors can be summarized as related to participants perceptions of: (1) external and internal stressors, (2) individuals' perception of their performance, and (3) the physical workload required by the task. The nature of the experiment imposed little or no physical workload on participants. Thus, it made sense that participants' would perceive TLX physical workload as separate and unrelated to other TLX constructs. The second factor suggested that as participants' perception of performance rose or fell, so did their level of frustration. The first factor, explaining the most variation in subjective mental workload, related internal stressors and emotional arousal (mental effort and frustration, respectively) with the external stressors felt by participants (mental and temporal demand). Frustration did not load cleanly on a single factor. Instead, it highly aligned with both internal-external stressors (factor 1) and with individuals' perception of their task performance (factor 2).

Table 5-1. Exploratory Factor Analysis showing the loadings of the three factors underlying TLX mental workload results (*n* = 261).

TLX Mental Workload Construct	**Factors 1**	**2**	**3**
Mental Demand	**.81**		
Mental Effort	**.80**		
Temporal Demand	**.67**		
Frustration	**.61**	**.59**	
Perception of Performance		**.89**	
Physical Demand			**.98**

Finding these underlying factors does not mean that the overall TLX mental workload or individual TLX construct scores are invalid. Instead, it is possible that the vigilance tasks in this experiment have a "mental workload signature" - namely, the three factors. As discussed in Chapter 2, a vigilance task is a task that requires sustained, concentrated attention over time to complete (Rose et al., 2002). It certainly appears that there is a GPM user comprehension "mental workload signature" that resembles the vigilance task mental workload signatures reported in previous literature (Rose et al., 2002; Warm, Dember, & Hancock, 1996). These findings may mean that this type of GPM user comprehension task generates specific "mental workload signatures" in participants. Further research with more participants is needed to confirm this conclusion.

5.2.2 Subjective Mental Workload and Self-Efficacy

Research Question 5: *When interpreting graphical business process information, how does user subjective mental workload relate to their self-efficacy after task completion?*

The recent trend towards increased reliance on BPM systems and the GPMs that are critical to their success highlights the need to understand the factors that increase individual manager's confidence in their judgments of interpretations of GPMs. Although there are several statistically significant correlations between average self-efficacy, self-efficacy constructs, TLX mental workload scores, and TLX mental workload constructs, all of these correlations were of little consequence ($r \leq - 0.4$). Exploratory factor analyses, that included TLX mental workload and the nine self-efficacy constructs, confirmed TLX mental workload as unrelated to self-efficacy (see Section 4.4.5 and Appendix O). The TLX mental workload constructs loaded on an entirely separate factor than the self-efficacy constructs that explained the least amount of variation (19.5%). The largest of the three factors, explaining 28.5% of the variation, loaded with all the positively worded self-efficacy questions. The second largest factor, explaining 23.0% of the variation, loaded with the negatively-worded and training materials-related self-efficacy questions.

The reason for these weak results may be partly due to methodological issues, such as: (a) there is no previous self-efficacy research related to the contexts of GPM user comprehension or BPM Systems, (b) there appears to be no GPM self-efficacy assessment instrument that exists, (c) the self-efficacy data collection methodology used in this experiment may have been flawed, or (d) all of the above.

5.2.2.1 Establishing a Baseline for GPM Self-Efficacy in GPM User Comprehension Tasks

No research was found that had studied self-efficacy in the contexts of GPM user comprehension or BPM Systems. Self-efficacy is highly task-specific, meaning self-efficacy refers to what a person perceives their capabilities to be with regard to a specific task (Marakas, Yi, & Johnson, 1998). For example, Wood, Atkins, & Tabernero (2000) found differences between two types of self-efficacy: information search efficacy and information processing efficacy on complex tasks. Staples et al.'s (1999) empirical study concluded there is a difference between remote work self-efficacy and information technology self-efficacy.

Due to the task-specific nature of self-efficacy, the differences between the training and experimental tasks provided no justifiable basis for hypothesizing a relationship between pre- and post-experiment self-efficacy. Because there was no pre-experiment baseline for establishing GPM self-efficacy, this study focused on the antecedents of self-efficacy instead of its effects. In prior research, pre- and post-task self-efficacy assessments are expected to be related because the tasks are similar (Compeau, Higgins, & Huff, 1999; Fagan, Neill, & Wooldridge, 2003; Staples et al., 1999). However, after the pilot study, the training task was changed, and the training tasks and the experimental tasks were fundamentally different. The training task was quite different from the experimental task in purpose, interpretation, and complexity. The purpose of the training task was to expose participants to the meaning of the GPM symbols they would encounter in the experimental task without introducing bias by training them on interpretation of a specific business process. It was decided that providing training on interpretation of a specific business process could bias or confound the experimental results because it might be difficult to determine if participants did not comprehend the GPM symbols or the business process in the experimental task. Finally, the training task was much simpler and far less complex than the experimental task. This meant that the task-specific experience gained during training that created pre-experiment self-efficacy was not appropriate to compare to post-experiment task performance and outcome expectancy.

As a result, past literature does not support creating a link in this study between pre- and post-task self-efficacy assessments. This is not a problem, because a goal of this research was to establish a baseline for GPM self-efficacy in these task contexts. However, the literature does provide other antecedents of self-efficacy that are directly related to TLX mental workload constructs, thus providing a foundation for establishing a baseline for GPM user self-efficacy in the context of BPM Systems.

More research is necessary to confirm these results. Without a baseline self-efficacy evaluation prior to this task, it is difficult to determine whether the task itself impacted self-efficacy. What these results do provide is a baseline for establishing future research and hypothetical relationships regarding self-efficacy in the contexts of GPM user comprehension and BPM Systems.

5.2.2.2 A Task-Specific GPM or BPM Self-Efficacy Instrument is Needed

Building on the previous point, no instrument found in the literature that assesses self-efficacy in the task-specific contexts of this study._Consequently, the nine self-efficacy question items used in this experiment are adapted from a well-established computer self-efficacy instrument (Compeau & Higgins, 1995; Compeau et al., 1999; Johnson & Marakas, 2000). Therefore, the lack of support for this hypothesis could be due, in part, to the lack of a self-efficacy instrument validated for this GPM user comprehension task. Lee & Bobko (1994) compares self-efficacy assessment methodologies and could provide valuable guidance in developing such an instrument. Future research will benefit from the development of a specific instrument for GPM user comprehension or BPM Systems self-efficacy contexts.

5.2.2.3 The Self-Efficacy Data Gathering Methodology May Be Flawed

Finally, these results can be due to the way the GPM user self-efficacy and TLX mental workload data were gathered and calculated. The TLX mental workload constructs were evaluated at three points within-subjects after each BPI Type. In contrast, self-efficacy was assessed between-subjects. This was in keeping with past research that typically assesses self-efficacy once during an experiment (usually pre-experiment) or sometimes twice (pre-experiment and post-experiment) (Compeau et al., 1999; Fagan et al., 2003; Staples et al., 1999). Because self-efficacy was assessed post-task, it was conceptualized in this research as an outcome of task performance. The GPM user comprehension task was not considered complete until a participant interpreted all three types of BPI. Therefore, self-efficacy was evaluated as the last assessment before participants completed the experiment. Although logical, this between-subjects self-efficacy data gathering strategy may have produced data that was not adequate to compare to each of the within-subjects TLX mental workload scores. In future research, self-efficacy should be assessed at the same time as subjective mental workload (i.e., three times within-subjects in this experiment) to address this issue.

In summary, this study has established specific characteristics for a GPM user comprehension task and has gathered post-experiment self-efficacy results. Future research could extend this study by:

1. Continuing to extend the self-efficacy literature to the context of BPM and GPM user comprehension tasks.
2. Hypothesizing a relationship between self-efficacy and GPM user comprehension task performance based on training using similar tasks.
3. Developing and validating a GPM user self-efficacy assessment instrument and determine under what task-specific circumstances this instrument is valid.

5.2.3 Cognitive Styles and Subjective Mental Workload during Task Performance

Research Question 6: *How do user cognitive styles affect the subjective mental workload they experience when interpreting graphical business process information?*

Correlation analysis did not result in any statistically significant correlations between TLX subjective mental workload, its constructs, and continuous MBTI scores for either the extroversion-introversion or sensing-intuitive cognitive styles. MANCOVAs testing these cognitive styles as covariates did not find them statistically significant in their effect on subjective mental workload.

5.2.3.1 Literature Fails to Explain the Cognitive Style vs. Mental Workload Results

This was a surprising finding because neuroscience, cognitive psychology, and MBTI literature predict that such a relationship exists (Rose et al., 2002, p. 198). Rose et al. (2002) cite several personality studies predicting participants scoring high on extroversion will perform worse on vigilance tasks with low stimulation (i.e., tasks requiring a high degree of concentrated attention for a significant period of time) which is similar to the experimental conditions of this study. Eysenck's and Gray's research on the biological basis of personality propose that introverts are more cortically aroused than extroverts. As a result, introverts should perform better on vigilance tasks that typically have low stimulation (Eysenck, 1967; J. A. Gray, 1987; J. R. Gray & Burgess, 2004; Patterson & Newman, 1993). Thus, introverts should have experienced less mental workload in performance of these experimental tasks, but this did not occur (cf. Avila, 2001; Chi et al., 2005; Gable, Reis, & Elliot, 2000; J. A. Gray, 1987; J. R. Gray et al., 2005; Hewig, Hagemann, Seifert, Naumann, & Bartussek, 2006; Jorm et al., 1999; Sutton & Davidson, 1997).

There was a similar lack of explanation for the sensing-intuitive cognitive style in the literature. According to Gardner and Martinkos' (1996) review of MBTI literature, sensing vs. intuitive research has produced mixed results. On the one hand, participants with MBTI scores leaning toward sensing are expected to expend less subjective mental workload than intuitives in learning tasks. Participants scoring higher on the sensing dimension should lose details when overwhelmed with information, be less frustrated with losing information, and only try to comprehend enough information to answer each question (Barkhi, 2002; Gardner & Martinko, 1996; Rubio et al., 2004), and thus, experience less subjective mental workload. Participants scoring higher on the MBTI intuitive side of the scale should prefer abstract summaries that stress possibilities, try to holistically gather and understand all of the information presented when answering the questionnaires, and as a result, experience more subjective mental workload than participants scoring higher in sensing. On the other hand, Gardner and Martinko (1996) cite several studies that show that intuitives were expected to prefer graphically-oriented information while sensors prefer raw data. Therefore, the literature does not help explain these non-significant results.

Obvious explanations for why these results contradicted the cognitive styles literature pointed to several possibilities: (1) there is not enough data to be significant, (2) student MBTI data in a lab experiment is not valid when performing tasks that involve interpreting BPI, or (3) using continuous scores based on MBTI Form F for the extroversion-introversion and sensor-intuitive cognitive styles are not sensitive enough instruments to produce reliable data. Although each of these alternatives is possible, it is also possible the GPMs may mitigate the effect of cognitive styles on user comprehension.

5.2.3.2 GPMs May Mitigate the Impacts of Cognitive Styles in GPM user Comprehension

In the same way that Wand and Weber suggest that GPMs may mitigate expert-novice differences in task performance, it may be the case that GPMs negate, minimize, mitigate, or compensate to some extent for the effects of MBTI cognitive styles on subjective mental workload. For example, MBTI sensors may find the graphical portrayals of BPI a logical way to organize and access the raw data. GPMs may also allow them to easily neglect superfluous information, find the required data relationships quickly, and comprehend just the relationships needed. As a result, MBTI sensors may not experience an excessive amount of subjective mental workload.

On the other hand, even though the actual amount of information may be overwhelming and trigger intuitives' BIS, the graphical format might help them feel more comfortable, allow them to withdraw inward to mentally process the information, while at the same time satisfy their need to holistically view the process. The graphical nature of GPMs may also appeal to MBTI intuitives preference for visualizing the big picture, and yet still allow them to easily drill down to the details without being overwhelmed by the information. As a result, their BIS system may not be triggered as quickly or to as great a degree as they might have otherwise experienced when confronted by another format for portraying the same amount of information. As a consequence, intuitives might experience significantly less subjective mental workload or an amount of mental workload comparable to sensors.

GPMs might also appeal to MBTI extroverts. Although GPMs may not stimulate extroverts' BAS as much as seeing or experiencing the real-world business process, GPMs do allow extroverts to visualize, touch the graphic to trace relationships, and give them something external to talk about with associates. Also, the extrovert cognitive style may be less susceptible to activating their BIS when using GPMs, and when activated, it may be activated to a lesser degree compared to introverts in the same situation.

Therefore, the combination of the GPM format and the nature of extroverts, introverts, sensors, and intuitives may actually create a middle ground for GPM users such that the subjective mental workload they experienced was not significantly different from the mental workload experienced from any of the other cognitive styles. If this is the case, it would be the most desirable outcome for GPM user comprehension. GPMs may allow the most efficient and effective user comprehension and possibly facilitate communication across participants with a variety of cognitive styles. Obviously, more research is required to confirm this supposition.

5.2.4 General Cognitive Abilities and Subjective Mental Workload during Task Performance

Research Question 7: *How do user general cognitive abilities affect the subjective mental workload they experience when interpreting graphical business process information?*

The findings showed GCA to have a significant impact on GPM user comprehension outcomes second only to GPM Type. Because GCA only affects subjective mental workload (in relation to BPI Type), the original hypothesis is only partially supported. There are four interesting findings related to GCA, three of which were not hypothesized but have important implications for GPM user comprehension.

5.2.4.1 GCA Affects Subjective Mental Workload

First, when considered as a covariate, GCA renders non-significant the effect of BPI Type on subjective mental workload. This suggests that the effect of BPI Type on mental workload are explained by variations in participants' GCA. This covariate effect was not manifest in the effects of GPM Type and the type of UET on subjective mental workload.

5.2.4.2 GCA Negates the Affects of BPI and UET on GPM User Comprehension

Second, GCA acted as a covariate that negated the effect of the type of UET on task accuracy and effect of BPI Type on task timeliness. Furthermore, variations in WPT scores have a direct, highly significant effect on task accuracy. Figure 5-5 shows the average WPT score and illustrates participants with higher than average WPT scores tended to produce higher task accuracy results. Also, GCA significantly affected three of the four dependent variables and negated the effect of two of the three independent variables.

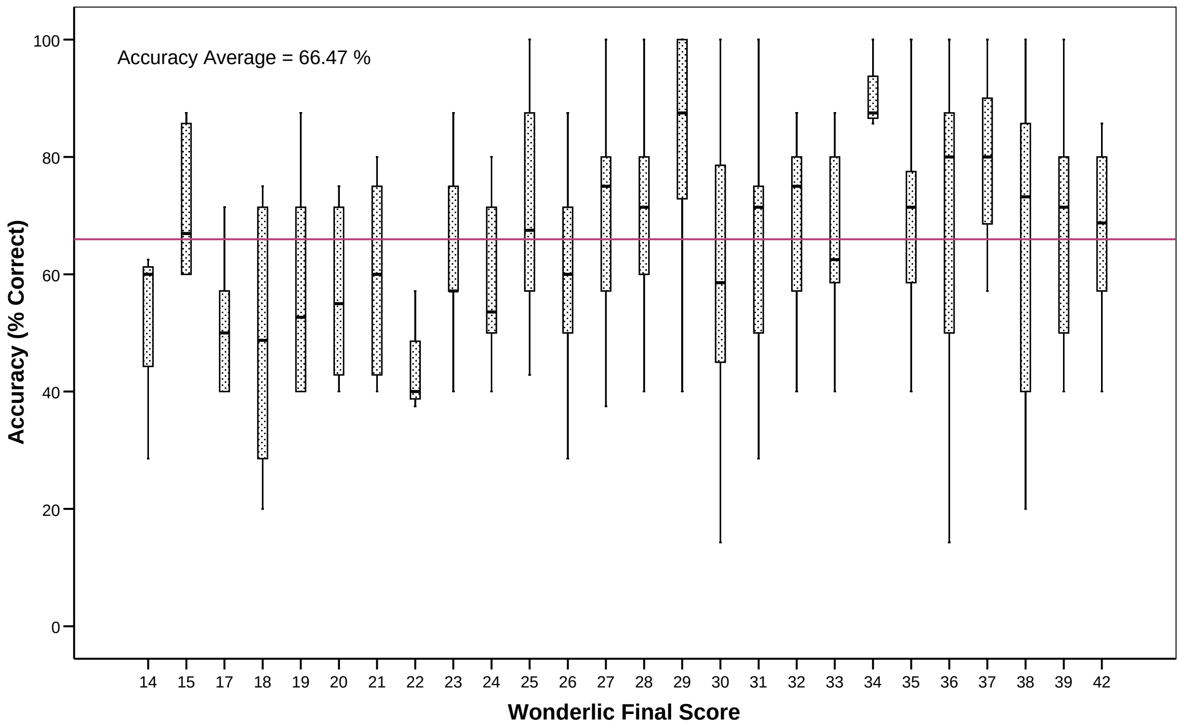


Figure 5-5. The accuracy of task performance is higher above the average accuracy for participants with higher WPT scores.

5.2.4.3 General Cognitive Abilities: A Possible GPM User Comprehension Task 'Signature'

In the context of GCA literature, these results are similar to Fisher and Fords' (1998) findings on the differential effects of WPT on learning outcomes. Their study showed that participants' accuracy on knowledge tests are a function of GCA and timeliness. This is important because recent debates about the validity of GCA compared to individual cognitive aptitude tests have shown that GCA tests, like the WPT, have much higher validity than narrow cognitive aptitude tests, especially in job performance contexts (Schmidt, 2002). Therefore, the GCA results in this experiment may be more valid than other narrow cognitive aptitude tests.

In addition, Woodcock (2002), well-known for research into both the broad and narrow cognitive aptitudes, states that the purpose of cognitive testing is to tell more about the task than an individual's IQ. Thus, these GCA results may reveal important information about GPM user comprehension tasks. These GCA results may suggest a cognitive abilities profile or "signature" that can be used as a basis for comparing participants and GPM user comprehension tasks across future studies. This is an interesting and important topic to explore in future research.

5.2.5 Attentional Abilities and Mental Workload during Task Performance

Research Question 8: *How do user attentional abilities affect the subjective mental workload they experience when interpreting graphical business process information?*

In this experiment, attentional abilities were shown to have a significant effect on subjective mental workload supporting most of the sub-hypotheses. Three out of four constructs had either direct or covariate effects on subjective mental workload which was in line with cognitive psychology research. Rose et al. (2002) specifically studied the relationship between the five most studied personality factors, subjective mental workload, and task performance on vigilance tasks (Rose et al., 2002). They found that only extroversion and conscientiousness (i.e., attention) had significant effects on subjective mental workload and cognitive vigilance task performance. Additionally, Rubio et al.'s (2004) study on the validation of subjective mental workload instruments found that the evaluation of attentional abilities in conjunction with subjective mental workload was an important predictor of cognitive task performance (i.e., accuracy and timeliness). Also, these results showing various DAPI constructs were related to the timeliness of task performance are in line with several studies relating conscientiousness or attention to time on task (Rose et al., 2002).

Although not hypothesized, it is not surprising that the DAPI construct Dual Cognitive-Physical Tasks Attention had a strong effect on timeliness and subjective mental workload. There are several studies that show even small amounts of physical activity have am impact on cognition (Hillman et al., 2006; Lieberman et al., 2005; Lyons & Crawford, 1997). The experimental task itself was not physically demanding, although participants did have to stand to interpret the GPMs mounted on the walls. Almost all of the students wrote their answers to the questionnaires using clipboards while standing.

In summary, it appears that attentional abilities impacted timeliness and subjective mental workload, but had only a small effect on task accuracy.

5.2.6 Integrating Individual Cognitive Differences and their Impacts on User Comprehension

How should these results testing individual cognitive differences be integrated to understand their effects on GPM user comprehension? Hypotheses testing the expected moderators of subjective mental workload (i.e., the cognitive styles and cognitive abilities of the participants) yielded interesting and somewhat unexpected findings. Despite several non-significant results, two outcomes of individual cognitive differences are important to consider in future research.

First, these results suggest a way of identifying a task-specific subjective mental workload "signatures" for GPM user comprehension tasks. The cognitive abilities of participants had the second highest effect (behind GPM Type) on subjective mental workload, self-efficacy, and task performance. GCA either moderated (as with UET and BPI) or directly impacted task accuracy. Attention directly impacted timeliness and mental workload. (Therefore, GPMs may mitigate cognitive styles and cognitive abilities might have the great impact on performance and mental workload after GPMs.) More research is needed to confirm these GCA results and identify the narrow cognitive aptitudes associated with GPM user comprehension tasks. In the future, when combined with the GCA results, these narrow cognitive aptitudes may be able to be used to create task-specific, cognitive-ability "signatures."

Second, in exploring reasons for this result, several methodological explanations, the BIS/BAS, personality, and MBTI literature led to the supposition that these GPMs may mitigate or minimize the polarizing effects of MBTI cognitive styles on subjective mental workload and task performance. Future research is needed to confirm this conclusion. If proven correct, this "nonresult" may be the most desirable result from a GPM user comprehension perspective, because it would mean that the graphical portrayal of BPI allow a variety of users with different cognitive styles to comprehend the information equally well. This could lead to improved BPM and BPM Systems development and utilization.

5.3 THE RELATIONSHIP BETWEEN COGNITIVE RESOURCES AND INDIVIDUAL COGNITIVE DIFFERENCES DURING GPM USER COMPREHENSION

The type of GPM had the most impact of any other factor on the dependent variables in this study. However, if only BPM cognitive resources were taken into account, the results would suggest that the type of UET and type of BPI had significant effects on the dependent variables in this experiment. In reality, by introducing variables representing key individual cognitive differences, it was shown that many of the effects of BPM cognitive resources were moderated by the GCA and attentional abilities of the participants. On the other hand, if only individual cognitive differences were studied in this experiment, the effects of different types of GPMs, for example, would not have been found. Therefore, research involving user comprehension needs to account for both BPM cognitive resources and individual cognitive differences if valid results are to be found.

From a joint perspective, these results seems to validate Wand and Weber's (1993) call for research that include the effects of conceptual models, differences in user cognitive abilities and cognitive styles, and how modeling techniques can mitigate expert-novice differences in GPM user comprehension. What literature there is that compares cognitive resources (e.g., BPM information artifacts, tacit knowledge, and explicit knowledge) to user comprehension outcomes often disregards the individual cognitive differences and psychological components of cognition operating within the mind of the GPM user. Future directions and conclusions are proposed in Chapter 6.

Chapter Six

CHAPTER 6 – CONCLUSIONS AND FUTURE DIRECTIONS

This research has empirically studied the extent to which graphical process models (GPMs) facilitate user comprehension of Business Process Management (BPM) cognitive resources despite cognitive differences between individuals. These components were incorporated into a theoretical framework that allowed the testing of the relationships between these components using a laboratory experiment.

This chapter summarizes and integrates the conclusions of this study. It also discusses the limitations of this study, proposes future research directions, and discusses the implications of this study for the reference literature.

6.1 CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This section summarizes the key conclusions of this study.

6.1.1 The Impacts of the BPM Information Artifact: the Type of Graphical Process Model

This study found that the type of GPM had the greatest effect on user comprehension of business process information (BPI). Contrary to the principle of Ontological Completeness, these results clearly demonstrated that metagraphs were easier for novice users to accurately comprehend in a timely manner compared to UML diagrams of the same BPI. Furthermore, using metagraphs produced less subjective mental workload and greater self-efficacy than users of UML diagrams for the participants in this study.

Although the principle of Ontological Completeness was not confirmed under the conditions in this experiment, it is not disproved. Several issues should be taken into account in future research, such as: (1) how to specifically and practically determine Ontological Completeness, (2) user motivation, (3) the complexity of the business process being modeled, and (4) the minimal amount of training to be considered a “trained” but still “novice” user. For example, this experiment primarily explored an individual's ability to interpret graph theoretical formalisms and the relationships among their respective symbology not necessarily the interpretation of GPM symbols to their real-world meanings. These issues should be taken into account in future GPM user comprehension research before the principle of Ontological Completeness can be either understood or discounted. At a minimum, boundary conditions for when, or if, the principle of Ontological Completeness is valid should be explored.

6.1.2 The Impact of Explicit BPM Knowledge: The Type of Business Process Information

As mentioned earlier, this study focused on user comprehension of GPM symbols representing different types of BPI, and not necessarily the interpretation of these symbols in relation to their meaning in the real-world. Given this delimitation, this study showed that task-centric BPI were easiest for all types of users to comprehend. These results showed that, in general, most people possess some knowledge about how to interpret task-centric BPI, such as flowcharts, but not the other types of BPI. Resource-centric BPI portrayed by these GPMs facilitated worse task performance, in terms of timeliness and mental workload, compared to other types of BPI. However, comprehending resource dependencies and information flows is critical to successful BPM facilitated by BPM systems.

6.1.3 The Impact of Tacit BPM Knowledge: The Type of User Educational Training

While there appeared to be some differences due to different types of user educational training (UET), neither industrial engineering (IE), computer science (CS), nor business management (MGT) students performed significantly better than another across all dependent variables associated with GPM user comprehension in this study. In agreement with Wand and Weber's (1993, p. 372) proposition, this study seems to illustrate that the type of GPM might be able to mitigate expert-novice tacit BPM knowledge differences in GPM user comprehension of BPI. This study presented sufficient evidence to justify further research to confirm this conclusion.

Additionally, motivation of the participants in a lab experiment may have been an issue in this study. Therefore, GPM user motivation, whether in students or BPM managers, needs to be explored and compared. In this study, participation was both required and voluntary, depending on the student. In the real-world, the use of BPM Systems is usually not voluntary. Organizations typically require managers to use these enterprise-level information systems in their daily work. Thus, a combination of lab and field empirical research is needed to further understand the impact of tacit BPM knowledge on user comprehension.

6.1.4 The Impact of Subjective Mental Workload on Task Performance

In this study, there did not appear to be a significant relationship between subjective mental workload and GPM user comprehension outcomes. There was no Yerkes-Dodson inverted-U relationship between subjective mental workload, its constructs, and task performance. This is not a surprising finding based on the empirical research related to the Yerkes-Dodson law. However, most of the research based on the Yerkes-Dodson relationship does not include the variables and issues Yerkes & Dodson originally studied when they proposed their relationship. Therefore, it is difficult to know if the Yerkes-Dodson law is an actual, theoretical law or an over-simplified tool for the communication of general psychological relationships. Because this study did not support Yerkes-Dodson, this study supports prior research suggesting the Yerkes-Dodson law is overly simplistic and other issues affect this relationship. This law contributes an important starting point for creating hypotheses and analyses that relate subjective mental workload and GPM user comprehension task performance.

Another interesting finding was that the exploratory factor analyses revealed three factors underlying participant assessments of the six NASA TLX mental workload constructs. Finding these underlying factors suggests that there may be GPM user "mental workload signatures" (Rose, Murphy, Byard, & Nikzad, 2002; Warm, Dember, & Hancock, 1996). Further research with more participants is needed to confirm this conclusion.

Finally, most research citing the Yerkes-Dodson relationship fails to include task complexity as Yerkes and Dodson did in their original research. Despite controlling for task difficulty in this study by modeling the same business process with both GPM Types, task complexity did appear to have an important impact on GPM user comprehension. The inherent differences between metagraphs and UML diagrams created differing amounts of complexity in this experiment. The experimental task GPMs were far more complex than the training task GPMs because they portrayed a larger quantity of BPI (Hanoch & Vitouch, 2004). The subsequent increase in emotional arousal due to the increased mental workload (compared to the training task) may have caused participants to exclude relevant information (Easterbrook, 1959; Teigen, 1994). Future research is needed to study these issues in greater depth than was accomplished in this research.

6.1.5 The Impact of Subjective Mental Workload on Self-Efficacy

This study provided a baseline for relating GPM self-efficacy to user comprehension task performance in the context of BPM Systems. Although, statistically significant relationships were not found between subjective mental workload and self-efficacy, this study makes a contribution to this literature by exploring mental workload as an antecedent to self-efficacy. Thus, it serves to provide an initial baseline for future research and to extend the self-efficacy literature to the contexts of BPM Systems and GPM user comprehension tasks. Self-efficacy in the context of BPM has not been studied before, and should be a component in future GPM user comprehension research.

The current research model should be revised based on these results by deleting the hypothesized relationship between self-efficacy and subjective mental workload. Instead, self-efficacy should be included as an antecedent of cognition that affects subjective mental workload in order to test a hypothesized link from task performance to self-efficacy.

Because self-efficacy is task-specific, task-specific BPM System and GPM user comprehension self-efficacy instruments need to be developed. Also, self-efficacy should be assessed at the same time as subjective mental workload, either within-subjects or between-subjects. Self-efficacy should be assessed after training (pre-experiment), as was done in this study, but BPM training tasks should be given to participants that are as complicated and similar to the experimental tasks. Subsequent analyses can then study the relationships between both outcome expectancy and self-efficacy in relation to GPM user comprehension.

6.1.6 Cognitive Styles as Moderating Factors: Extroversion-Introversion and Sensing-Intuition

Using continuous MBTI data allowed extensive analyses of cognitive styles in relation to subjective mental workload and task performance. Yet, this study concluded that neither the MBTI extroversion-introversion nor sensing-intuitive dimensions significantly affected subjective mental workload or task performance of the participants. Although this result was puzzling, BAS, BIS, personality, and MBTI literature suggests that it was possible that the nature of GPMs portraying BPI may have minimized or negated the impact of these cognitive styles on subjective mental workload and task performance. This conclusion needed further investigation, but if substantiated, it could be an important finding that may facilitate improved GPM user comprehension, collaboration, system development, and BPM System usage.

6.1.7 Cognitive Abilities as Moderating Factors: General Cognitive Ability

Cognitive abilities played a significant role in affecting subjective mental workload in this research, as well as other GPM user comprehension outcomes. For example, General Cognitive Abilities (GCA) had a significant effect on GPM user comprehension, second only to the type of GPM. GCA significantly affected user comprehension task accuracy. GCA also seemed to negate the effect of UET on task accuracy, as well as the effect of the type of BPI on both task timeliness and subjective mental workload. This suggests that GCA is the real underlying factor that covaried with BPI and UET to make them statistically significant when they were originally analyzed.

6.1.8 Cognitive Abilities as Moderating Factors: Attentional Abilities

This was the first study to include attentional abilities and the first application of the DAPI (Crawford, Brown, & Moon, 1993; Lyons & Crawford, 1997) in the context of information systems or GPM user comprehension and BPM literature. Attentional abilities were found to significantly affect task timeliness and subjective mental workload of participants. Future research is recommended to include attentional abilities as a separate construct affecting GPM user comprehension.

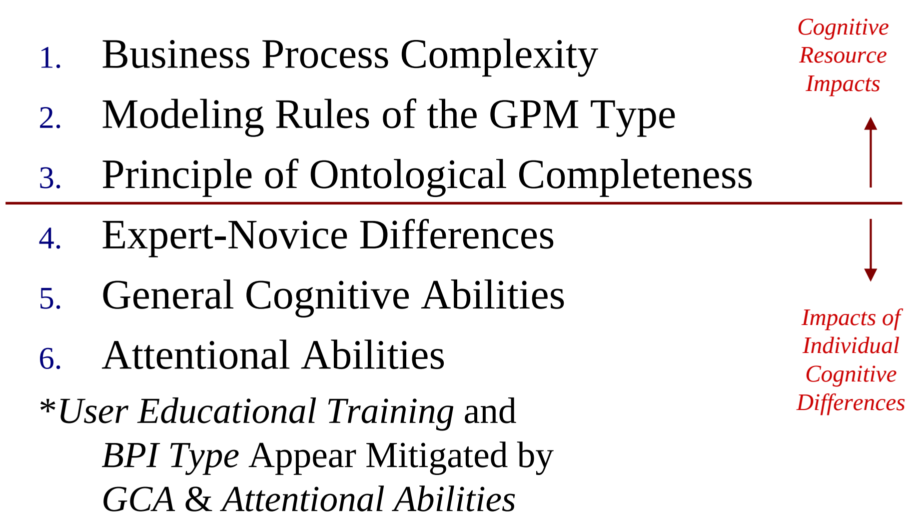


Figure 6-1. Integrating individual conclusions: the hierarchy of factors affecting GPM user comprehension.

6.1.9 Integration of Research Findings

In summary, Figure 6-1 summarizes how the findings of this study are integrated to increase academic and practitioner understanding of GPM user comprehension in the context of BPM Systems. Although the type of GPM had the most impact of any other variable on the dependent variables in this study, the pilot study revealed that the complexity of the process itself had the most influence GPM user comprehension. The specifics of the business process determine how the GPM modeling rules and syntax are applied to create the graphical representation of the BPI. The more complex a process is, the more difficult it is to model and lay out given the GPM syntax. The resulting graphical representation of the business process is then comprehended by the user. Metagraphs were clearly easier for users to comprehend than UML diagrams of the simple business process used in this experiment, contrary to the principle of Ontological Completeness. However, given the process complexity and GPM syntax considerations affecting the graphical representations, it is uncertain whether this experiment actually tested the principle of Ontological Completeness. In summary, cognitive resources related to the business process and aspects of types of GPM were the most important factors affecting GPM user comprehension.

By including individual cognitive differences in this experiment, it was discovered that the impacts of UET and BPI were mitigated by both the GCA and attentional abilities of the participants. Additionally, although not hypothesized, it was discovered that the GCA of participants directly affected task accuracy. Therefore, cognitive differences between individuals were discovered to be secondary to the impacts of GPM type but critical to understanding GPM user comprehension.

This study illustrates the advantage of a theoretical framework that integrates both the key cognitive resources and individual cognitive differences to study GPM user comprehension. If only BPM cognitive resources were included in this experiment, the research would have shown that the type of UET and BPI, in addition to the type of GPM, significantly affects GPM user comprehension. On the other hand, if GPM user comprehension were studied from only a cognitive science perspective, this experiment would suggest that participants' cognitive abilities were the cause of variation in user comprehension outcomes. Past studies that have attempted to integrate cognitive resource and individual cognitive differences apparently have been limited and do not account for all the variables included in this study. The theoretical framework was developed using concepts from Activity Theory and Distributed Cognition theory, and the research model extended these theories to empirical and experimental research identified as necessary to advance these theories. Therefore, this integrated theoretical framework and experiment provides an important contribution to be used as a benchmark for comparison of past and future research.

6.2 LIMITATIONS OF THIS RESEARCH

The conclusions of this study were limited due to participants being third and fourth-year university students. Another limitation of using students is the cognitive complexity issues stemming from the typically younger age of student participants compared to the ages of typical BPM managers (Hendrick, 1984). However, student subjects provided the most logical means of attempting experimental control given the diversity of business processes, the tacit knowledge diversity of real-world BPM managers, and the fact that academic education provided a measure of control of tacit knowledge. Students also provided a population of novice users with relatively no experience and limited bias toward specific BPM tasks, business processes, or the GPMs used in BPM Systems.

Several methodological issues were also found to be limitations of this study. For example, GPMs are typically viewed in BPM Systems using computer screens, but in this study, participants studied the GPMs printed on paper and posted on a wall. Computer screens were not used to portray these GPMs so that screen size and scrolling issues would not add time and manipulation effects that would hinder user comprehension. Another methodological issue is that participants were only required to interpret GPM symbols and not the real-world business process terminology that the symbols represented.

Lastly, the complexity of the business process might have limited or affected user comprehension. The GPMs used in the experiment portrayed a relatively simple business process – a bank loan application process – first published as an illustration of how metagraphs can be applied to BPM and workflow management systems. This process was chosen to minimize modeling mistakes in the experiment and because there were limited examples in the literature that illustrate how metagraphs can be applied to model multiple BPI perspectives. Although GPM complexity was controlled and not explicitly tested in this experiment, GPM user comprehension could have been biased toward metagraphs and how complexity is modeled by metagraphs, compared to more complex business processes in the real-world. This gives rise to an interesting issue for future research: how to package the BPI portrayed in GPMs to minimize the complexity yet maximizing the effectiveness of GPM user comprehension.

6.3 IMPLICATIONS FOR THE LITERATURE

There is a great deal of prior research studying cognition and individual cognitive differences related to user comprehension. There is also a good deal of research relating different cognitive resources and user comprehension. There are several theories and variable relationships in the literature that are of interest in this study. However, this research appears to be the first study that developed and utilized an theoretical framework that integrated the key BPM cognitive resources and individual cognitive differences affecting GPM user comprehension in the context of BPM and BPM Systems. As a result, this study has implications for management systems engineering as well as several reference literatures, including BPM, BPM Systems, workflow management, HCI, and cognitive ergonomics.

6.3.1 Practitioner Implications for Management Systems Engineering and BPM

There are two general areas of implication for practitioners in this literature: implications for BPM managers who will use the GPMs to make decisions and implications for BPM System developers. Practitioners who use these GPMs to make BPM decisions can use the conclusions of this study in several ways. Managers' GCA and attentional abilities should be evaluated. BPM tasks can then categorized according to the levels of GCA and attention that are required for the task. Based on these results, BPM managers can be (1) profiled and selected for specific BPM tasks requiring their specific GCA abilities for accurate comprehension and (2) design GPM training targeted at different levels of GCA and attention of participants.

For BPM System developers, this research shows that the complexity of the business process and the type of GPM, specifically its modeling rules and syntax, most influence user comprehension. GPMs of business processes should be partitioned into smaller "chunks" that easily comprehensible to users. By selecting a GPM type whose syntax includes a smaller number of symbols, users will be able to easier comprehend the BPI in the GPM. The GPM type selected may mitigate individual cognitive differences and consequently, improve collective user comprehension. Further research is needed to test and verify these recommendations.

6.3.2 Implications for Management Systems Engineering and BPM

Management systems engineering studies the relationships between people and technology in the management of organizations. A host of previous literature describes BPM needs, GPMs, and information technologies associated with BPM Systems, but has not studied the management system that relates BPM managers with the formal GPMs used in BPM Systems. Because BPM and BPM Systems are important topics of study in the near future, this research has significant implications for BPM, BPM Systems, and enterprise-level information systems literature in relation to management systems engineering.

This study extends the literature on BPM systems, as well as the workflow management and enterprise-level information systems literature, by adding empirical, theory-driven user comprehension research to this increasingly important topic area. This study contributes empirical evidence as to the importance of the type of GPM and differences in user cognitive abilities to the successful comprehension of the BPI portrayed by BPM Systems. This study is a first step in extending and integrating various related literatures to study the enterprise-wide management system that is of growing importance to today's organizations.

Future empirical research should further compare user comprehension of different formal GPMs under a variety of task conditions. The limits of how and under what conditions GPMs may mitigate individual cognitive differences and differences in tacit and explicit BPM knowledge is an important topic for future research. Also, the theoretical framework proposed in this study may be used as a metamodel to map more limited past research to highlight new areas of management system research related to BPM and BPM Systems. Finally, this research model can be used in future field studies to help identify the boundary conditions for GPM user comprehension. Understanding GPM user comprehension in this context may also benefit research and industry by contributing to understanding the impact of knowledge transfer, management practices, and communication that improves the performance of both people and processes.

6.3.3 Implications for GPM User Comprehension Research in the Context of BPM Systems

This study was a first step to extending the GPM literature related to BPM Systems by empirically testing whether GPMs could be effectively and efficiently comprehended by novice users and under BPM task-specific conditions. The research and practical implications of this study may help identify the GPMs and the conditions under which novice users could better comprehend BPI. This research indicates that the

GPM itself may negate, mitigate, or minimize the impacts of novice-expert and cognitive style differences in novice GPM users. Also, the combination of the subjective mental workload, GCA, and attentional abilities may provide user "profiles" that can help assist research and practitioners in delineating GPM user comprehension in task-specific contexts.

Future research is also needed to further understand why metagraphs facilitated better performance and why UML diagrams did not. If the boundary conditions for GPM user comprehension can be identified, criteria can be applied to any type of GPM that may be able to positively impact user comprehension outcomes. Also, practitioners should consider experimenting with metagraphs as their primary visual interface in BPM Systems because they apparently facilitate more accurate, timely, and less mentally demanding user comprehension of BPI.

BPM System developers and future researchers should focus on developing better training and BPI display methods to facilitate faster user comprehension that is less mentally taxing. The complexity of GPMs was a problem for novice users, because of the number of task, resource, and information-centric elements and how they were related. This study suggests that, as business processes became more complex, GPM user comprehension may be better facilitated by dividing and packaging large GPMs into smaller, integrated sub-graphs or "chunks." This design approach may help novice users more easily view the GPMs on a computer monitor and drill down to comprehend specific BPI, while at the same time, remain oriented in relation to the overall business process. The optimal size of these GPM sub-packages will need to be determined by future research.

Future research should also place an emphasis on the interpretation of GPM symbols back to real-world business processes. Future studies can also focus on why resource allocation information portrayed by these GPMs facilitated less desirable user comprehension outcomes, primarily timeliness and mental workload, and why other types of BPI did not. For practitioners, these results suggest that the type of BPI portrayed by BPM Systems affects user comprehension in BPM managers. Future research and practice should place an emphasis on increasing GPM user comprehension of these resource-centric and information-centric BPI. For practitioners, these results suggest that the type of BPI portrayed by BPM Systems significantly affect user comprehension and training is needed to address the less comprehensible BPI.

Additionally, future research should develop and validate either a GPM user comprehension task self-efficacy assessment instrument and determine under what BPM task-specific circumstances this instrument is valid. Future research should also control for both the time that participants are allowed to become familiar with interpreting different GPMs and comparisons between expert vs. novice interpreters of these GPMs. Finally, this research should be extended to evaluate individual-level vs. group-level cross-functional and collaborative interpretations of different types of GPMs. For example, suggested future research questions include:

- What is the minimal amount of training necessary to consider novice users equivalently trained across different types of GPM, BPI, and user educational training (UET)?
- Is there a difference in user comprehension if the GPMs are labeled using the actual terminology of the business process instead of reference labels?
- Is information lost when users interpret from GPM symbols to reference label meanings to real-world meanings, and, if so, what information is lost by users?
- Because modeling involves task, resource, and information-centric BPI element dependencies, how do user comprehension outcomes vary in relation to the number of task, resource, and information-centric BPI elements and dependencies required when modeling different business processes?
- How does the level of complexity of business process affect GPM user comprehension outcomes?
- How is GPM complexity minimized while, at the same time, GPM user comprehension outcomes are maximized?

6.3.4 Implications for Future Empirical Cognitive Research in a BPM System Context

There is a great deal of prior research studying cognition and some of the cognitive differences between individuals, but no BPM-specific user comprehension research was found. This study demonstrates that future research in BPM Systems can benefit from applying various cognition-related constructs. It furthered the application of cognitive theory and personality literature to the BPM and IS domains. This study extends related cognitive science research by supporting the assertion that BPM Systems need to be developed to address individual cognitive differences if GPM user comprehension is to be improved. For example, this study applied subjective mental workload and the NASA-TLX to GPM user comprehension contexts. It also proposes using TLX results and factor analyses as possible mental workload “signatures” to help delineate BPM task types and complexities. Several implications of this study are important for future research:

- Future research is needed to further understand the impact of tacit BPM knowledge. Lab research should be conducted with more students from differing BPM-related professional disciplines as well as students from other universities. This would increase the statistical power of this study and further increase understanding of the effects of different types of UET on GPM user comprehension.
- Eventually, both expert and novice BPM professionals with different educational and professional backgrounds should be included in lab experiments before extending this research to field studies.
- Future research should attempt to use instruments that continuous data so that cognition-related data and user comprehension outcomes and be more justifiably analyzed and compared.
- Attempts should be made to experimentally control for cognitive styles as independent variables in an experimental design in order to investigate the possibility of GPMs minimizing the effect of cognitive styles during BPM user comprehension.
- Besides further GCA research, future research should include instruments assessing users’ narrow cognitive aptitudes to understand their effects on GPM user comprehension outcomes. These results provide initial information that suggest future, more specific research into the narrow cognitive aptitudes that may help develop a cognitive profile or “signature” that can be used to describe GPM user comprehension in BPM and BPM System task contexts.
- GPM user motivation and attentional abilities also need to be an important consideration and topic of any future BPM Systems research.

This study has started to address a gap in prior literature by theoretically integrating and empirically testing key individual cognitive differences and cognitive resources that impact GPM user comprehension. The GPM user comprehension research model used in this study can be further validated and extended in future research. This theoretical framework, as well as the results of this experiment, can serve as the first step in a future family of empirical studies that begins to study the large number of context variables that can affect usability and user comprehension of large-scale enterprise-level information system (as suggested is needed by Basili & Lanubile (1999)).

6.3.5 Implications for Related Areas of Industrial Engineering

Besides management systems engineering, this research extends the HCI and cognitive ergonomics areas of industrial engineering by increasing understanding of GPM user comprehension. For example, this research model extends both Activity Theory and Distributed Cognition theory to empirical, experimental research contexts (as proposed to prior research (Hollan, Hutchins, & Kirsh, 2000; Kuutti, 1995)) as well as to the domains of GPM user comprehension, BPM and BPM Systems.

Future research should focus on why UET and BPI seem to be mitigated by GCA, and attentional abilities. For practitioners, these findings suggest that, although the type of UET a novice user possesses produced differences in user comprehension, the GCA and attentional abilities of these users minimized or moderated these effects. This suggests that training practitioners in how to interpret BPI should involve evaluation of GCA and attentional abilities as well as tailoring training to the needs of BPM managers with different educational backgrounds.

By integrating key cognitive differences between individuals and BPM cognitive resources, this research confirmed or pointed out several limitations in prior research. For example, cognitive fit and RID approaches are limited in their explanatory capabilities without the accounting for individual cognitive differences and a theory to explain why a cognitive “fit” or RID “match” is good or poor. Additionally, this research seemed to confirm prior analyses suggesting that traditional applications of the Yerkes-Dodson law is overly simplistic to explain the relationships between task performance and mental workload. Further research is needed to investigate the alternative finding that factor analysis may revel a GPM user comprehension mental workload “signature” or profile.

The integrated theoretical research framework can serve as a benchmark for future GPM user comprehension research, specifically related to management systems engineering, but also in the HCI and cognitive ergonomics areas of industrial engineering. This is because this framework is unique in integrating the key cognitive resources (tacit knowledge, explicit knowledge and information artifacts) as well as key individual cognitive differences (cognitive styles, cognitive abilities [GCA and attention] and subjective mental workload) affecting GPM user comprehension outcomes (such as task performance and self-efficacy).

With the advent of ever more powerful and complex suites of enterprise-level information systems, industrial engineering approaches are needed to help understand and better integrate people with these technologies to improve decision-making and task performance as well as the development of improved enterprise-level information systems. It is hoped that this research will provide a foundation on which to build future research that contributes to the study of GPM user comprehension in the context of BPM and BPM Systems.

REFERENCES

Ackerman, M. S., & Halverson, C. A. (2000). Reexamining organizational memory. *Association for Computing Machinery. Communications of the ACM, 43*(1), 58.

Agarwal, R., De, P., & Sinha, A. P. (1999). Comprehending object and process models: an empirical study. *IEEE Transactions on Software Engineering, 25*(4), 541-556.

Agarwal, R., Sinha, A. P., & Tanniru, M. (1996). The role of prior experience and task characteristics in object-oriented modeling: An empirical study. *International Journal of Human-Computer Studies, 45*(6), 639-667.

Aguilar-Saven, R. S. (2004). Business process modelling: review and framework. *International Journal of Production Economics, 90*(2), 129-149.

Aks, D. J., & Coren, S. (1990). Is susceptibility to distraction related to mental ability? *Journal of Educational Psychology, 82*(2), 388-390.

Alm, H., & Nilsson, L. (1995). The effects of a mobile telephone task on driver behaviour in a car following situation. *Accident Analysis & Prevention, 27*(5), 707-715.

Amaravadi, C. S., & Lee, I. (2005). The dimensions of process knowledge. *Knowledge and Process Management, 12*(1), 65-76.

Annett, J. (2002). Subjective rating scales: science or art? *Ergonomics, 45*(14), 966-987.

Anonymous. (2007). *UML Resource Page*. Retrieved January 13, 2007, from http://www.uml.org/

Apostolou, D., & Mentzas, G. (2003). Experiences from knowledge management implementations in companies of the software sector. *Business Process Management Journal, 9*(3), 354.

Avila, C. (2001). Distinguishing BIS-mediated and BAS-mediated disinhibition mechanisms: A comparison of disinhibition models of Gray (1981,1987) and of Patterson and Newman (1993). *Journal of Personality and Social Psychology, 80*(2), 311-324.

Baddeley, A. (2003a). Working memory and language: an overview. *Journal of Communication Disorders, 36*(3), 189-208.

Baddeley, A. (2003b). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4*(10), 829-839.

Baddeley, A., Chincotta, D., & Adlam, A. (2001). Working memory and the control of action: Evidence from task switching. *Journal of Experimental Psychology: General, 130*(4), 641-657.

Bandura, A. (1986). *Social foundations of thought and action: a social cognitive theory*. Englewood Cliffs, N.J.: Prentice-Hall.

Bandura, A., & Locke, E. A. (2003). Negative self-efficacy and goal effects revisited. *Journal of Applied Psychology, 88*(1), 87.

Barkhi, R. (2002). Cognitive style may mitigate the impact of communication mode. *Information & Management, 39*(8), 677-688.

Bartlett, F. C. (1932). *Remembering: An Experimental and Social Study*. London: Cambridge University Press.

Basili, V. R., & Lanubile, F. (1999). Building knowledge through families of experiments. *IEEE Transactions on Software Engineering, 25*(4), 456-473.

Basu, A., & Blanning, R. W. (2000). A formal approach to workflow analysis. *Information Systems Research, 11*(1), 17-36.

Basu, A., & Blanning, R. W. (2003). Synthesis and decomposition of processes in organizations. *Information Systems Research, 14*(4), 337.

Basu, A., & Kumar, A. (2002). Research commentary: Workflow management issues in e-business. *Information Systems Research, 13*(1), 1-14.

Bernstein, D. A., Roy, E., Skrull, T. K., & Wickens, C. D. (1991). *Psychology*. Boston: Houghton Mifflin Company.

Bess, T. L., Harvey, R. J., & Swartz, D. (2003). *Hierarchical Confirmatory Factor Analysis of the Myers-Briggs Type Indicator.* Paper presented at the Annual Conference of the Society for Industrial and Organizational Psychology, Orlando, FL USA.

Bierwagen, T., Eyferth, K., & Helbing, H. (1996). Radar screen information access: An exploratory investigation. *Control Engineering Practice, 4*(8), 1177-1182.

Blanchard, B. S., & Fabrycky, W. J. (2006). *Systems engineering and analysis* (4th ed.). Upper Saddle River, N.J.: Pearson Prentice Hall.

Boff, K. R. (2006). Revolutions and shifting paradigms in human factors & ergonomics. *Applied Ergonomics, 37*(4), 391-399.

Boland, R. J., Jr., & Tenkasi, R. V. (2001). Communication and collaboration in distributed cognition. In G. M. Olson, T. W. Malone & J. B. Smith (Eds.), *Coordination theory and collaboration technology* (pp. 51-66). Mahwah, N.J.: Lawrence Erlbaum Associates.

Boland, R. J., Jr., Tenkasi, R. V., & Te'eni, D. (1994). Designing Information Technology to Support Distributed Cognition. *Organization Science, 5*(3), 456-475.

Bowman, D. B., Markham, P. M., & Roberts, R. D. (2001). Expanding the frontier of human cognitive abilities: so much more than (plain) g! *Learning and Individual Differences, 13*(2), 127-158.

Braarud, P. O. (2001). Subjective Task Complexity and Subjective Workload: Criterion Validity for Complex Team Tasks. *International Journal of Cognitive Ergonomics, 5*(3), 261-273.

Broadhurst, P. L. (1959). The interaction of task difficulty and motivation: The Yerkes Dodson law revived. *Acta Psychologica, 16*, 321-338.

Cabrera, A., & Cabrera, E. F. (2002). Knowledge-sharing dilemmas. *Organization Studies, 23*(5), 687-710.

Campbell, J. P., Dunnette, M. D., Lawler, E. E. I., & Weick, K. E. J. (1970). Expectancy Theory. In D. A. Mankin, R. Ames & M. A. Grodsky (Eds.), *Managerial Behavior, Performance, and Effectiveness* (pp. 343-348): McGraw-Hill, Inc. McGraw-Hill Book Company.

Cannon-Bowers, J. A., & Salas, E. (2001). Reflections on shared cognition. *Journal of Organizational Behavior, 22*(2), 195.

Capraro, R. M., & Capraro, M. M. (2002). Myers-Briggs type indicator score reliability across studies: A meta-analytic reliability generalization study. *Educational and Psychological Measurement, 62*(4), 590-602.

Carlson, J. G. (1985). Recent assessments of the Myers-Briggs Type Indicator. *Journal of Personality Assessment, 49*, 356-365.

Carlyn, M. (1977). An assessment of the Myers-Briggs Type Indicator. *Journal of Personality Assessment, 41*, 461-473.

Carpenter, P. A., Miyake, A., & Just, M. A. (1995). Language Comprehension - Sentence and Discourse Processing. *Annual Review of Psychology, 46*, 91-120.

Carroll, J. M. (Ed.). (2003). *HCI models, theories, and frameworks: toward a multidisciplinary science*. Amsterdam ; Boston: Morgan Kaufmann.

Carroll, J. M., & Olson, J. R. (Eds.). (1987). *Mental Models in Human-Computer Interaction: Research Issues about what the User of Software Knows*. Washington, DC: National Academy Press.

Carskadon, T. G. (1979). Clinical and counseling aspects of the Myers-Briggs Type Indicator: a research review. *Research on Psychological Types, 1*, 2-31.

Chalmers, P. A. (2003). The role of cognitive theory in human-computer interface. *Computers in Human Behavior, 19*(5), 593-607.

Chen, I. J., & Popvich, K. (2003). Understanding customer relationship management (CRM): People, process and technology. *Business Process Management Journal, 9*(5), 672.

Chi, S. E., Park, C. B., Lim, S. L., Park, E. H., Lee, Y. H., Lee, K. H., et al. (2005). EEG and personality dimensions: A consideration based on the brain oscillatory systems. *Personality and Individual Differences, 39*(3), 669-681.

Cimino, J. J. (1998). Distributed cognition and knowledge-based controlled medical terminologies. *Artificial Intelligence in Medicine, 12*(2), 153-168.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, N.J.: L. Erlbaum Associates.

Cohen, J. (1992). A Power Primer. *Psychological Bulletin, 112*(1), 155-159.

Collet, C., Petit, C., Champely, S., & Dittmar, A. (2003). Assessing workload through physiological measurements in bus drivers using an automated system during docking. *Human Factors, 45*(4), 539-548.

Compeau, D. R., & Higgins, C. A. (1995). Computer self-efficacy - development of a measure and initial test. *MIS Quarterly, 19*(2), 189-211.

Compeau, D. R., Higgins, C. A., & Huff, S. (1999). Social cognitive theory and individual reactions to computing technology: A longitudinal study. *MIS Quarterly, 23*(2), 145-158.

Craik, K. (1943). *The Nature of Explanation*. UK: Cambridge University Press.

Crawford, H. J., Brown, A. M., & Moon, C. E. (1993). Sustained attentional and disattentional abilities: Differences between low and highly hypnotizable persons. *Journal of Abnormal Psychology, 102*(4), 534-543.

Crosman, P. L. (2004, JUN). Pain Free BPM. *Transform, 13*, 16-22.

Crowston, K. (1997). A coordination theory approach to organizational process design. *Organization Science, 8*(2), 157-175.

Curtis, B. (1984). *Fifteen years of psychology in software engineering: Individual differences and cognitive science.* Paper presented at the Proceedings of the 7th Institute of Electrical and Electronics Engineers (IEEE) International Conference on Software Engineering, Orlando, Florida, United States.

Curtis, B., Kellner, M. I., & Over, J. (1992). Process modeling. *Communications of the ACM (Association for Computing Machinery), 35*(9), 75-90.

D'Amico, E. J., Neilands, T. B., & Zambarano, R. (2001). Power analysis for multivariate and repeated measures designs: A flexible approach using the SPSS MANOVA procedure. *Behavior Research Methods Instruments & Computers, 33*(4), 479-484.

Daradoumis, T., & Marques, J. M. (2002). Distributed Cognition in the Context of Virtual Collaborative Learning. *Journal of Interactive Learning Research, 13*(1-2), 135-148.

Davenport, E., & Hall, H. (2002). Organizational Knowledge and Communities of Practice. *Annual Review of Information Science and Technology (ARIST), 36*, 171-227.

Davenport, T. H., & Beers, M. C. (1995). Managing information about processes. *Journal of Management Information Systems, 12*(1), 57.

Davis, D. L., & Elnicki, R. A. (1984). User Cognitive Types for Decision Support Systems. *Omega-International Journal of Management Science, 12*(6), 601-614.

de Croock, M. B. M., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). High versus low contextual interference in simulation-based training of troubleshooting skills: effects on transfer performance and invested mental effort. *Computers in Human Behavior, 14*(2), 249-267.

de Haan, M. (2002). Distributed Cognition and the Shared Knowledge Model of the Mazahua: A Cultural Approach. *Journal of Interactive Learning Research, 13*(1-2), 31-50.

De Vito, A. J. (1985). Review of the Myers-Briggs Type Indicator. In J. V. Mitchell (Ed.), *The ninth mental measurement yearbook* (Vol. 2, pp. 1000). Lincoln: University of Nebraska Press.

Decortis, F., Noirfalise, S., & Saudelli, B. (2000). Activity theory, cognitive ergonomics and distributed cognition: three views of a transport company. *International Journal of Human-Computer Studies, 53*(1), 5-33.

Dehler, C. (1998). Computer-mediated distributed cognitions: cultivating collective knowledge and personal competencies. *ACM Special Interest Group on Computer Uses in Education (SIGCUE) Outlook, 26*(1), 15-19.

Dodrill, C. B. (1981). An Economical Method for the Evaluation of General Intelligence in Adults. *Journal of Consulting and Clinical Psychology, 49*(5), 668-673.

Dodrill, C. B. (1983). Long-Term Reliability of the Wonderlic Personnel Test. *Journal of Consulting and Clinical Psychology, 51*(2), 316-317.

Dodrill, C. B., & Warner, M. H. (1988). Further Studies of the Wonderlic Personnel Test as a Brief Measure of Intelligence. *Journal of Consulting and Clinical Psychology, 56*(1), 145-147.

Dunn, C., & Grabski, S. (2001). An investigation of localization as an element of cognitive fit in accounting model representations. *Decision Sciences, 32*(1), 55-94.

Dussault, C., Jouanin, J. C., Philippe, M., & Guezennec, C. Y. (2005). EEG and ECG changes during simulator operation reflect mental workload and vigilance. *Aviation Space and Environmental Medicine, 76*(4), 344-351.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review, 66*(3), 183-201.

Edinger, J. D., Shipley, R. H., Watkins, C. E., Jr., & Hammett, E. B. (1985). Validity of the Wonderlic Personnel Test as a Brief IQ Measure in Psychiatric Patients. *Journal of Consulting & Clinical Psychology, 53*(6), 937-939.

Edwards, J. A., Lanning, K., & Hooker, K. (2002). The MBTI and social information processing: An incremental validity study. *Journal of Personality Assessment, 78*(3), 432-450.

Eppler, M. J., Seifried, P. M., & Ropnack, A. (1999). *Improving Knowledge Intensive Processes Through an Enterprise Knowledge Medium.* Paper presented at the Proceedings of the Association for Computing Machinery (ACM) Special Interest Group on Computer Personnel Research (SIGCPR) Annual Conference, New Orleans, LA.

Eriksson, H.-E., & Penker, M. (2000). *Business modeling with UML: business patterns at work*. New York: John Wiley & Sons.

Eyring, J. D., Johnson, D. S., & Francis, D. J. (1993). A Cross-Level Units-of-Analysis Approach to Individual Differences in Skill Acquisition. *Journal of Applied Psychology, 78*(5), 805-814.

Eysenck, H. J. (1967). *The biological basis of personality*. Springfield, Ill.,: Thomas.

Eysenck, M. W., & Flanagan, C. (2000). *Psychology for AS level*. London ; Philadelphia, PA: Psychology Press.

Eysenck, M. W., & Keane, M. T. (1990). *Cognitive Psychology: A Student's Handbook*. London, UK: Lawrence Erlbaum Associates.

Fagan, M. H., Neill, S., & Wooldridge, B. R. (2003). An empirical investigation into the relationship between computer self-efficacy, anxiety, experience, support and usage. *Journal of Computer Information Systems, 44*(2), 95.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (In Press). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*.

Field, A. P. (2005). *Discovering statistics using SPSS* (2nd ed.). London; Thousand Oaks, Calif.: Sage Publications.

Fisher, S. L., & Ford, J. K. (1998). Differential effects of learner effort and goal orientation on two learning outcomes. *Personnel Psychology, 51*(2), 397.

Flor, N. V., & Maglio, P. P. (1997). *A Case Study of a Representational Activity at a Customer Centered Business.* Paper presented at the Proceedings of the Eighteenth International Conference on Information Systems, Atlanta, GA USA.

Flor, N. V., & Maglio, P. P. (2004). Modeling business representational activity online: A case study of a customer-centered business. *Knowledge-Based Systems, 17*(1), 39-56.

Fonseca, F. T. (2007). The double role of ontologies in information science research. *Journal of the American Society for Information Science and Technology, Accepted for Publication in June 2006*.

Gable, S. L., Reis, H. T., & Elliot, A. J. (2000). Behavioral activation and inhibition in everyday life. *Journal of Personality and Social Psychology, 78*(6), 1135-1149.

Garbis, C. (2000). *Communication and coordination through public and private representations in control rooms.* Paper presented at the Conference on Human Factors in Computing Systems (CHI '00), The Hague, The Netherlands.

Gardner, W. L., & Martinko, M. J. (1996). Using the Myers-Briggs Type Indicator to study managers: A literature review and research agenda. *Journal of Management, 22*(1), 45-83.

Garner, S. (2002). *Reducing the Cognitive Load on Novice Programmers* (141 Reports--Descriptive; 150 Speeches/Meeting Papers). Australia; Western Australia.

Gentner, D., & Gentner, D. R. (1983). Flowing waters or teemings crowds: mental models of electricity In D. Gentner & A. L. Stevens (Eds.), *Mental Models* (pp. 99-129). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Gentner, D., & Stevens, A. L. (Eds.). (1983). *Mental Models*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

George, C. E. (2000). *Experiences with Novices: The Importance of Graphical Representations in Supporting Mental Models.* Paper presented at the Proceedings of the 12th Annual Workshop of the Psychology of Programming Interest Group (PPIG), Corzena, Italy.

Gershenson, C. (2006). Cognitive paradigms: which one is the best? *Cognitive Systems Research 5*(2), 135-156.

Giordano, D. (2002). Evolution of interactive graphical representations into a design language: a distributed cognition account. *International Journal of Human-Computer Studies, 57*(4), 317-345.

Goldstein, H. W., Yusko, K. P., & Nicolopoulos, V. (2001). Exploring Black-White subgroup differences of managerial competencies. *Personnel Psychology, 54*(4), 783.

Goranson, H. T. (1999). *The agile virtual enterprise: cases, metrics, tools*. Westport, Conn.: Quorum Books.

Gou, H. M., Huang, B. Q., Liu, W. H., & Li, X. (2003). A framework for virtual enterprise operation management. *Computers in Industry, 50*(3), 333-352.

Gray, J. A. (1972). The psychophysiological basis of introversion-extraversion: A modification of Eysenck's theory. In V. D. Nebylitsyn & J. A. Gray (Eds.), *The biological bases of individual behaviour* (pp. 182-205). San Diego: Academic Press.

Gray, J. A. (1981). A critique of Eysenck's theory of personality. In H. J. Eysenck (Ed.), *A model for personality* (pp. 246-276). Berlin ; New York: Springer-Verlag.

Gray, J. A. (1987). *The psychology of fear and stress* (2nd ed.). Cambridge ; New York: Cambridge University Press.

Gray, J. R., & Burgess, G. C. (2004). Personality differences in cognitive control? BAS, processing efficiency, and the prefrontal cortex. *Journal of Research in Personality, 38*(1), 35-36.

Gray, J. R., Burgess, G. C., Schaefer, A., Yarkoni, T., Larsen, R. J., & Braver, T. S. (2005). Affective personality differences in neural processing efficiency confirmed using fMR1. *Cognitive Affective & Behavioral Neuroscience, 5*(2), 182-190.

Green, P., & Rosemann, M. (2000). Integrated process modeling: An ontological evaluation. *Information Systems: The 11th International Conference on Advanced Information System Engineering, 25*(2), 73-87.

Gronau, N., & Weber, E. (2004, June 17-18). *Management of knowledge intensive business processes.* Paper presented at the Proceedings of the Business Process Management: Second international conference, BPM Potsdam, Germany.

Gruber, H. E., & Gruber, J. J. V. (Eds.). (1977). *The Essential Piaget*. New York: Basic Books.

Grumbles, D., & Crawford, H. J. (1981, October). *Differential attentional skills and hypnotizability.* Paper presented at the Annual Meeting of the Society for Clinical and Experimental Hypnosis, Portland, OR.

Ha, C. H., Kim, J. H., Lee, S. J., & Seong, P. H. (2006). Investigation on relationship between information flow rate and mental workload of accident diagnosis tasks in NPPs. *IEEE Transactions on Nuclear Science, 53*(3), 1450-1459.

Hall, C., & Harmon, P. (2006). *The 2006 Enterprise Architecture, Process Modeling & Simulation Tools Report* (Report): Business Process Trends.

Halverson, C. (2002). Activity Theory and Distributed Cognition: Or What Does CSCW Need to DO with Theories? *Computer Supported Cooperative Work: The Journal of Collaborative Computing, 11*(1-2), 243-267.

Hammer, M. (1996). *Beyond reengineering: how the process-centered organization is changing our work and our lives* (1st ed.). New York: HarperBusiness.

Hammer, M., & Champy, J. (2003). *Reengineering the corporation: a manifesto for business revolution* (Revised ed. of the 2001 ed. ed.). New York: HarperBusiness Essentials.

Hancock, P. A., & Ganey, H. (2003). From the Inverted-U to the Extended-U: The Evolution of a Law of Psychology. *Journal of Human Performance in Extreme Environments, 7*(1), 5-14.

Hanoch, Y., & Vitouch, O. (2004). When less is more - Information, emotional arousal and the ecological reframing of the Yerkes-Dodson law. *Theory & Psychology, 14*(4), 427-452.

Harel, D., & Gery, E. (1997). Executable object modeling with statecharts. *Computer, 30*(7), 31.

Hart, S. G., & Staveland, L. E. (1988a). Development of a multi-dimensional workload rating scale: Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (Vol. 52, pp. 139-183). Amsterdam, The Netherlands:: Elsevier.

Hart, S. G., & Staveland, L. E. (1988b). *NASA Task Load Index (TLX) V 1.0 Users Manual* Unpublished manuscript.

Hart, S. G., & Wickens, C. D. (1990). Workload assessment and prediction. In H. R. Booher (Ed.), *An Approach to Systems Integration* (pp. 257-296). New York: Van Nostrand Reinhold.

Hartmann, E., Sunde, T., Kristensen, W., & Martinussen, M. (2003). Psychological measures as predictors of military training performance. *Journal of Personality Assessment, 80*(1), 87-98.

Harvey, R. J. (1996). Reliability and validity. In A. L. Hammer (Ed.), *MBTI applications: A decade of research on the Myers-Briggs Type Indicator* (pp. 5-29). Palo Alto, CA: Consulting

Psychologists Press.

Hawkins, K. A., Faraone, S. V., Pepple, J. R., Seidman, L. J., & Tsuang, M. T. (1990). WAIS-R Validation of the Wonderlic Personnel Test as a Brief Intelligence Measure in a Psychiatric Sample. *Psychological Assessment, 2*(2), 198-201.

Hayes, J., & Allinson, C. W. (1994). Cognitive style and its relevance for managers. *British Journal of Management, 5*, 53-71.

Hendrick, H. W. (1984). Cognitive complexity, conceptual systems and organizational design and management: Review and ergonomic implications. In H. W. Hendrick & O. Brown, Jr. (Eds.), *Human Factors in Organizational Design and Management* (pp. 15-25). North-Holland: Elsevier Science Publishers B.V.

Hertzberg, F. (1968). One More Time: How Do You Motivate Employees? *Harvard Business Review*.

Hewig, J., Hagemann, D., Seifert, J., Naumann, E., & Bartussek, D. (2006). The relation of cortical activity and BIS/BAS on the trait level. *Biological Psychology, 71*(1), 42-53.

Hill, S. G., Iavecchia, H. P., Byers, J. C., Bittner, A. C., Zaklad, A. L., & Christ, R. E. (1992). Comparison of four subjective workload rating scales. *Human Factors, 34*(4), 429-439.

Hillman, C. H., Motl, R. W., Pontifex, M. B., Posthuma, D., Stubbe, J. H., Boomsma, D. I., et al. (2006). Physical activity and cognitive function in a cross-section of younger and older community-dwelling individuals. *Health Psychology, 25*(6), 678-687.

Hislop, D. (2002). Mission impossible? Communicating and sharing knowledge via information technology. *Journal of Information Technology, 17*(3), 165-177.

Hlupic, V. (2003). *Knowledge and business process management*. Hershey, PA: Idea Group Pub.

Hlupic, V., Pouloudi, A., & Rzevski, G. (2002). Towards an integrated approach to knowledge management: 'hard', 'soft' and 'abstract' issues. *Knowledge and Process Management, 9*(2), 90.

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction (TOCHI), 7*(2), 174-196.

Hollnagel, E. (1997). Cognitive ergonomics: it's all in the mind. *Ergonomics, 40*(10), 1170-1182.

Hollnagel, E., & Woods, D. D. (2005). *Joint cognitive systems: Foundations of cognitive systems engineering*. Boca Raton, FL: Taylor & Francis.

Horsky, J., Kaufman, D. R., Oppenheim, M. I., & Patel, V. L. (2003). A framework for analyzing the cognitive complexity of computer-assisted clinical ordering. *Journal of Biomedical Informatics, 36*(1-2), 4-22.

Hough, J. R., & Ogilvie, d. (2005). An Empirical Test of Cognitive Style and Strategic Decision Outcomes. *Journal of Management Studies, 42*(2), 417-448.

Huitt, W. (2003). *The information processing approach to cognition*. Retrieved March 22, 2005, from http://chiron.valdosta.edu/whuitt/col/cogsys/infoproc.html

Huitt, W. (2004). *The cognitive system*. Retrieved March 22, 2005, from http://chiron.valdosta.edu/whuitt/col/cogsys/cogsys.html

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, Mass.: MIT Press.

Irons, D. M. (1982). *Cognitive correlates of programming tasks in novice programmers.* Paper presented at the Proceedings of the 1982 conference on Human factors in computing systems, Gaithersburg, Maryland, United States.

Jarvenpaa, S. L., Dickson, G. W., & DeSanctis, G. (1985). Methodological Issues in Experimental IS Research: Experiences and Recommendations. *MIS Quarterly, 9*(2).

Jensen, A. R., & Weng, L. J. (1994). What Is a Good G. *Intelligence, 18*(3), 231-258.

Johnson-Laird, P. N. (1983). *Mental Models: Towards a Cognitive Science of Language, Inference and*

Consciousness. Cambridge, UK: Cambridge University Press.

Johnson, R. D., & Marakas, G. M. (2000). Research report: The role of behavioral modeling in computer skills acquisition - Toward refinement of a model. *Information Systems Research, 11*(4), 402-417.

Jorm, A. F., Christensen, H., Henderson, A. S., Jacomb, P. A., Korten, A. E., & Rodgers, B. (1999). Using the BIS/BAS scales to measure behavioural inhibition and behavioural activation: Factor structure, validity and norms in a large community sample. *Personality and Individual Differences, 26*(1), 49-58.

Jung, H. S., & Jung, H. S. (2001). Establishment of overall workload assessment technique for various tasks and workplaces. *International Journal of Industrial Ergonomics, 28*(6), 341-353.

Just, M. A., & Carpenter, P. A. (1992). A Capacity Theory of Comprehension - Individual-Differences in Working Memory. *Psychological Review, 99*(1), 122-149.

Kabeli, J., & Shoval, P. (2005a). A Comparison of the FOOM and OPM Methodologies for User Comprehension of Analysis Specifications. In J. Krogstie, T. A. Halpin & K. Siau (Eds.), *Information Modeling Methods and Methodologies* (pp. 175-194): Idea Group.

Kabeli, J., & Shoval, P. (2005b). Comprehension and quality of analysis specifications--a comparison of FOOM and OPM methodologies. *Information and Software Technology, 47*(4), 271-290.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The Expertise Reversal Effect. *Educational Psychologist, 38*(1), 23-31.

Kaptelinin, V., Nardi, B. A., Bødker, S., Carroll, J., Hollan, J., Hutchins, E., et al. (2003, April 5-10). *Panel: Post-cognitivist HCI: Second-Wave Theories.* Paper presented at the Computer-Human Interaction (CHI), Ft. Lauderdale, Florida, USA.

Karagiannis, D., Junginger, S., & Strobl, R. (1996). Introduction to Business Process Management Systems Concepts. In B. Scholz-Reiter & E. Stickel (Eds.), *Business Process Modeling* (pp. 81-106). Berlin et al.: Springer.

Kellogg, R. T. (2001). Long-term working memory in text production. *Memory & Cognition, 29*(1), 43-52.

Kieras, D. E., & Bovair, S. (1984). The role of a mental model in learning to operate a device. *Cognitive Science, 8*(3), 255-273.

Kintsch, W. (1988). The Role of Knowledge in Discourse Comprehension - a Construction Integration Model. *Psychological Review, 95*(2), 163-182.

Kintsch, W. (2005). An overview of top-down and bottom-up effects in comprehension: The CI perspective. *Discourse Processes, 39*(2-3), 125-128.

Kirsch, L. J. (1996). The Management of Complex Tasks in Organizations: Controlling the Systems Development Process. *Organization Science, 7*(1), 1-21.

Kirschner, P. A. (2002). Cognitive Load Theory: Implications of Cognitive Load Theory on the Design of Learning. *Learning and Instruction, 12*(1), 1-10.

Klein, S. B. (1982). *Motivation: biosocial approaches*. New York: McGraw-Hill.

Kroeger, O., Thuesen, J. M., & Rutledge, H. (2002). *Type talk at work: how 16 personality types determine your success on the job* (Rev. and updated. ed.). New York: Dell Pub.

Kurstedt, H. A. (2000). *Management Systems Theory, Applications, and Design* Unpublished manuscript, Virginia Tech, Blacksburg, VA.

Kuutti, K. (1995). Activity Theory as a potential framework for human-computer interaction research. In B. A. Nardi (Ed.), *Context and consciousness: Activity Theory and human computer interaction* (pp. 17-44). Cambridge: MIT Press.

Lee, C., & Bobko, P. (1994). Self-Efficacy Beliefs - Comparison of 5 Measures. *Journal of Applied Psychology, 79*(3), 364-369.

Lee, Y. H., & Liu, B. S. (2003). Inflight workload assessment: Comparison of subjective and physiological measurements. *Aviation Space and Environmental Medicine, 74*(10), 1078-1084.

Lens, W., & de Volder, M. (1980). Achievement motivation and intelligence test scores: A test of the Yerkes-Dodson hypothesis. *Psychologica Belgica, 20*(1), 49-59.

Lenz, K., & Oberweis, A. (2003). Inter-organizational business process management with XML nets. *Petri Net Technology for Communication-Based Systems, 2472*, 243-263.

Leont'ev, A. N. (1974). The problem of activity in psychology. *Soviet Psychology, 13*(2), 4-33.

Leont'ev, A. N. (1978). *Activity, consciousness, and personality*. Englewood Cliffs, N.J.: Prentice-Hall.

Leont'ev, A. N. (1989). The problem of activity in the history of soviet psychology. *Soviet Psychology, 27*(1), 22-39.

Lichtenberg, P., Bachner-Melman, R., Ebstein, R. P., & Crawford, H. J. (2004). Hypnotic Susceptibility: Multidimensional Relationships With Cloninger's Tridimensional Personality Questionnaire, COMT Polymorphisms, Absorption, and Attentional Characteristics. *International Journal of Clinical & Experimental Hypnosis, 52*(1), 47-72.

Lieberman, H. R., Bathalon, G. P., Falco, C. M., Kramer, F. M., Morgan, C. A., & Niro, P. (2005). Severe decrements in cognition function and mood induced by sleep loss, heat, dehydration, and undernutrition during simulated combat. *Biological Psychiatry, 57*(4), 422-429.

Light, A. (2005, Feb 4). Gartner predicts: Nearly Half of IT Jobs will be Lost to Automation by 2015. *UsabilityNews.com*.

Lipsey, M. W. (1990). *Design sensitivity: statistical power for experimental research*. Newbury Park, Calif.: Sage Publications.

Lowry, P. B., Cherrington, J. O., & Watson, R. R. (2002). *The e-business handbook*. Boca Raton, Fla.: St. Lucie Press.

Luqi, Barnes, P. D., & Zyda, M. (1990). *Graphical support for reducing information overload in rapid prototyping.* Paper presented at the Proceedings of the Twenty-Third Annual Hawaii International Conference on System Sciences.

Lyons, L. C., & Crawford, H. J. (1997). Sustained attentional and disattentional abilities and arousability: Factor analysis and relationships to hypnotic susceptibility. *Personality and Individual Differences, 23*(6), 1071-1084.

MacLeod, D. (2004). Cognitive Ergonomics. *Industrial Engineer, 36*(3), 26-30.

Madhavan, R., & Grover, R. (1998). From embedded knowledge to embodied knowledge: New product development as knowledge management. *Journal of Marketing, 62*(4), 1.

Malone, T. W., Crowston, K., & Herman, G. A. (2003). *Organizing business knowledge: the MIT process handbook*. Cambridge, Mass.: MIT Press.

Marakas, G. M., Yi, M. Y., & Johnson, R. D. (1998). The multilevel and multifaceted character of computer self-efficacy: Toward clarification of the construct and an integrative framework for research. *Information Systems Research, 9*(2), 126-163.

Marc, T. J. (2005). The Transnational Corporation, Corporate Social Responsibility and the 'Outsourcing' Debate. *Journal of American Academy of Business, Cambridge, 6*(2).

Markus, M. L., Majchrzak, A., & Gasser, L. (2002). A design theory for systems that support emergent knowledge processes. *MIS Quarterly, 26*(3), 179-212.

Marmaras, N., & Kontogiannis, T. (2001). Cognitive Tasks. In G. Salvendy (Ed.), *Handbook of industrial engineering: technology and operations management* (3rd ed., pp. 1013-1040). New York: Wiley.

Marshall, C. (2000). *Enterprise modeling with UML: designing successful software through business analysis*. Reading, Mass.: Addison-Wesley.

Martin-Michiellot, S., & Mendelsohn, P. (2000). Cognitive Load While Learning with a Graphical Computer Interface. *Journal of Computer Assisted Learning, 16*(4), 284-293.

Mayer, R. E., & Moreno, R. (2003). Nine Ways to Reduce Cognitive Load in Multimedia Learning. *Educational Psychologist, 38*(1), 43-52.

Mayes, D. K., Sims, V. K., & Koonce, J. M. (2001). Comprehension and workload differences for VDT and paper-based reading. *International Journal of Industrial Ergonomics, 28*(6), 367-378.

McCutcheon, L. E. (2002). *North American Journal of Psychology, 2002* (022 Collected Works--Serials). Florida.

Miers, D., Harmon, P., & Hall, C. (2006). *The 2006 BPM Suites Report Release 2.0* (Report): Business Process Trends.

Miller, G. A. (1956). The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *The Psychological Review, 63*, 81-97.

Miyake, S. (1997). Factors influencing mental workload indexes. *Journal of UOEH (University of Occupational and Environmental Health), 19*(4), 313-325.

Miyake, S. (2001). Multivariate workload evaluation combining physiological and subjective measures. *International Journal of Psychophysiology, 40*(3), 233-238.

Moody, D. L. (2004). Cognitive load effects on end user understanding of conceptual models: An experimental analysis. In *Advances in Databases and Information Systems, Proceedings* (Vol. 3255, pp. 129-143).

Moore, J. L., & Rocklin, T. R. (1998). The distribution of distributed cognition: Multiple interpretations and uses. *Educational Psychology Review, 10*(1), 97-113.

Morabito, J., Sack, I., & Bhate, A. (1999). *Organization modeling: innovative architectures for the 21st century*. Upper Saddle River, NJ: Prentice Hall PTR.

Moreno, R. (2002, June 24-29). *Who Learns Best with Multiple Representations? Cognitive Theory Implications for Individual Differences in Multimedia Learning.* Paper presented at the Proceedings of the 14th World Conference on Educational Multimedia, Hypermedia & Telecommunications (ED-MEDIA), Denver, Colorado.

Moroney, W. F., Biers, D. W., & Eggemeier, F. T. (1995). Some measurement and methodological considerations in the application of subjective workload measurement techniques. *International Journal of Aviation Psychology, 5*(1), 87-106.

Morris, M. G., Speier, C., & Hoffer, J. A. (1999). An examination of procedural and object-oriented systems analysis methods: Does prior experience help or hinder performance? *Decision Sciences, 30*(1), 107-136.

Morrow, D. G., Menard, W. E., Ridolfo, H. E., Stine-Morrow, E. A. L., Teller, T., & Bryant, D. (2003). Expertise, cognitive ability, and age effects on pilot communication. *International Journal of Aviation Psychology, 13*(4), 345-371.

Mullane, J., & McKelvie, S. J. (2001). Effects of Removing the Time Limit on First and Second Language Intelligence Test Performance. *Practical Assessment, Research & Evaluation, 7*(23).

Muller, K. E., LaVange, L. M., Landesman-Ramey, S., & Ramey, C. T. (1992). Power calculations for general linear multivariate models including repeated measures applications. *Journal of the American Statistical Association, 87*, 1209-1226.

Muller, K. E., & Peterson, B. L. (1984). Practical methods for computing power in testing the multivariate general linear hypothesis. *Computational Statistics and Data Analysis, 2*, 143-158.

Murray, J. B. (1990). Review of research on the Myers-Briggs Type Indicator. *Perceptual and Motor Skills, 70*, 1187-1202.

Myers, I. B. (1993). *Introduction to type* (5th ed.). Palo Alto, CA: Consulting Psychologists.

Myers, I. B., & McCaulley, M. H. (1989). *Manual: A guide to the development and use of the Myers-Briggs Type Indicator*. Palo Alto, CA: Consulting Psychologists Press.

Myers, I. B., McCaulley, M. H., & Most, R. (1985). *Manual: A guide to the development and use of the Myers-Briggs Type Indicator*. Palo Alto, Ca.: Consulting Psychologists Press.

Myers, I. B., & Myers, P. B. (1995). *Gifts differing: understanding personality type*. Palo Alto, Calif.: Davies-Black Pub.

Nardi, B. A. (1998). Concepts of cognition and consciousness: Four voices. *Journal of Computer Documentation, 22*(1), 31-48.

Neisser, U. (1967). *Cognitive psychology* New York: Appleton-Century-Crofts.

Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, N.J.,: Prentice-Hall.

Nordbotten, J. C., & Crosby, M. E. (1999). The effect of graphic style on data model interpretation. *Information Systems Journal, 9*(2), 139-155.

Norman, D. A. (1983). Some observations on mental models. In D. Gentner & A. L. Stevens (Eds.), *Mental Models*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Norman, D. A. (1986). Cognitive Engineering. In D. A. Norman & S. W. Draper (Eds.), *User centered system design: new perspectives on human-computer interaction* (pp. xiii, 526 p.). Hillsdale, N.J.: L. Erlbaum Associates.

Norman, D. A. (1988). *The psychology of everyday things*. New York: Basic Books.

Norman, D. A. (1993). *Things that make us smart: defending human attributes in the age of the machine*. Reading, Mass.: Addison-Wesley Pub. Co.

Norman, D. A. (2002). *The design of everyday things* (1st Basic paperback. ed.). New York: Basic Books.

Nygren, T. E. (1991). Psychometric properties of subjective workload measurement techniques: Implications for their use in the assessment of perceived mental workload. *Human Factors, 33*(1), 17-33.

O'Connor, J., & McDermott, I. (1997). *The art of systems thinking: essential skills for creativity and problem solving*. London: Thorsons.

O'Donnell, A. M. (1998). Special issue: Distributed cognition - Introduction. *Educational Psychology Review, 10*(1), 1-2.

O'Rourke, C., Fishman, N., & Selkow, W. (2003). *Enterprise architecture using the Zachman Framework*. Boston: Course Technology a division of Thomson Learning.

Orlikowski, W. J., & Iacono, C. S. (2001). Research commentary: Desperately seeking the "IT" in IT research - A call to theorizing the IT artifact. *Information Systems Research, 12*(2), 121-134.

Osborn, C. S. (1998). Systems for sustainable organizations: Emergent strategies, interactive controls and semi-formal information. *Journal of Management Studies, 35*(4), 481-509.

Ould, M. A. (2003). Preconditions for putting processes back in the hands of their actors. *Information and Software Technology, Special Issue on Modelling Organisational Processes, 45*(15), 1071-1074.

Paas, F. G. W. C., Renkl, A., & Sweller, J. (2003). Cognitive Load Theory and Instructional Design: Recent Developments. *Educational Psychologist, 38*(1), 1-4.

Paas, F. G. W. C., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive Load Measurement as a Means to Advance Cognitive Load Theory. *Educational Psychologist, 38*(1), 63-71.

Paas, F. G. W. C., & Van Merrienboer, J. J. G. (1994). Variability of Worked Examples and Transfer of Geometrical Problem-Solving Skills: A Cognitive-Load Approach. *Journal of Educational Psychology, 86*(1), 122-133.

Palmer, N. (2003). *BPM 2003 Market Milestone Report* (No. 20031023-BPM). Boston, MA Delphi Group.

Palmer, N. (2005). *BPM 2005 Market Milestone Report*. Boston: Delphi Group - A Perot Systems Company.

Patterson, C. M., & Newman, J. P. (1993). Reflectivity and Learning from Aversive Events - toward a Psychological Mechanism for the Syndromes of Disinhibition. *Psychological Review, 100*(4), 716-736.

Pearson, D. W., Albert, P., Besombes, B., Boudarel, M. R., Marcon, E., & Mnemoi, G. (2002). Modelling enterprise networks: A master equation approach. *European Journal of Operational Research, 138*(3), 670.

Pedhazur, E., J., & Schmelkin, L. P. (1991). *Measurement, Design, and Analysis: An Integrated Approach*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Perry, M. (2003). Distributed Cognition. In J. M. Carroll (Ed.), *HCI models, theories, and frameworks: toward a multidisciplinary science* (pp. 193-223). Amsterdam ; Boston: Morgan Kaufmann.

Petri, C. A. (1962). *Kommunikation mit Automaten*. Bonn (in German): Springer

Piaget, J. (1983). Piaget's theory. In P. Mussen (Ed.), *Handbook of Child Psychology* (4th ed., Vol. 1). New York: Wiley.

Pittenger, D. J. (1993). The Utility of the Myers-Briggs Type Indicator. *Review of Educational Research, 63*(4), 467-488.

Postrel, S. (2002). Islands of shared knowledge: Specialization and mutual understanding in problem-solving teams. *Organization Science, 13*(3), 303.

Ramesh, B., & Tiwana, A. (1999). Supporting collaborative process knowledge management in new product development teams. *Decision Support Systems, 27*(1-2), 213-235.

Reinig, B. A. (2003). Toward an understanding of satisfaction with the process and outcomes of teamwork. *Journal of Management Information Systems, 19*(4), 65.

Rencher, A. C. (2001). *Methods of Multivariate Analysis* (2nd ed.). New York: John Wiley & Sons, Inc.

Rogers, Y. (1997). *A brief Introduction to distributed cognition* Unpublished manuscript, Brighton, UK.

Rose, C. L., Murphy, L. B., Byard, L., & Nikzad, K. (2002). The role of the big five personality factors in vigilance performance and workload. *European Journal of Personality, 16*(3), 185-200.

Rosson, M. B. (1996). Human factors in programming and software development. *ACM Computing Surveys, 28*(1), 193-195.

Rubio, S., Díaz, E., Martín, J., & Puente, J. M. (2004). Evaluation of Subjective Mental Workload: A Comparison of SWAT, NASA-TLX, and Workload Profile Methods. *Applied Psychology An International Review, 53*(1), 61-86.

Ryan, S. D., Bordoloi, B., & Harrison, D. A. (2000). Acquiring conceptual data modeling skills: the effect of cooperative learning and self-efficacy on learning outcomes. *31*(4), 9-24.

Sadler-Smith, E. (2001). The relationship between learning style and cognitive style. *Personality and Individual Differences, 30*(4), 609-616.

Saggino, A., Cooper, C., & Kline, P. (2001). A confirmatory factor analysis of the Myers-Briggs type indicator. *Personality and Individual Differences, 30*(1), 3-9.

Salas, E., & Cannon-Bowers, J. A. (2001). Shared cognition - Special issue preface. *Journal of Organizational Behavior, 22*, 87-88.

Salgado, J. F., Anderson, N., Moscoso, S., Bertua, C., de Fruyt, F., & Rolland, J. P. (2003). A Meta-Analytic Study of General Mental Ability Validity for Different Occupations in the European Community. *Journal of Applied Psychology 88*(6), 1068-1081.

Sampler, J. L., & Short, J. E. (1998). Strategy in dynamic information-intensive environments. *Journal of Management Studies, 35*(4), 429-436.

Satzinger, J. W. (1998). The effects of conceptual consistency on the end user's mental models of multiple applications. *Journal of End User Computing, 10*(3), 3-14.

Schael, T. (1998). *Workflow management systems for process organizations* (2nd ed.). Berlin: Springer.

Schmidt, F. L. (2002). The role of general cognitive ability and job performance: Why there cannot be a debate. *Human Performance, 15*(1-2), 187-210.

Schmidt, F. L., & Hunter, J. (2004). General Mental Ability in the World of Work: Occupational Attainment and Job Performance. *Journal of Personality & Social Psychology, 86*(1), 162-173.

Schneiderman, B., Mayer, R., McKay, D., & Heller, P. (1977). Experimental Investigations of the Utility of Detailed Flowcharts in Programming. *Communications of the ACM, 20*(6), 373-381.

Serve, M., Yen, D. C., Wang, J.-C., & Lin, B. (2002). B2B-enhanced supply chain process: Toward building virtual enterprises. *Business Process Management Journal, 8*(3), 245.

Shanteau, J., Weiss, D. J., Thomas, R. P., & Pounds, J. C. (2002). Performance-based assessment of expertise: How to decide if someone is an expert or not. *European Journal of Operational Research, 136*(2), 253-263.

Shayo, C., Olfman, L., & Teitelroit, R. (1999). An exploratory study of the value of pretraining end-user participation. *Information Systems Journal, 9*(1), 55-79.

Sheil, B. A. (1981). The psychological study of programming. *ACM Computing Surveys, 13*(1), 101-120.

Sheth, A. P., van der Aalst, W., & Arpinar, I. B. (1999). Processes driving the networked economy. *IEEE Concurrency, 7*(3), 31.

Shieh, G. (2003). A comparative study of power and sample size calculations for multivariate general linear models. *Multivariate Behavioral Research, 38*, 285-307.

Shoval, P., Danoch, R., & Balabam, M. (2004). Hierarchical entity-relationship diagrams: the model, method of creation and experimental evaluation. *Requirements Engineering, 9*(4), 217-228.

Sinha, A. P., & Vessey, I. (1992). Cognitive Fit - an Empirical-Study of Recursion and Iteration. *IEEE Transactions on Software Engineering, 18*(5), 368-379.

Smith, H., & Fingar, P. (2003). *Business process management: the third wave* (1st ed.). Tampa, Fla.: Meghan-Kiffer Press.

Soloway, E., Ehrlich, K., & Bonar, J. (1982). *Tapping into tacit programming knowledge.* Paper presented at the Proceedings of the conference on human factors in computing systems, Gaithersburg, Maryland, United States.

Staples, D. S., Hulland, J. S., & Higgins, C. A. (1999). A self-efficacy theory explanation for the management of remote workers in virtual organizations. *Organization Science, 10*(6), 758-776.

Sternberg, R. J., & Grigorenko, E. L. (1997). Are Cognitive Styles Still in Style? *American Psychologist, 52*(7), 700-712.

Strickland, B. B. (2001a). *The Gale encyclopedia of psychology* (2nd ed.). Detroit, MI: Gale Group.

Strickland, B. B. (2001b). Information-Processing Theory. In *Gale Encyclopedia of Psychology* (2nd ed.): Thomson Gale.

Suchman, L. A. (1987). *Plans and situated actions: the problem of human-machine communication*. Cambridge [Cambridgeshire]; New York: Cambridge University Press.

Susi, T., & Ziemke, T. (2001). Social cognition, artefacts, and stigmergy: A comparative analysis of theoretical frameworks for the understanding of artefact-mediated collaborative activity. *Cognitive Systems Research, 2*(4), 273-290.

Sutton, S. K., & Davidson, R. J. (1997). Prefrontal brain asymmetry: A biological substrate of the behavioral approach and inhibition systems. *Psychological Science, 8*(3), 204-210.

Teigen, K. H. (1994). Yerkes-Dodson: A law for all seasons. *Theory & Psychology, 4*(4), 525-547.

Tischler, L. (1994). The MBTI factor structure. *Journal of Psychological Type, 31*, 24-31.

Turban, E., King, D., Lee, J., Warkentin, M., & Chung, H. M. (2002). *Electronic Commerce: A Managerial Perspective* (2nd ed.). Upper Saddle River, NJ 07458: Prentice-Hall.

Tzeng, O. C. S., Outcalt, D., Boyer, S. L., Ware, R., & Landis, D. (1984). Item Validity of the Myers-Briggs Type Indicator. *Journal of Personality Assessment, 48*(3), 255-256.

Umanath, N. S., & Vessey, I. (1994). Multiattribute Data Presentation and Human Judgment - a Cognitive Fit Perspective. *Decision Sciences, 25*(5-6), 795-824.

Vacha-Haase, T., & Thompson, B. (2002). Alternative ways of measuring counselees' Jungian psychological-type preferences. *Journal of Counseling and Development, 80*(2), 173-179.

Valcke, M. M. A., & Dochy, F. J. R. C. (1992). *Knowledge Profiles of Students with Low and High Prior Knowledge States* (143 Reports--Research No. OTIC-RR-35). Netherlands: Open Univ., Heerlen (Netherlands). Centre for Educational Technological Innovation.

van der Aalst, W. M. P. (1994). Putting high-level Petri nets to work in industry. *Computers in Industry, 25*(1), 45-54.

van der Aalst, W. M. P. (2000). Loosely coupled interorganizational workflows: modeling and analyzing workflows crossing organizational boundaries. *Information & Management, 37*(2), 67-75.

van der Aalst, W. M. P. (2004). Business process management demystified: A tutorial on models, systems and standards for workflow management. In J. Desel, W. Reisig & G. Rozenberg (Eds.), *Lectures on Concurrency and Petri Nets* (Vol. 3098, pp. 1-65). Berlin: Springer-Verlag.

van der Aalst, W. M. P., Desel, J., & Oberweis, A. (2000). *Business process management: models, techniques, and empirical studies*: Springer.

van der Aalst, W. M. P., ter Hofstede, A. H. M., & Weske, M. (2003, June 26-27). *Business process management: A survey.* Paper presented at the Proceedings of the International Conference on Business Process Management (BPM 2003), Eindhoven, the Netherlands.

van Duijn, M., Keijzer, F., & Franken, D. (2006). Principles of minimal cognition: Casting cognition as sensorimotor coordination. *Adaptive Behavior, 14*(2), 157–170.

van Gerven, P. W. M., Paas, F. G. W. C., van Merrienboer, J. J. G., & Schmidt, H. G. (2002). Cognitive Load Theory and Aging: Effects of Worked Examples on Training Efficiency. *Learning and Instruction, 12*(1), 87-105.

van Merrienboer, J. J. G., Kirschner, P. A., & Kester, L. (2003). Taking the Load Off a Learner's Mind: Instructional Design for Complex Learning. *Educational Psychologist, 38*(1), 5-13.

van Merrienboer, J. J. G., Schuurman, J. G., de Croock, M. B. M., & Paas, F. G. W. C. (2002). Redirecting Learners' Attention during Training: Effects on Cognitive Load, Transfer Test Performance and Training Efficiency. *Learning and Instruction, 12*(1), 11-37.

Van Roon, A. M., Mulder, L. J. M., Althaus, M., & Mulder, G. (2004). Introducing a baroreflex model for studying cardiovascular effects of mental workload. *Psychophysiology, 41*(6), 961-981.

Varela, F. J., Thompson, E., & Rosh, E. (1999). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

Vernadat, F. B. (1996). *Enterprise modeling and integration: principles and applications*. London ; New York: Chapman & Hall.

Vernadat, F. B. (2002a). Enterprise modeling and integration (EMI): Current status and research perspectives. *Annual Reviews in Control, 26*(1), 15-25.

Vernadat, F. B. (2002b). UEML: towards a unified enterprise modelling language. *International Journal of Production Research, 40*(17), 4309-4321.

Vessey, I. (1991). Cognitive Fit - a Theory-Based Analysis of the Graphs Versus Tables Literature. *Decision Sciences, 22*(2), 219-240.

Vitense, H. S., Jacko, J. A., & Emery, V. K. (2003). Multimodal feedback: an assessment of performance and mental workload. *Ergonomics, 46*(1-3), 68-87.

Wagter, R. (2005). *Dynamic enterprise architecture: how to make it work*. Hoboken, N.J.: J. Wiley.

Wand, Y., & Weber, R. (1993). On the ontological expressiveness of information systems analysis and design grammars. *Journal of Information Systems, 3*(3), 217-237.

Wand, Y., & Weber, R. (2002). Research commentary: Information systems and conceptual modeling - A research agenda. *Information Systems Research, 13*(4), 363-376.

Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and workload in automated systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and Human Performance: Theory and Applications* (pp. 183-200). Mahwah, N.J.: Lawrence Erlbaum Associates.

Wensley, A. (2003). Business process management revisited. *Knowledge and Process Management, 10*(4), 217.

Weske, M., van der Aalst, W. M. P., & Verbeek, H. M. W. (2004). Advances in business process management. *Data & Knowledge Engineering, 50*(1), 1-8.

Wheeler, P., Jessup, C., & Martinez, M. (2002). The Keirsey Temperament Sorter: Investigating the impact of personality traits in accounting. *Advances in Accounting Behavioral Research*, 247-277.

Wickens, C. D. (1992). *Engineering psychology and human performance* (2nd ed.). New York, NY: HarperCollins Publishers.

Wickens, C. D., & Carswell, C. M. (1995). The proximity compatibility principle: its psychological foundation and relevance to display design. *Human Factors, 37*(3), 473-494.

Wilson, G. F., & Russell, C. A. (2003). Real-time assessment of mental workload using psychophysiological measures and artificial neural networks. *Human Factors, 45*(4), 635-643.

Winer, B. J., Brown, D. R., & Michels, K. M. (1991). *Statistical principles in experimental design* (3rd ed.). New York: McGraw-Hill.

Winslow, L. E. (1996). Programming Pedagogy -- A Psychological Overview. *SIGCSE Bulletin, 28*(3), 17-22.

Winsor, D. A. (2001). Learning to do knowledge work in systems of distributed cognition. *Journal of Business and Technical Communication, 15*(1), 5-28.

Winton, W. M. (1987). Do introductory textbooks present the Yerkes-Dodson Law correctly? *American Psychologist, 42*(2), 202-203.

Wohed, P., van der Aalst, W. M. P., Dumas, M., ter Hofstede, A. H. M., & Russell, N. (2004). *Pattern-based Analysis of UML Activity Diagrams* (No. WP 129). Eindhoven: Eindhoven University of Technology.

Wolf, C., & Harmon, P. (2006). *The State of Business Process Management* (Report): Business Process Trends.

Woltz, D. J. (2003). Implicit cognitive processes as aptitudes for learning. *Educational Psychologist, 38*(2), 95-104.

Woltz, D. J., Gardner, M. K., & Gyll, S. P. (2001). The role of attention processes in near transfer of cognitive skills. *Learning and Individual Differences, 12*(3), 209-251.

Wood, R. E., Atkins, P., & Tabernero, C. (2000). Self-efficacy and strategy on complex tasks. *Applied Psychology-an International Review-Psychologie Appliquee-Revue Internationale, 49*(3), 430-446.

Wood, R. E., & Bandura, A. (1989). Social Cognitive Theory of Organizational Management. *Academy of Management Review, 14*(3), 361-384.

Woodcock, R. W. (1990). Theoretical Foundations of the Wj-R Measures of Cognitive-Ability. *Journal of Psychoeducational Assessment, 8*(3), 231-258.

Woodcock, R. W. (2002). New Looks in the Assessment of Cognitive Ability. *Peabody Journal of Education, 77*(2), 6-22.

Wright, P. C., Fields, R. E., & Harrison, M. D. (2000). Analyzing human-computer interaction as distributed cognition: The resources model. *Human-Computer Interaction, 15*(1), 1-41.

Yanchar, R. J. (1984). *Hypnotic susceptibility and its relation to selective and divided attention.* Paper presented at the Meeting of the Society for Clinical and Experimental Hypnosis, San Antonio, TX.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*, 459-482.

Yeung, A. S., Lee, C. F. K., Pena, I. M., & Ryde, J. (2000, January 4-8). *Toward a Subjective Mental Workload Measure.* Paper presented at the International Congress for School Effectiveness and Improvement, Hong Kong, China.

Zachman, J. A. (1999). A framework for information systems architecture. *IBM Systems Journal, 38*(2-3), 454-470.

Zelm, M., Vernadat, F. B., & Kosanke, K. (1995). The CIMOSA business modelling process. *Computers in Industry, 27*(2), 142.

Zhang, J. (1996a). External representations in complex information processing tasks. In A. Kent, H. Lancour, W. Z. Nasri & J. E. Daily (Eds.), *Encyclopedia of Library and Information Science*. New York: Marcel Dekker, Inc.

Zhang, J. (1996b). A representational analysis of relational information displays. *International Journal of Human-Computer Studies, 45*(1), 59-74.

Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science, 21*(2), 179-217.

Zhang, J., & Norman, D. A. (1994). Representations in distributed cognitive tasks. *Cognitive Science, 18*(1), 87-122.

zur Muehlen, M. (2004a). Organizational Management in Workflow Applications Issues and Perspectives. *Information Technology and Management, 5*(3-4), 271-291.

zur Muehlen, M. (2004b). *What are Workflow and Business Process Management?*, from http://www.workflow-research.de/Research/index.html

zur Muehlen, M. (2004c). *Workflow-based Process Controlling. Foundation, Design, and Application of workflow-driven Process Information Systems*. Berlin: Logos Verlag.

APPENDIX

A INSTITUTIONAL REVIEW BOARD (IRB) DOCUMENTS

A.1 INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL DOCUMENTS

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Institutional Review Board

Dr. David M. Moore
IRB (Human Subjects)Chair
Assistant Vice President for Research Compliance
CVM Phase II- Duckpond Dr., Blacksburg, VA 24061-0442
Office: 540/231-4991; FAX: 540/231-6033
email: moored@vt.edu

DATE: August 3, 2005

MEMORANDUM

TO: Eileen M. Van Aken ISE 0118
Bret Swan

FROM: David Moore

SUBJECT: **IRB Expedited Approval:** "The Effects of Graphical Process Models on Business Process Management Task Outcomes" IRB # 05-470

This memo is regarding the above-mentioned protocol. The proposed research is eligible for expedited review according to the specifications authorized by 45 CFR 46.110 and 21 CFR 56.110. As Chair of the Virginia Tech Institutional Review Board, I have granted approval to the study for a period of 12 months, effective August 3, 2005.

Virginia Tech has an approved Federal Wide Assurance (FWA00000572, exp. 7/20/07) on file with OHRP, and its IRB Registration Number is IRB00000667.

cc: File
Department Reviewer: Thurmon E. Lockhart
T. Coalson 0118

A Land-Grant University - Putting Knowledge to Work
An Equal Opportunity/Affirmative Action Institution

VirginiaTech

Office of Research Compliance
Institutional Review Board
1880 Pratt Drive (0497)
Blacksburg, Virginia 24061
540/231-4991 Fax: 540/231-0959
E-mail: moored@vt.edu
www.irb.vt.edu
FWA00000572(expires 7/20/07)
IRB # is IRB00000667.

DATE: July 21, 2006

MEMORANDUM

TO: Eileen M. Van Aken
Bret Swan

Approval date: 8/3/2006
Continuing Review Due Date:7/19/2007
Expiration Date: 8/2/2007

FROM: David M. Moore

SUBJECT: **IRB Expedited Continuation 1:** "The Effects of Graphical Process Models on Business Process Management Task Outcomes" , IRB # 05-470

This memo is regarding the above referenced protocol which was previously granted expedited approval by the IRB. The proposed research is eligible for expedited review according to the specifications authorized by 45 CFR 46.110 and 21 CFR 56.110. Pursuant to your request, as Chair of the Virginia Tech Institutional Review Board, I have granted approval for extension of the study for a period of 12 months, effective as of August 3, 2006.

Approval of your research by the IRB provides the appropriate review as required by federal and state laws regarding human subject research. As an investigator of human subjects, your responsibilities include the following:

1. Report promptly proposed changes in previously approved human subject research activities to the IRB, including changes to your study forms, procedures and investigators, regardless of how minor. The proposed changes must not be initiated without IRB review and approval, except where necessary to eliminate apparent immediate hazards to the subjects.
2. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.
3. Report promptly to the IRB of the study's closing (i.e., data collecting and data analysis complete at Virginia Tech). If the study is to continue past the expiration date (listed above), investigators must submit a request for continuing review prior to the continuing review due date (listed above). It is the researcher's responsibility to obtained re-approval from the IRB before the study's expiration date.
4. If re-approval is not obtained (unless the study has been reported to the IRB as closed) prior to the expiration date, all activities involving human subjects and data analysis must cease immediately, except where necessary to eliminate apparent immediate hazards to the subjects.

cc: File
Department Reviewer:Thurmon E. Lockhart
T. Coalson 0118

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE UNIVERSITY AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

A.2 INSTITUTIONAL REVIEW BOARD (IRB) PARTICIPANT DOCUMENTS

Informed Consent for Participants of Investigative Projects
Grado Department of Industrial and Systems Engineering
Virginia Tech

TITLE: The Effects of Graphical Process Models on Business Process Management Task Outcomes

INVESTIGATORS: Eileen M. Van Aken, Ph.D. and Bret Swan

PURPOSE

The objective of this study is to evaluate factors affecting the ease, accuracy, and time it takes participants to interpret different types of graphical process models that portray business process management (BPM) information.

PROCEDURE

If you choose to participate in this study, you will be asked to do the following:

- Complete pretest assessments of your personal preferences for understanding information, your ability to focus your attention, your general cognitive abilities, and your educational background related to this study.
- Complete a short training to give you a basic understanding of one type of graphical process model.
- Complete four short questionnaires assessing how well you understanding of BPM information portrayed by a single type of graphical process model.

The estimated amount of time required for each student to participate in the study will total approximately 3 hours: about 1-2 hours to complete the pretest assessments (on their own time before the actual lab experiment) and between 30 and 60 minutes for the training and experimental tasks in the lab itself.

If you choose to participate, you will be given a set of pretest assessments to fill out at your own leisure before a given date. You will then be asked to sign up for a single block of time to complete both the training and experimental tasks. At the end of the experiment, your performance on the experimental tasks will be evaluated in terms of both accuracy and timeliness.

RISKS OF PARTICIPATION

The risk involved with this study only includes those associated with normal use of a computer.

BENEFITS and COMPENSATION

After the study is completed, you will receive a personal profile of your scores and what they mean from your MBTI, Wonderlic, and DAPI assessments.

Additionally, you will have the opportunity to win one of two gift certificates. The participant with the best overall experimental task score (calculated by combining both your task accuracy and task timeliness results into a single score) will receive a $200 gift certificate to the business of your choice. In addition, the participant with the best overall score from each academic discipline (industrial engineering courses, computer science courses, and management courses) will receive a $100 gift certificate.

ANONYMITY AND CONFIDENTIALITY
The data from this study will be kept strictly confidential. No data will be released to anyone but the principal investigator and graduate students involved in the project without written consent of the subject. Data will be identified by participant ID number.

FREEDOM TO WITHDRAW
You are free to withdraw at any time from the study for any reason. Circumstances may come up that the researcher will determine that you should not continue as a subject in the study. For example, an illness, computer failure, or responses on your questionnaire that do not meet the criteria for selection for participation could be reasons to have the researchers stop your participation in the study.

APPROVAL OF RESEARCH
This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Tech, and by the Grado Department of Industrial and Systems Engineering. You will receive a copy of this form to take with you.

SUBJECT PERMISSION
I have read the informed consent and fully understand the procedures and conditions of the project. I have had all my questions answered, and I hereby give my voluntary consent to be a participant in this research study. I agree to abide by the rules of the project. I understand that I may withdraw from the study at any time.

If I have questions, I will contact:

- Principal Investigator: Bret Swan, Ph.D. Candidate, Grado Department of Industrial and Systems Engineering, 230-2789 or bswan@vt.edu.
- Chairman, Institutional Review Board for Research Involving Human Subjects: David Moore, 231-4991.

Signature of Participant

____ Date:

Signature of Project Director or his Authorized Representative:

____ Date:

Signature of Witness to Oral Presentation:

____ Date:

B PILOT STUDY: PARTICIPANT SCRIPTS & HANDOUTS

The following documents and scripts were given to participants that participate in the experiment.

B.1 PILOT TRAINING TASK SCRIPTS

[NOTE: The following task introduction was given to participants. Brackets indicate wording that was changed depending on the Type of Graphical Process Modeling technique participants will use when performing the task.]

This experiment consists of two phases: a training phase and an experimental phase. During the training phase, you will be given instruction and allowed to practice interpreting simplified diagrams of a business process. During the experimental phase, you will apply what you have learned to the interpretation of diagrams that represent a real-world business process.

<u>Training Phase:</u>

In order to train you in how to interpret *[this type] of graphical process model, you will play the role of a new manager in a bank that is trying to understand your bank's loan application process. This business process takes the completed loan application of the customer and performs several tasks that use different types of resources and information, to determine whether an application for a loan is to be accepted or rejected. You have been asked to read and interpret three different graphical process models that depict three different views of the same loan application process:

(a) A task-centric view of the loan application process

(b) A resource-centric view of the loan application process

(c) An information-centric view of the loan application process

Your training will proceed in this order:

(1) You will be presented with one of the above diagrams.

(2) You will be read the document that will explain how to read and interpret the symbols on this diagram.

(3) You will be asked to answer some questions that allow you to practice interpreting this type of diagram.

(4) When you have completed the short training on this diagram, you will be presented with the 2nd type of diagram and repeat steps 2 and 3.

(5) When you have completed the practice questions for the 2nd type of diagram, you will be presented with the 3rd type of diagram and repeat steps 2 and 3.

(6) When you have completed the practice questions for the 3rd type of diagram, you will be asked to answer practice questions about how the 1st, 2nd, and 3rd diagrams interact. You will only be allowed to proceed to step 7 when you have answer all the practice questions correctly.

(7) When you have completed step 6, you will be asked to fill out a survey that assesses the mental effort you had to apply to this training exercise.

(8) Once step 7 is completed, you will have completed the training and are ready to begin the experimental phase.

The experimental phase will proceed in a similar way to the training phase, except (a) the diagrams will be different, (b) you will be asked to answer a few more questions about each diagram – these will be the same kinds of questions you answered in the training phase, and (c) you will be asked to complete the mental workload questionnaire after each set of questions – instead of only at the end as in the training phase.

REMEMBER!

During the experiment, you will win the gift certificates if you have BOTH the highest number of correct answers AND the lowest time spent answering the questions. In other words, you are trying to maximize how many questions you answer correctly and minimize the amount of time you take to answer those questions.

Good Luck!!

B.2 PILOT TRAINING TASK DESCRIPTION – BANK LOAN APPROVAL PROCESS

Task Description: The training tasks you are based on a loan approval business process[1]. You represent a manager in this company that has been asked to read and interpret graphical process models that describe different types of BPM task information prior to attending an important meeting to discuss this business process. The loan approval process is modeled as using [UML, Petri net, or metagraph] diagrams. The following is a key to the abbreviations used in these maps as follows:

- *A task is an ordered pair of reports, the first of which is an input to the task and the second of which is its output. A task is executed when the inputs are used to determine the outputs. *For example,
- *A resource is an entity associated with one or more tasks, and the resource must be available if the tasks are to be executed. Several resources may be associated with a single task, and vice versa. Resources may be people, a statement of information, software, an information system, or a document (called an 'abstract') in the context of this experiment. For example,
- *An information element is an atomic data item. For example, an individual or set of numbers, characters, words, images, or icons (as would be found in a document).
- *A process is a set of tasks that connects one set of information elements, to another set of information elements. All inputs for any task in the process must be either in the source or in the output of some other task(s) in the system.

There are eight tasks in the loan approval process, as follows:

T_1: Credit Risk Rating - The loan officer uses account data, the applicant's credit history, and applicant data to calculate the applicant's credit rating.

T_2: Property Appraisal Task - The property appraiser uses data about the property along with data about comparable properties to calculate the appraised value of the property.

T_3: Risk Assessment Task - The loan officer uses the applicant's credit rating, the appraised value of the property, and the loan amount to calculate the level of risk associated with the loan.

[1] adapted from Basu and Blanning (2000)

T_4: Loan Amount Reduction Task - If the risk of the loan is determined to be a bad risk, the branch manager uses the appraised value of the property and the level of risk associated with the loan to calculate a new loan amount.

T_5: Risk Exposure Assessment Task - The risk analyst and the property appraiser use the appraised value of the property, the loan amount, and the current bank portfolio of loans to calculate the bank's current risk exposure.

T_6: Acceptable Risk Assessment Task - The system examines the risk associated with the loan and performs the calculations needed to determine whether the risk is acceptable.

T_7: The Loan is Approved - If the level of risk is acceptable, the loan officer uses the risk associated with the loan and the bank's risk exposure to decide whether to approve the loan.

T_8: The Loan is Rejected - If the loan application represents a bad risk, the loan officer rejects the application.

There are six resources used in the loan application process:

- R_1: a property appraiser;
- R_2: the branch manager;
- R_3: a loan officer;
- R_4: a risk analyst;
- R_{10}: a completed loan application from a customer;
- R_{11}: an automated bank information system;

Finally, there are information elements in the loan approval process:

- IE_1: account data of the applicant;
- IE_2: applicant data from the loan application;
- IE_3: credit history of the applicant;
- IE_4: data about the property for which the loan is sought;
- IE_5: data about comparable properties;
- IE_6: applicant's credit rating;
- IE_7: the amount of the loan;
- IE_8: the appraised value of the property;
- IE_9: the current bank portfolio of loans;
- IE_{10}: the bank's level of acceptable risk;
- IE_{11}: the level of risk associated with the loan;
- IE_{12}: the bank's current risk exposure;
- IE_{13}: a statement that the application is approved;
- IE_{14}: a statement that the application is rejected.

B.3 PILOT EXPERIMENTAL TASK SCRIPTS

Introduction to the Experimental Tasks

Now that training is completed, you will be asked to follow a similar procedure to complete the experimental tasks.

For this experiment, consider the example of a business process that determines the daily status of a billing monitoring control points that are required to fulfill Sarbanes-Oxley (SOX) compliance.

Experimental Task Description – A Sarbanes-Oxley Business Process

Sarbanes-Oxley (SOX) laws are a set of recent federal regulations that mandate the auditability of business accounting and operational processes, in order to avoid the types of scandals and company failures that occurred recently in companies such as Enron and WorldCom.

You work for a company that prepares bills and records payments for millions of customers per month. Currently, your organization complies with Sarbanes-Oxley federal laws using very a labor intensive process. Your company is beginning the process of preparing to implement a SOX Business Process Management (BPM) information system. In order to implement this new information system, the SOX business process must be diagrammed using graphical process models and then managers with specific functional expertise across the organization must verify that the models are correct. You represent one of these managers that will participate in the development and implementation of the new SOX BPM information system.

Your Assignment

Your current assignment is to understand the daily SOX business process as part of your responsibilities on the BPM system development team. You have been asked to review and interpret graphical process models that describe the SOX business process your company uses prior to an important meeting in which you will assist other managers in providing feedback on the development of the new SOX BPM information system.

Your normal duties do not include performance of this process; therefore, you are not expected to have any prior knowledge of the SOX business process or its components. What's more, this is the first time that any manager in the company has seen the process modeled in this way, therefore you are not expected to have any previous expertise with reading and interpreting these graphical models that describe the company's SOX business process.

Background on the SOX Business Process

The SOX business process is performed and completed daily. A SOX manager begins the process each day by saving a blank copy of the SOX Billing Process Monitoring (BPM) template using Adobe Acrobat. The current day's date is added to the current day's unsigned, unlocked SOX BPM document (see Table B-1 below).

There are four control points that this manager must reconcile and report on the status each day. The manager opens the reports associated with each control point and checks values within these reports to see if the values match. If the values match, the manager records on the SOX BPM template that they reconcile and moves on to another control point.

If the values do not match, or if the reports are not available, the manager opens a ticket in the Issue Tracker system and records the problem. He or she then seeks to resolve the issue. If the issue is resolved and the values on the reports reconcile, the manager records the resolution in the Issue Tracking system, closes the issue, records the Issue Tracking identification number on the SOX BPM document, records the issue as reconciled on the SOX BPM template, and then moves to reconciling another control point.

If the control point cannot be reconciled within the work day, the manager records this as an outstanding issue in the Issue Tracking system, records the Issue Tracking identification number on the SOX BPM document, and records the issue as not being reconciled on the SOX BPM document. He or she also adds notes that briefly explain the issue and what has been done that day to resolve it.

Table B-1. A Blank Sarbanes-Oxley Billing Process Monitoring (BPM) Document

Process Name	**Daily Sarbanes-Oxley (SOX) Billing Process Monitoring Control Points S01, S02, S03, and S04**
Date	
Who to Contact	
Sarbanes-Oxley (SOX) Reference Number	

What to verify daily:				
S01 **Does the *ALPHA Biller report* [SOX BPM System] match the *Daily Bank Files Received Report* YY/MM/DD for USA Bank totals [email]?**	**Status**	**Yes**	**Go to next step**	
		No	**Investigate**	**Issue #:**
S02 **Does the *BETA Biller Report* [SOX BPM System] match the *Payment Log for BETA Billers* [email]?**	**Status**	**Yes**	**Go to next step**	
		No	**Investigate**	**Issue #:**
S03 **Does the *DELTA Card Report* [SOX BPM System] match the *DELTA Biller Report* [email entitled: DELTA Card Payment]?**	**Status**	**Yes**	**Go to next step**	
		No	**Investigate**	**Issue #:**
S04 **Does the expected files column on the *ECHO Primary BPM Report* [SOX BPM System] match the *ALPHA Biller Report* [SOX BPM System]?**	**Status**	**Yes**	**End of procedure**	
		No	**Investigate**	**Issue #:**

All control points can either be worked sequentially or in parallel. At the end of the day the manager places his or her electronic signature on each control point (using Adobe Acrobat) to certify the reconciliation status of each control point.

Once the SOX manager certifies (i.e. signs off on) all the control points, unlocked, unsigned SOX BPM template is passed to the Center Manager for her review and signature. The

Center Manager (a) reviews the unsigned, unlocked SOX BPM document for errors and to clarify outstanding issues, (b) makes any notes on the document that she deems necessary, and (c) uses the Adobe Acrobat to electronically sign the document. The signed, unlocked SOX BPM document is then locked using Adobe Acrobat security settings so that no changes can be made to the document by others. (This is a required for SOX compliance.) The signed and locked SOX BPM document is then placed in the appropriate folder on the SOX network drive for SOX documentation and archiving purposes. The process starts over the next day.

Your Objective in this Experiment

The purpose of this study is to see how well you are able to interpret these depictions with the minimal experience and training provided to you. You will be asked to answer four separate sets of questions about three different views of the billing process:

(a) Interpret *process management information* using a task-centric [metagraph/UML]* diagram.

(b) Interpret *resource allocation information* using a resource-centric [metagraph/ UML]* diagram.

(c) Interpret *information systems analysis information* using an information-centric [metagraph/ UML]* diagram.

Interpret interactions between the tasks, resources, and information elements portrayed on these three [metagraph/UML]* diagrams.

You will be asked to answer questions for each section of the sections of the experiment above (A, B, C, and D). After completing each set of questions for A, B, C, and D listed above, you will please fill-out the questionnaire assessing the mental workload you experienced while performing that task.

Are there any questions?

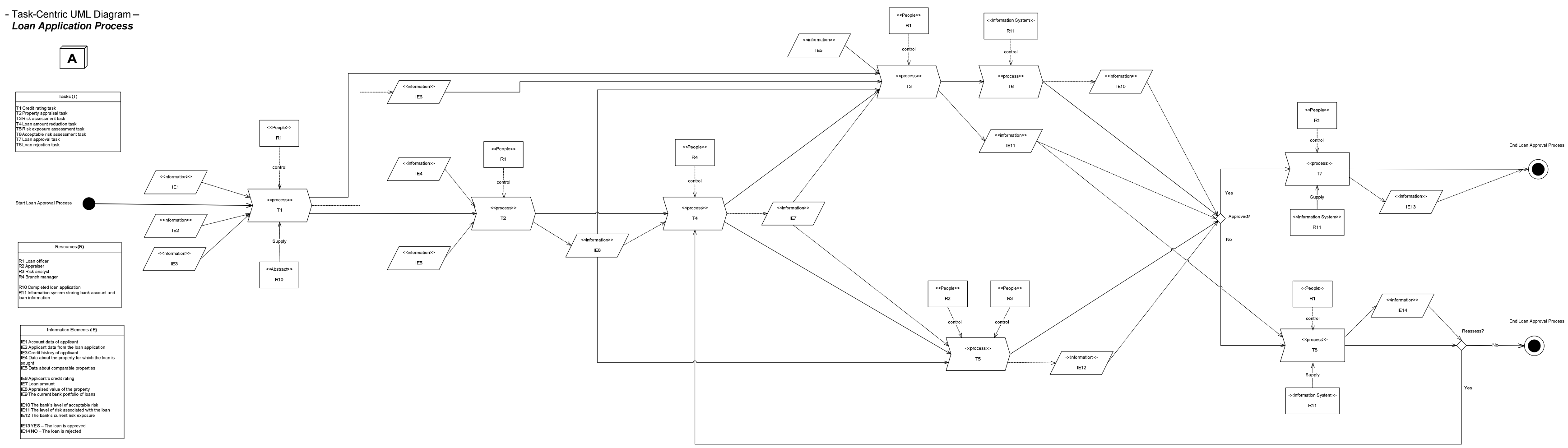
You may begin the experiment by opening to your first map and answering the associated questions.

C UML GRAPHICAL PROCESS MODELS: USED FOR THE PILOT STUDY TRAINING TASK & USED FOR THE EXPERIMENTAL TASK IN THE ACTUAL STUDY

Participants used the following UML diagrams in the Pilot Study Training Tasks and in the Actual Experiment in the experiment tasks.

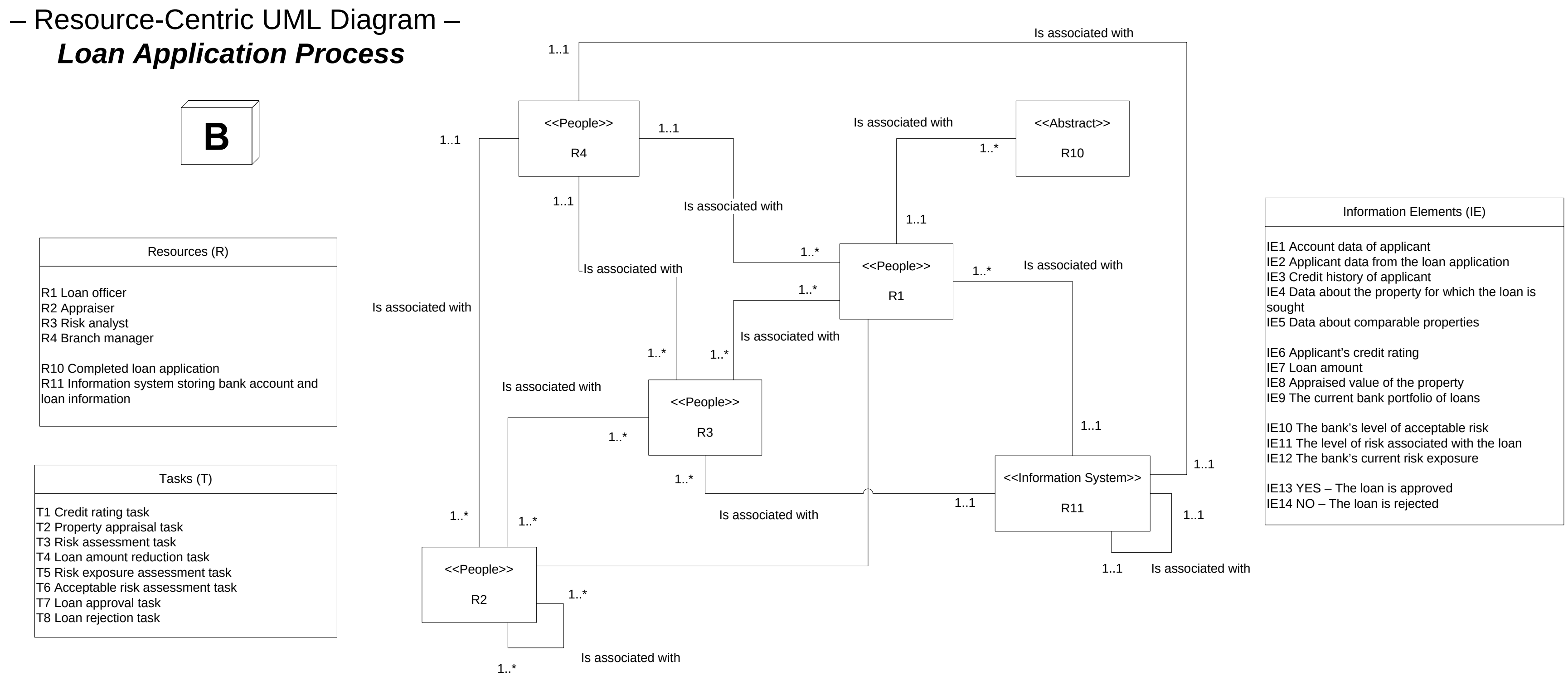
C.1 TASK-CENTRIC UML DIAGRAM

Used in the Pilot Study as the Training Diagrams and the Actual Experiment in the Experimental Task



C.2 RESOURCE-CENTRIC UML DIAGRAM

Used in the Pilot Study as the Training Diagrams and the Actual Experiment in the Experimental Task

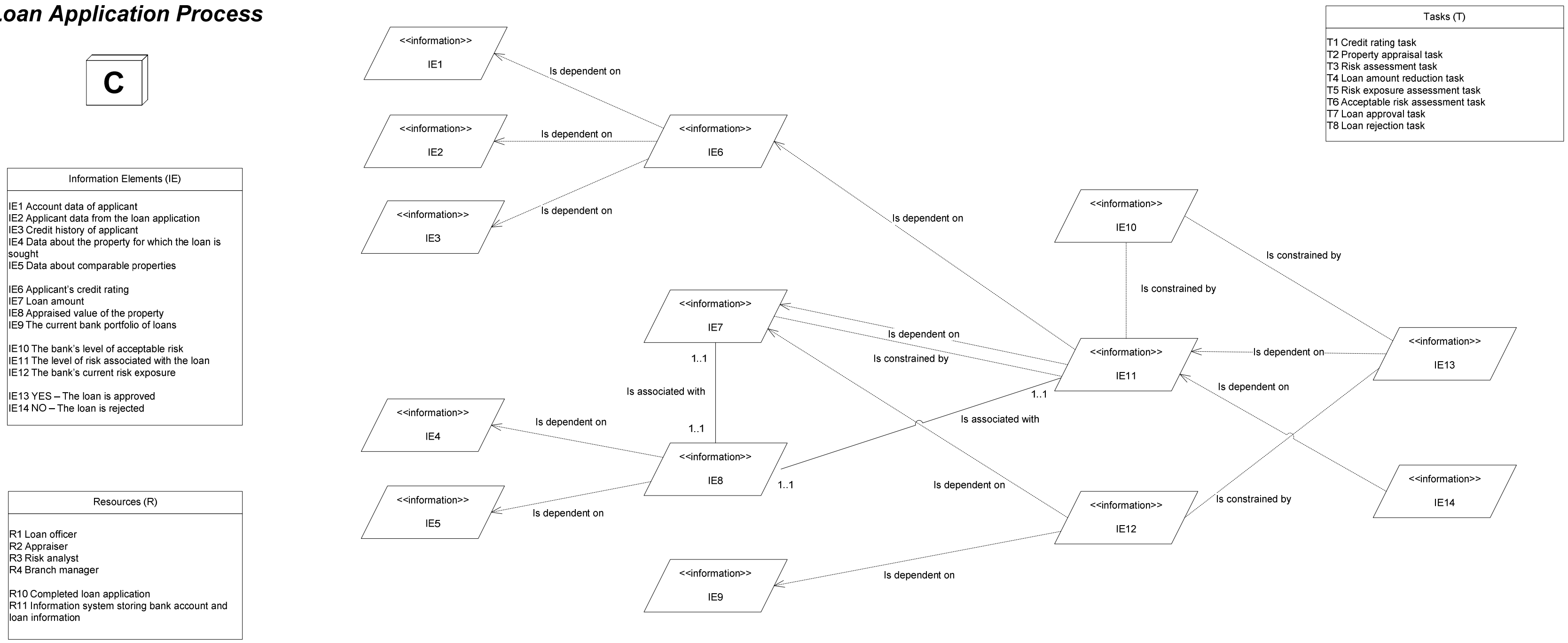


C.3 INFORMATION-CENTRIC UML DIAGRAM -

Used in the Pilot Study as the Training Diagrams and the Actual Experiment in the Experimental Task

- Information-Centric UML Diagram –

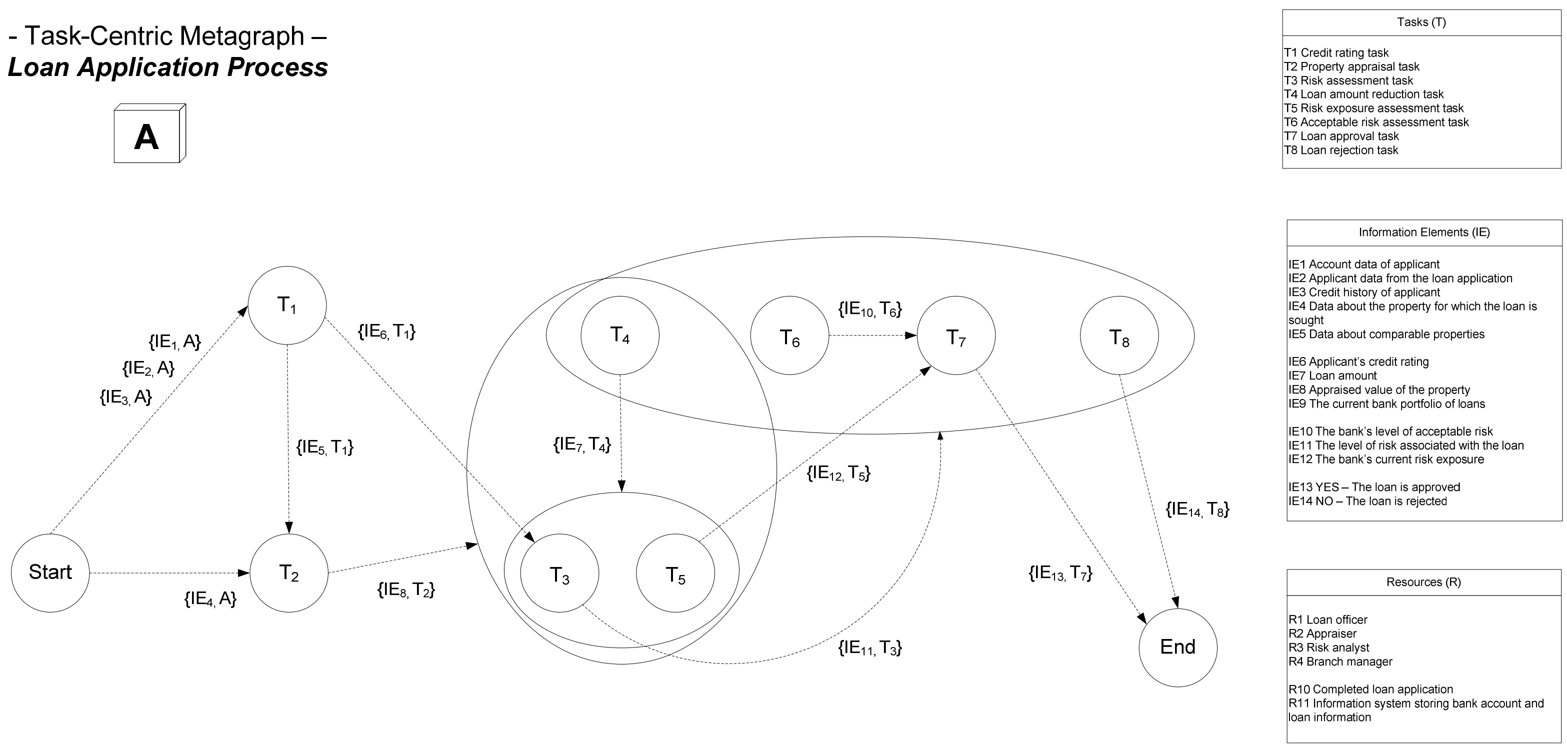
Loan Application Process



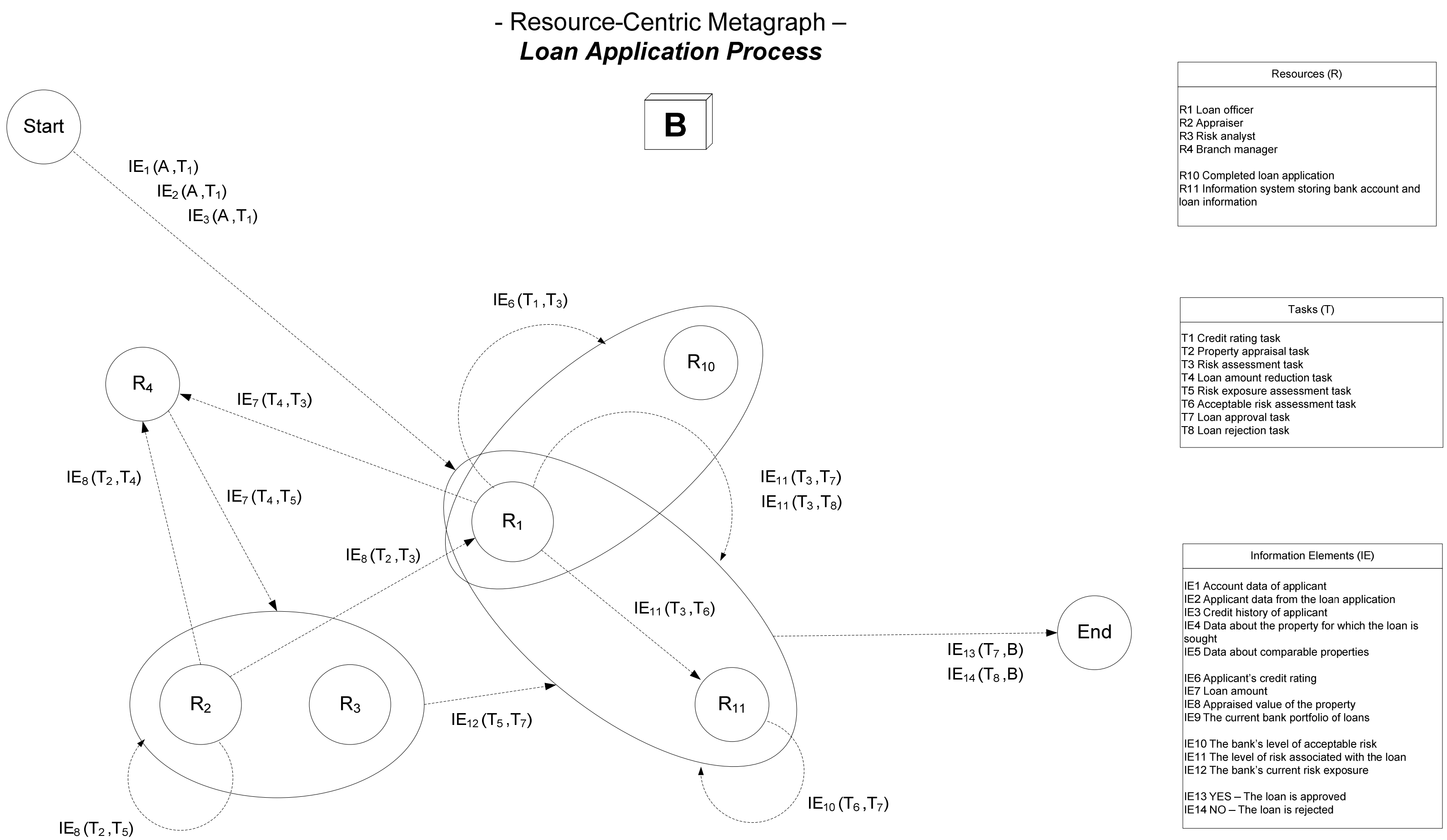
D METAGRAPH GRAPHICAL PROCESS MODELS: USED FOR THE PILOT STUDY TRAINING TASK & USED FOR THE EXPERIMENTAL TASK IN THE ACTUAL STUDY

Participants used the following metagraph diagrams in the Pilot Study Training Tasks and in the Actual Experiment in the experiment tasks.

D.1 TASK-CENTRIC METAGRAPH DIAGRAM



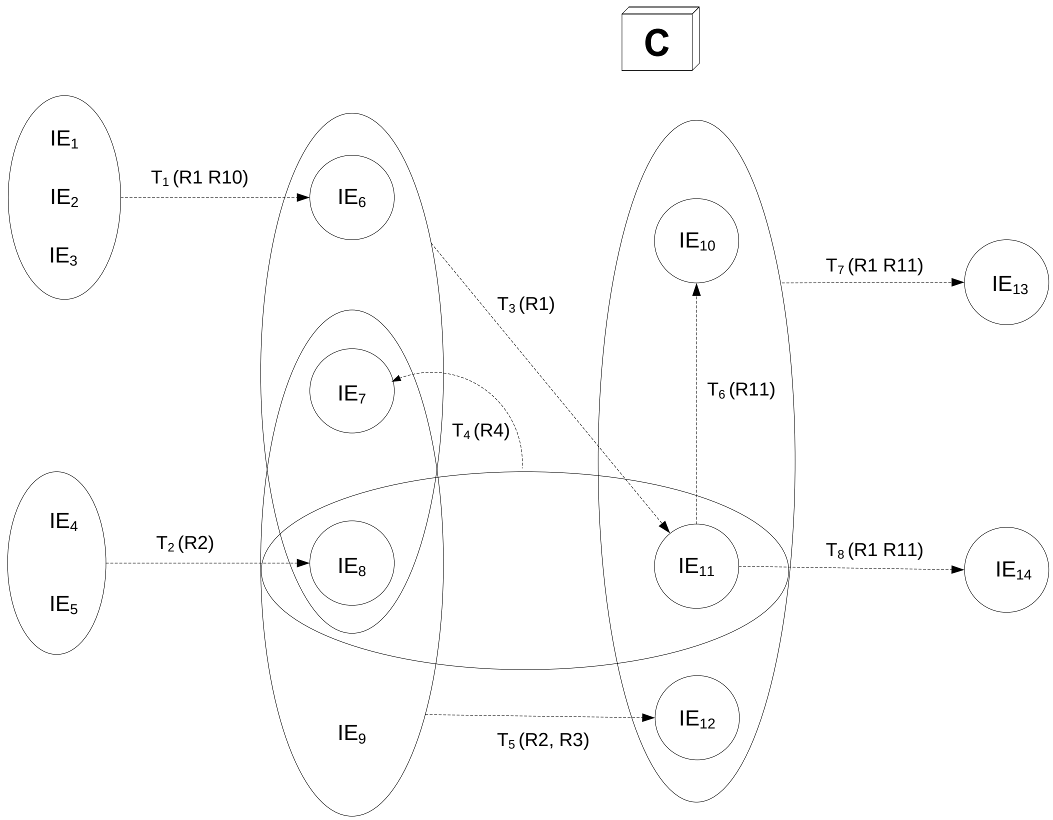
D.2 RESOURCE-CENTRIC METAGRAPH DIAGRAM



D.3 INFORMATION-CENTRIC METAGRAPH DIAGRAM

- Information-Centric Metagraph -

Loan Application Process



Information Elements (IE)

IE1 Account data of applicant
IE2 Applicant data from the loan application
IE3 Credit history of applicant
IE4 Data about the property for which the loan is sought
IE5 Data about comparable properties

IE6 Applicant's credit rating
IE7 Loan amount
IE8 Appraised value of the property
IE9 The current bank portfolio of loans

IE10 The bank's level of acceptable risk
IE11 The level of risk associated with the loan
IE12 The bank's current risk exposure

IE13 YES – The loan is approved
IE14 NO – The loan is rejected

Tasks (T)

T1 Credit rating task
T2 Property appraisal task
T3 Risk assessment task
T4 Loan amount reduction task
T5 Risk exposure assessment task
T6 Acceptable risk assessment task
T7 Loan approval task
T8 Loan rejection task

Resources (R)

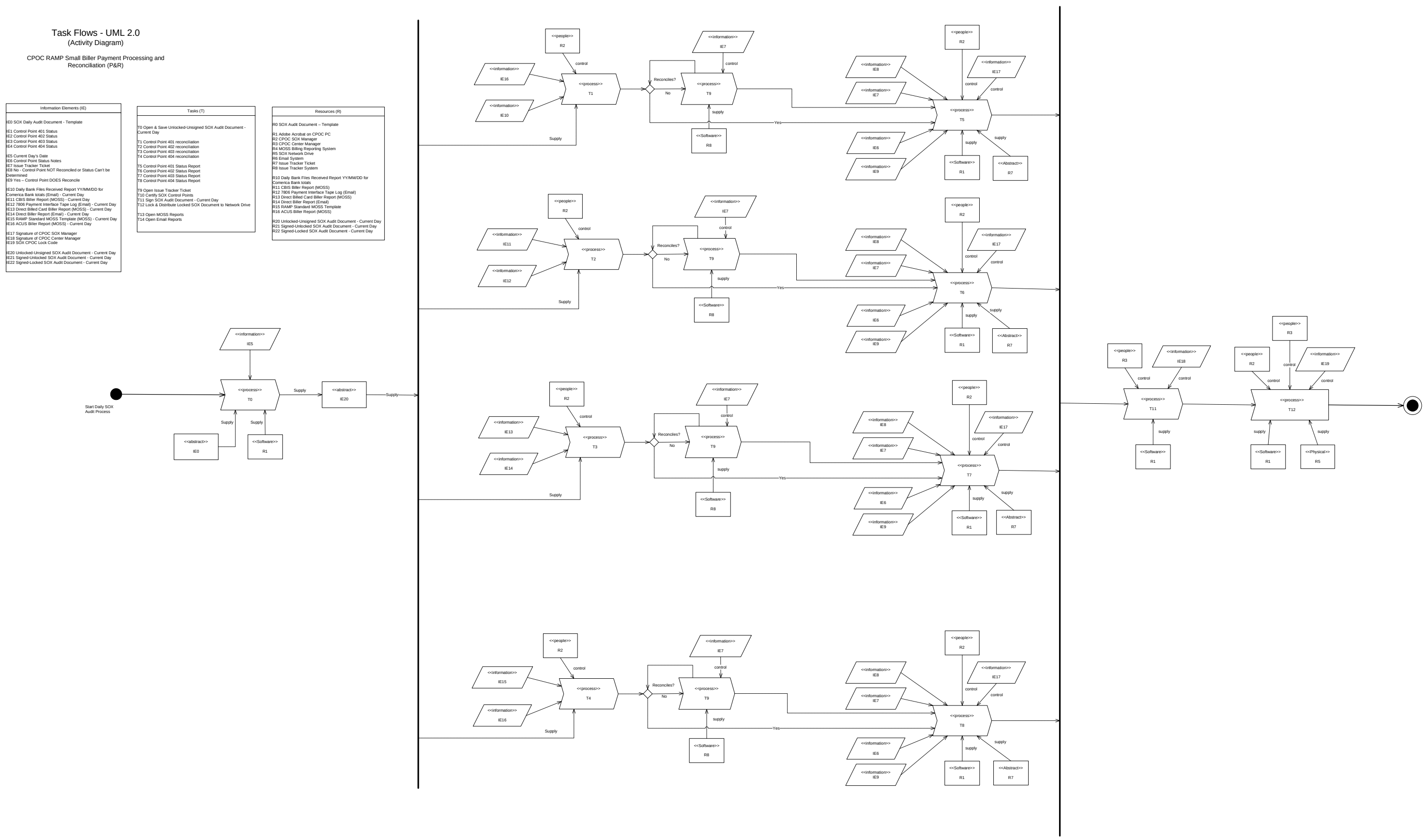
R1 Loan officer
R2 Appraiser
R3 Risk analyst
R4 Branch manager

R10 Completed loan application
R11 Information system storing bank account and loan information

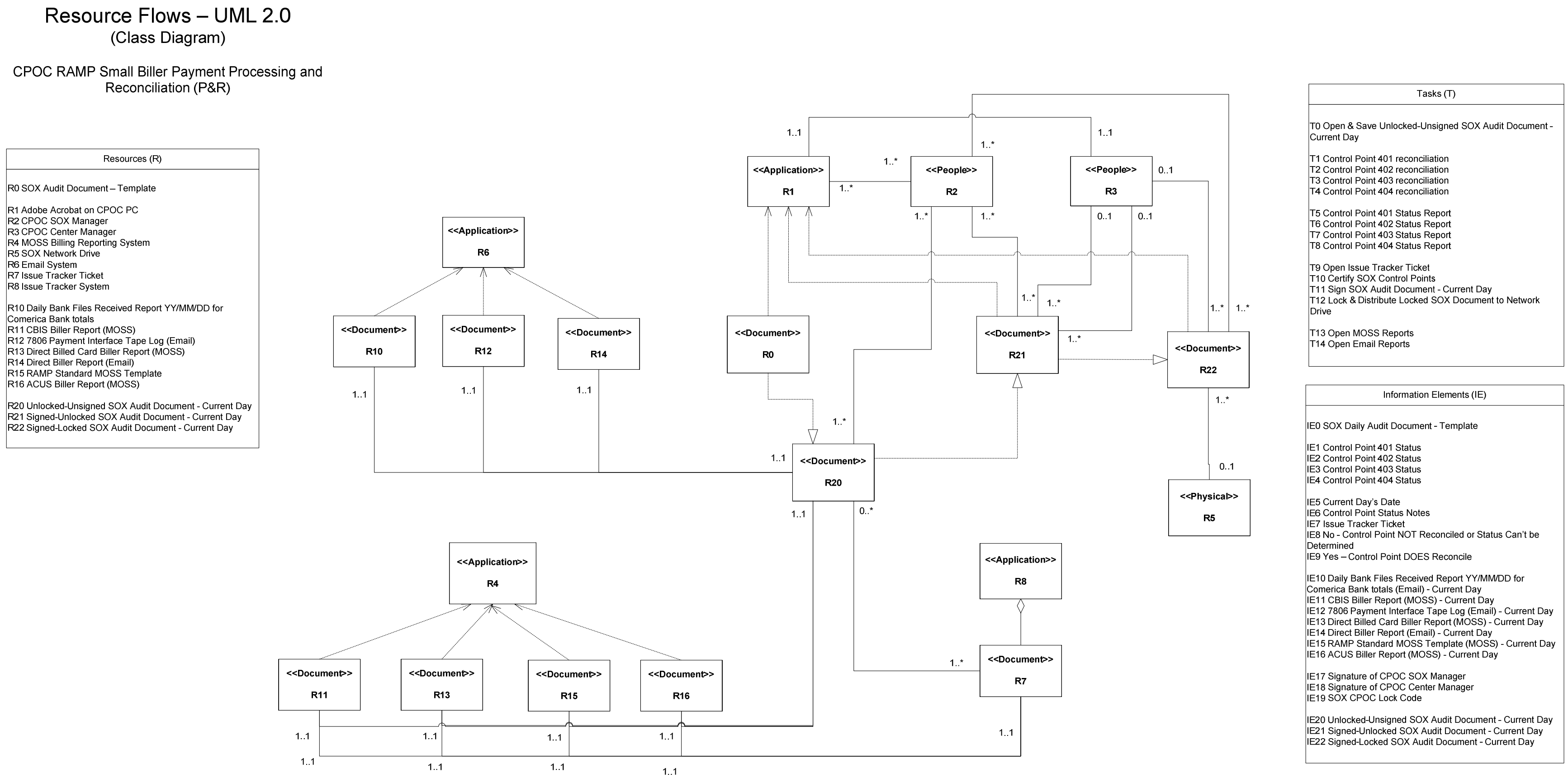
E EXPERIMENT UML GRAPHICAL PROCESS MODELS USED IN THE PILOT STUDY

Participants in the pilot study were asked in the experimental tasks to interpret the following UML diagrams.

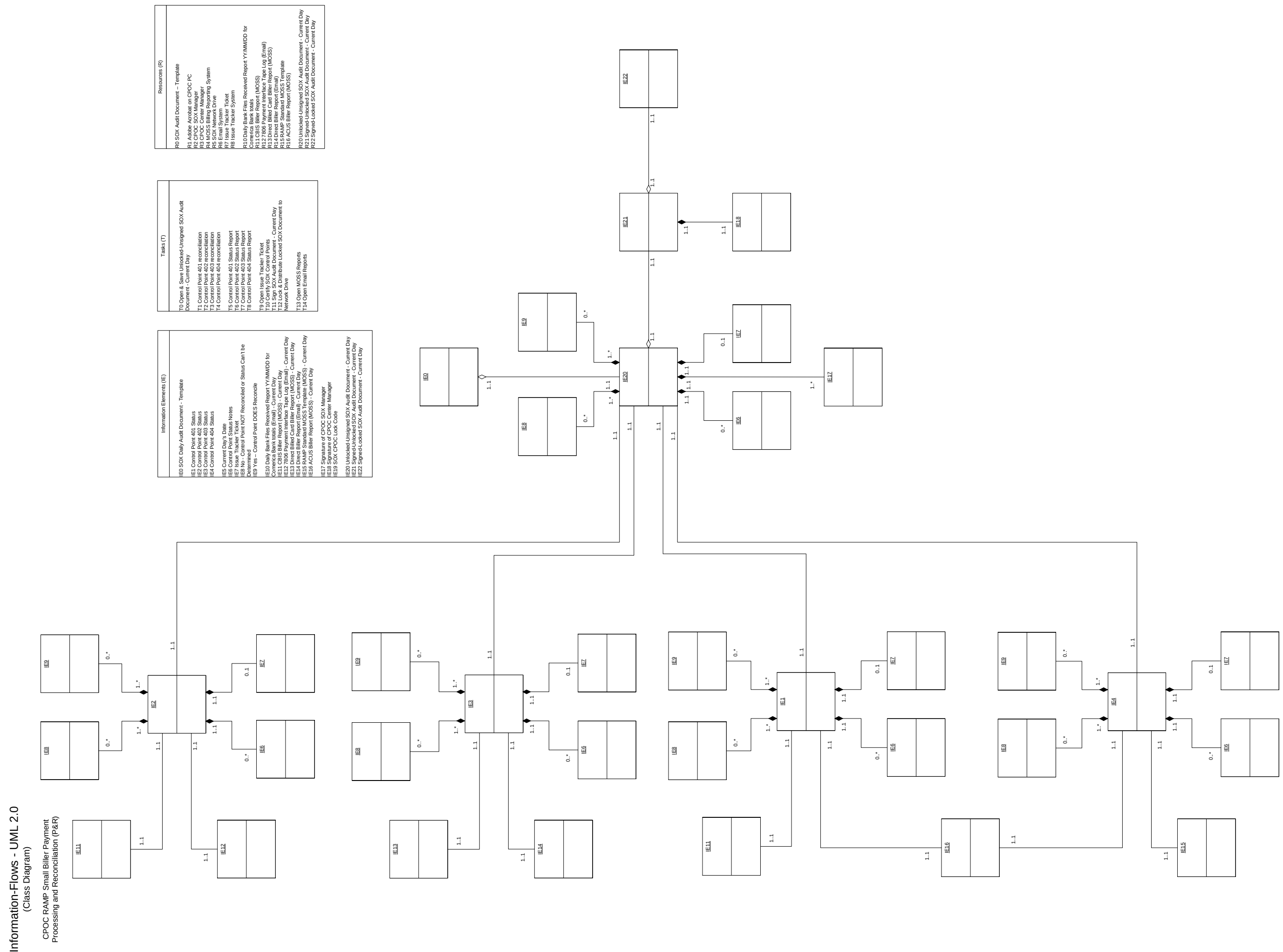
E.1 PILOT EXPERIMENT TASK-CENTRIC UML DIAGRAM



E.2 Pilot Experiment Resource-Centric UML Diagram



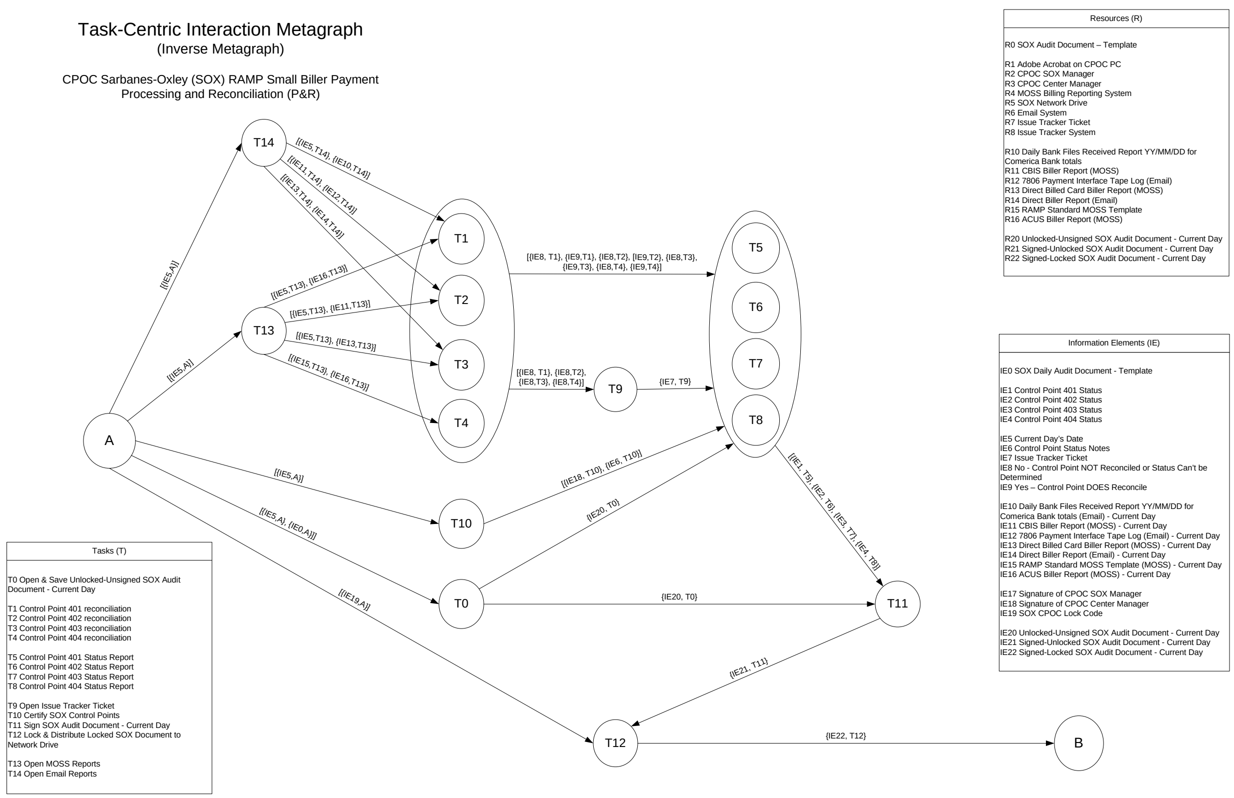
E.3 PILOT EXPERIMENT INFORMATION-CENTRIC UML DIAGRAM



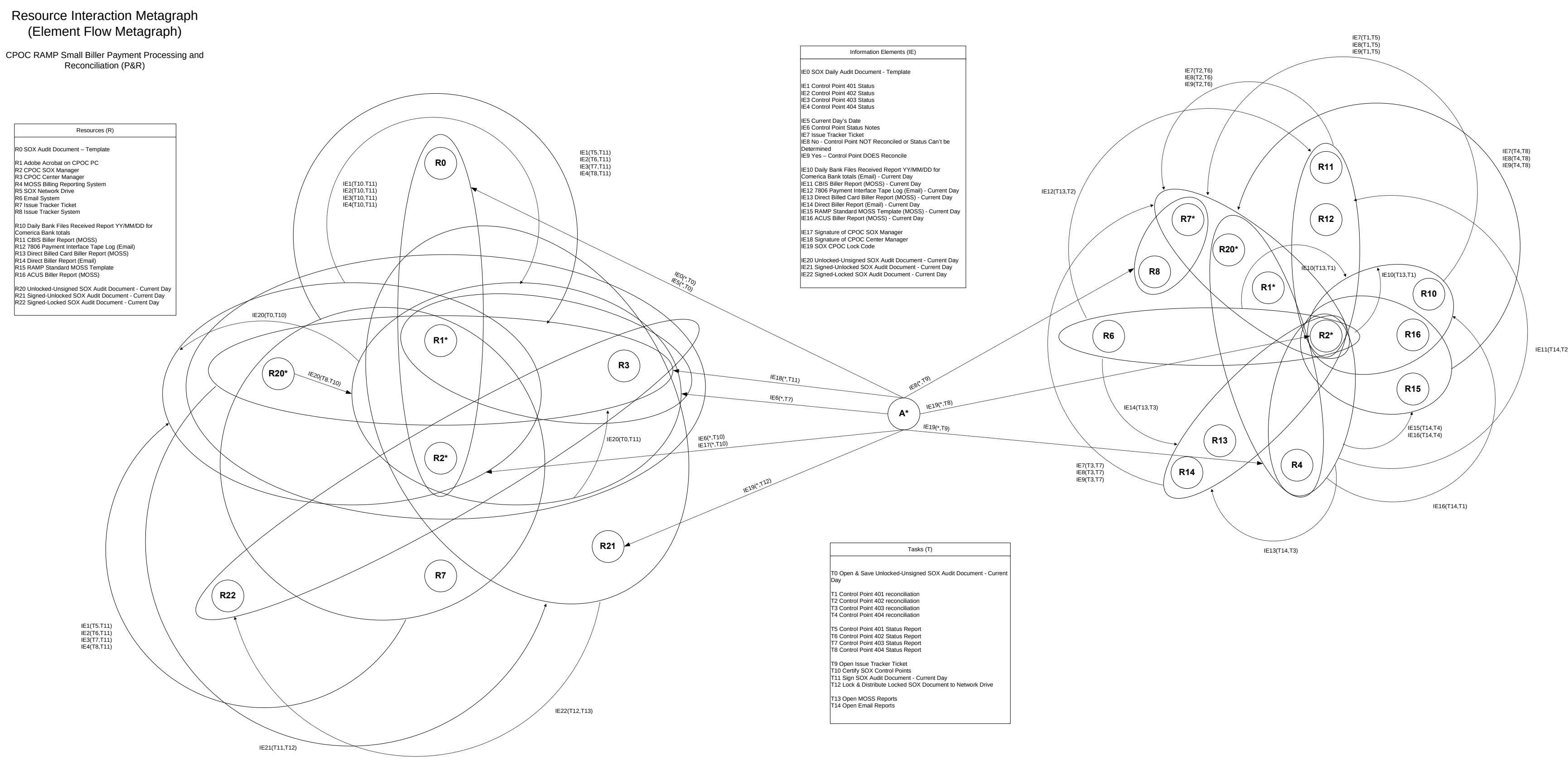
F EXPERIMENT METAGRAPH GRAPHICAL PROCESS MODELS USED IN THE PILOT STUDY

Participants in the pilot study were asked in the experimental tasks to interpret the following metagraph diagrams deemed unsuitable for the actual experiment.

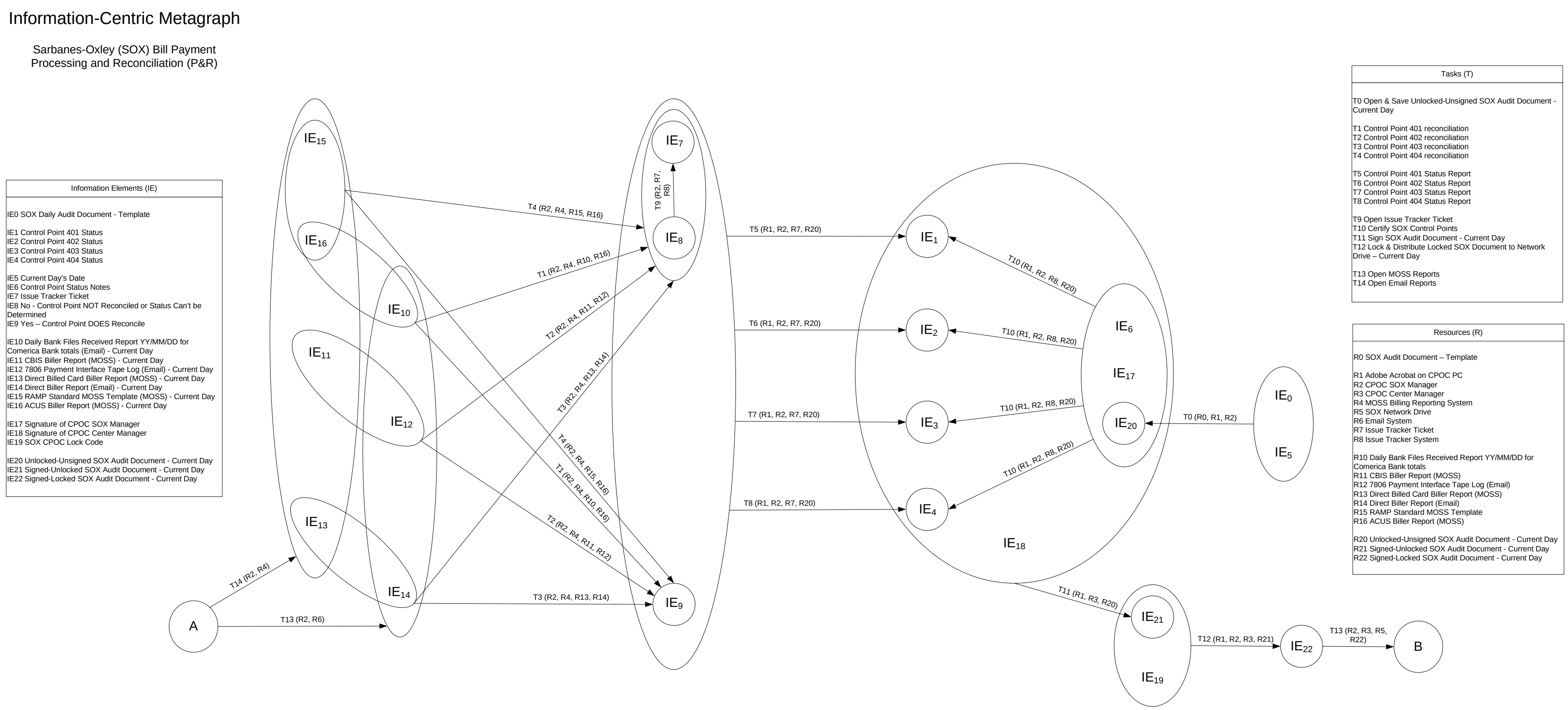
F.1 PILOT EXPERIMENT TASK-CENTRIC METAGRAPH DIAGRAM



F.2 PILOT EXPERIMENT RESOURCE-CENTRIC METAGRAPH DIAGRAM



F.3 PILOT EXPERIMENT INFORMATION-CENTRIC METAGRAPH DIAGRAM



G PILOT STUDY PROCEDURES

A pilot study was conducted with nine participants to refine the experimental procedures and materials prior to performing the actual experiment. Pilot study participants were given pre-experiment assessments, randomly assigned to treatment groups, and completed the given pilot study tasks.

1. Approval for the experiment was obtained from the Virginia Tech Institutional Review Board (IRB).
2. Training and experimental user comprehension task sets, assessment packages, and timeliness data collection procedures were prepared for the pilot study.
3. Participants were recruited for the pilot study primarily from graduate students with research experience, in order to provide informed feedback.
4. Participants arrived at the scheduled time, and were randomly assigned to pilot study training and experimental tasks.
5. Pre-experiment assessments were administered to pilot study participants. Pilot study participants:
   A. Reviewed the research purpose and instructions.
   B. Chose whether or not to sign the IRB Informed Consent form.
   C. Completed the Demographic and Prior Experience Questionnaire.
   D. Completed the MBTI Form F.
   E. Completed the Differentional Attentional Processes Inventory (DAPI).
   F. Completed the 12-minute the Wonderlic Personnel Test (WPT) Form A.
6. Participants received training handouts and instruction from the facilitator. They were encouraged to verbalize their observations so that their feedback on the lab experiment could be recorded.
7. The facilitator was careful to give instruction and answer questions using only the information available in the handouts.
8. The training task began and the facilitator started the stopwatch. Each participant began the set of user comprehension tasks and completed *task accuracy* questionnaires.
9. After a participant completed interpretation of one *Type of BPI*, the *task accuracy* questionnaires, data was collected on:
   A. *Time on task* (in seconds) recorded by facilitator.

   B. The NASA-TLX subjective *mental workload* dimensions completed by the participants.

10. When participants finished all three BPI interpretation tasks, they completed:
    A. Fifteen NASA-TLX paired comparison ratings of TLX dimensions.
    B. The self-efficacy questionnaire.
11. Training task assessments were then collected by the facilitator.
12. The facilitator handed out the instructions and scenario for the experimental tasks. He verbally read through these documents and answered last minute questions.
13. Participants were then allowed time to collect and prepare to use all the training and experiment handouts during the experimental tasks.
14. Experimental task questionnaires and assessment packages were then passed out to the participants.
15. Participants began the experimental user comprehension tasks. Steps 8, 9, and 10 were repeated.
16. After completion of their experimental task set, the facilitator collected all experimental assessments.
17. Pilot study participants were then encouraged to provide any final observations and feedback on the pilot lab experiment.
18. Pilot study participants were thanked and given the promised rewards for participation.
19. The facilitator completed notes on observations related to the pilot study treatment group.

The pilot study was then evaluated and the experimental procedure was adjusted prior to deployment.

H PILOT STUDY FINDINGS

The following were the issues were observed in the pilot study, and corresponding solutions were developed for the experimental study.

H.1 GPM SIZE AND LAB WORKSTATIONS ISSUES

The participant workstation configuration, as originally conceived, was not workable for the actual lab experiment. In designing the pilot study, the GPM maps were too large to be easily readable on a computer screen; to see the GPMs, participants had to both zoom in and scroll to see the necessary details, or, if the whole GPM was put on the screen, the details on the GPM were not able to be easily read. Therefore:

1. It was determined that having participants interpret the GPMs on a computer screen creates a level of difficulty that adds an extra random variable that is not of interest in this experiment. Several studies show that text comprehension outcomes are negatively impacted when participants interpret information from a computer screen as opposed to a paper presentation, including lower *accuracy*, lower *timeliness*, and higher subjective *mental workload*, (Mayes, Sims, & Koonce, 2001; Wastlund, Reinikka, Norlander, & Archer, 2005). Therefore, the lab experiment was changed to allow participants to interpret paper printouts of the training and experimental task GPMs large enough to easily see the details.
2. The experiment GPMs were found to be too complex to be easily readable when printed on letter or legal size paper. Therefore, GPMs were printed on size D (22" x 35") paper. (Training task GPMs worked well on letter sized paper.)
3. During the pilot study, the size D GPMs were too large for easy manipulation on a desk, so the decision was made to hang the experimental GPMs on the walls of the lab for the experiment.
4. Another advantage of hanging the GPMs on the wall is that this arrangement permitted two participants from the same treatment group to be working on the same set of three GPMs. This was possible because of the assignment of treatment task BPIs were ordered to reduce learning order bias. Therefore, no more than two participants were permitted on a set of three GPMs whenever possible.

5. Participants were encouraged to stand in front of each GPM they were interpreting, fill out the assessment on the clipboard, and to not look at other GPMs. The small size of the font of the GPMs and the distance individual GPMs were hung from each other encouraged participants to focus on the assigned GPM and discouraged participants from trying to look at other related GPMs.

H.2 Computer vs. Paper Assessment Issues

Similar to the problems observed with GPMs, completing assessments on the computer was too awkward and unworkable when participants were asked to interpret wall-mounted GPMs. Participants' *time on task* was not accurate because participants had to travel between the computer and the wall-mounted GPMs. Therefore:

A. All training and experimental assessments were collected using pencil and paper.
B. Participants were provided a desk and a clipboard to use during the training and experimental tasks.

H.3 Timeliness Data Collection Issues

Since the *time on task* data were not collected on the computer, data were collected by the facilitator using a stopwatch. Therefore the procedure was changed to the following:

A. Participants were started on their tasks by the facilitator and the running time was recorded.
B. When participants completed the task accuracy questionnaire related to a particular BPI type, they call out that they are finished to the facilitator. The facilitator recorded the finish time.
C. Times on task for each participant are calculated by subtracting the start times from the finish times to the whole second.

H.4 Training and Experimental Task Complexity Issues

Task complexity was the primary cause of problems in the pilot study. Both the training and experimental tasks were too complex and required too much time for participants to complete. During the pilot study, the level of complexity was controlled by using two real-world business processes with different numbers of GPM components: in pilot study training, a bank loan application process, and in the pilot study experiment, a billing system monitoring process.

Although novice GPM users were able to interpret both processes, the pilot study determined that the more complex business process (the billing system monitoring process) took far too long to interpret to be practical for this experiment. Time to complete the training tasks, training assessments, experimental tasks, and experiment assessments varied between 90 and 150 minutes. This provided an unworkable time schedule for the experiment.

Furthermore, pilot study participants became mentally fatigued by the time the experimental tasks were presented. The training business process (the bank loan application process) was complex enough that it took participants a long enough time to interpret that the mental fatigue of the participants became a factor that seemed to contaminate the user comprehension results of billing system monitoring process. If introduced into the actual lab study, mental fatigue and time pressures would have created significant bias in the results. Therefore, the following changes were made to the experiment:

A. The billing system monitoring process was dropped from the experiment, and the less complex business process (i.e., the bank loan process) was selected for the actual experiment.
B. The training tasks were simplified to focus specifically on how to read and interpret specific GPM symbols and not to practice reading a real business process.
C. Training tasks were completed using simple diagrams that demonstrated basic symbols and relationships of the GPMs.
D. The training task questionnaire were changed to reflect new training GPMs, but the exact type of questions participants would see in the experiment was preserved. Also, the correct answers to the questions were included on the back of the paper so they could study and understand why training task answers were correct.

These changes in task difficulty reduced the total time of the training and experiment by approximately 50% and substantially reduced mental fatigue in participants compared to the early pilot study results.

H.5 SELF-DIRECTED VS. FACILITATOR-LED TRAINING ISSUES

The original training plan was to have participants complete three simple training tasks until they scored 100% using a self-directed training approach. The training plan was designed to assure a relatively equal level of GPM experience in all participants prior to the experiment, as well as to reduce the impact of a facilitator on experimental results. However, this self-directed training approach was quickly observed to be too time-consuming, confusing, and complex. Verbal training and feedback by the facilitator was required. Therefore training changes included:

A. The training procedure was led by the facilitator.
B. The facilitator read through the training materials with the participants; essentially providing a verbal version of the training documents. He was careful not to add to or eliminate sections of the training documents for any treatment group.
C. A Frequently Asked Questions (FAQ) training document was prepared for participants based on the questioned asked during the pilot study.
D. Questions to the facilitator were allowed. However, the facilitator answered questions using the training documents, and did not provide more detailed information than the training materials contained.
E. With the elimination of self-directed training in favor of a facilitator-moderated training approach, providing training to separate sets of participants at the same time on two different GPM treatment groups was unworkable. Therefore, all participants at a scheduled time were assigned to the same treatment group.
F. Correct answers were included on the back of the training questionnaires. Participants were to study these questions until they felt comfortable understanding the correct answers.

After the above changes were made, the total time to complete the training and the experimental tasks and assessments was reduced to between 45 and 90 minutes. In addition, bias due to other mental fatigue-related issues (described above) was reduced.

H.6 Assessment Instrument Issues

The assessment instruments performed as intended with only a few minor adjustments. Changes were made to the demographics questionnaire to add questions assessing whether English was participants native language, more courses were added, and confusing wording was revised. The task *accuracy* questionnaires were edited for wording and for discrepancies found in answers by pilot study participants.

However, during the first treatment group of the actual experiment, participants' responses to three resource-centric GPM questions and one information-centric GPM question had to be eliminated due to discrepancies in interpretation and imprecision of the wording in these questions that were not discovered in the pilot study. The final task *accuracy* dataset included the percentage of correct answers from eight task-centric GPM questions, five resource-related GPM questions, and seven information-centric GPMs. One reason these question problems may not have been discovered during the pilot study was that the actual experimental task was used as the training task during the pilot study. During the pilot study, participants were not motivated in the same way and may have not taken the training task questions as seriously as they did experimental task questions. Consequently, these questionnaire wording issues went undiscovered during the pilot study.

I ACTUAL EXPERIMENT PARTICIPANT SCRIPTS & HANDOUTS

The following documents and scripts were given to participants in the actual experiment.

I.1 TRAINING OVERVIEW HANDOUT

[NOTE: The following Training Overview was given to participants at the beginning of the Training Phase. Participants were allowed to use this document through both the training and experiment phases.]

TRAINING OVERVIEW

This lab experiment consists of two phases: a training phase and an experimental phase. During the training phase, you will be given instruction and allowed to practice interpreting simplified diagrams of a business process. During the experimental phase, you will apply what you have learned during training to the interpretation of diagrams that represent another real-world business process.

The following are definitions of important terms you will see in the training and experiment:

- A <u>process</u> is a set of tasks that connects one set of information elements to another set of information elements. All inputs for any task in the process must be either in the form of information elements or from the output of some other task(s) in the system. For example, all three diagrams [A], [B], and [C] are used to describe different views of the same business process.
- A <u>task</u> is executed when inputs are used to determine outputs. For example see T1 on the task-centric diagram [A].
- A <u>resource</u> is an entity associated with one or more tasks, and the resource must be available if the tasks are to be executed. Several resources may be associated with a single task, and vice versa. Resources may be a person, a statement of information, piece of software, an information system, or a document in the context of this experiment. For example, see R2 on the resource-centric diagram [B].
- An <u>information element</u> is a single data item. An information element can be a single or a set of numbers, characters, words, images, or icons (as would be found in a document). For example, see IE21 on the information-centric diagram [C].

This business process begins with a completed customer loan application and then performs several tasks to determine whether the application is accepted or rejected. You will be asked to read and interpret three different graphical process models:

(a) A task-centric view of the loan application process **(Diagram A)**

(b) A resource-centric view of the loan application process **(Diagram B)**

(c) An information-centric view of the loan application process **(Diagram C)**

In order to assess your understanding of the business process, you will be asked to answer four sets of questions: (A) questions about task relationships, (B) questions about resource relationships, (C) questions about relationships among information elements, and (D) questions about how that tasks, resources, and information elements interact in the process.

Training Phase:

Training is designed to allow you the chance to familiarize yourself with different aspects of the diagrams and what questions will be asked. Although the facilitator will keep track of your time spent in training, this time does not count toward your winning the prizes. Feel free to take as long as you need to feel confident. Your training on the diagrams used in this experiment will proceed in this order:

(1) You will be presented with four sets of documents that explain and illustrate the diagrams and questions used in this experiment.
   a. Training Overview (this document)
   b. Frequently Asked Questions (FAQ) Reference Document
   c. Samples of Questions asked in the experiment
   d. A short questionnaire evaluating the mental workload you experienced and the confidence you feel after your training

(2) The facilitator will read the Training Overview and Diagram Training documents to will explain how to read and interpret the symbols on this diagram.

(3) The facilitator will overview the FAQ reference to familiarize you with how to look up answers to questions you may have.

(4) You will be asked to complete a set of sample questions about the training process models.
   e. These questions will be similar to those you will see in the experiment. The correct answers to these questions are provided on the back of the questionnaires.
   f. Please try to figure out the answer to the question and then try to understand why your answer is correct or incorrect.

g. During training, the facilitator cannot answer questions directly, but if the answer to your question is listed in the training materials, he can suggest where you can look to find the answer.

(5) When you finish with the training questions:

h. Raise your hand and inform the facilitator (this is important to make sure your time on task is recorded accurately).

i. Complete the short assessment of mental workload

j. Complete the sheet evaluating the importance to you of the different aspects of the mental workload you just experienced in the training task.

k. Answer the few questions on *Self-Efficacy*.

(6) When you have completed step 5, place your documents in your folder and wait for the facilitator to hand you the experiment materials. Do not begin the experiment until told to do so by the facilitator so that you time performing the task can be accurately recorded.

The experimental phase will proceed in a way similar to the training phase. You will answer similar questions except the diagrams will be different and you will be asked to complete the mental workload questionnaire after each set of questions. The facilitator will keep track of your time, but will not be able to provide any answers to help during the experiment.

<u>You may refer to your training materials at any time during the experiment</u>.

Please wait for the facilitator to tell you to begin before proceeding with the training.

I.2 UML DIAGRAM FREQUENTLY ASKED QUESTIONS (FAQ) HANDOUT

UML Diagrams Frequently Asked Questions (FAQ)

1. What do the words **directly**, **indirectly**, **immediately**, and "**in the entire process**" mean on the questionnaire?

    - The words directly and immediately refer to tasks, resources, or information elements that are related to the object in the question by a line or arrow (pointing into or out of the object in the question). They DO NOT refer to tasks, resources, or information elements that are not directly connected to the object referred to in the question. For example, see question T1.1 in the Training Questionnaire.
    - The words indirectly and "across the entire process" asks you to identify all objects even if they are not directly connected to the object in question. For example, see question CI4.1.

2. What do the words **precede, before,** and **follows** mean on the questionnaire?

    - The words precede or before mean that questions asks you to look for tasks, resources, or information elements that come before the object referred to in the question. For example, see question R2.1.
    - The word follows refers to tasks, resources, or information elements that come after the object referred to in the question. For example, see question T2.1
    - Any of these words can be combined to with the words directly, indirectly, immediately, and "in the entire process." For example, see question T2.1.

3. What do the words **most utilized, least utilized, "performed the most", most critical,** and **least critical** mean on the questionnaire?

    - The words most utilized, most critical, or "performed the most" refer to tasks, resources, or information elements that are used by or associated with the most other tasks, resources, or information elements. This is usually indicated by the number of lines connected to the object. For example, see question T3.1.
    - The words least utilized, least critical, or "performed the least" refer to tasks, resources, or information elements that are used by or associated with the fewest other tasks, resources, or information elements. This is usually indicated by the number of lines connected to the object. For example, see question T3.2.

4. Should these maps be read like a flowchart? Should we assume the process "flows" left to right on the maps?

    - Only 1 map should be read as a flow (left to right) - the task-centric [A] map.
    - The resource-centric [B] and information-centric [C] maps should be seen as a "snapshot" or picture of the associations between either resources or information elements. They are not to be read as flowcharts (left to right).

5. What maps can I use for the CI questions?

    - You may use all three diagrams to answer the questions label CI.

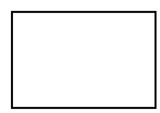
6. Can I use all three maps to answer Task (T), Resource (R), and Information Element (IE) questionnaires?

    - No. You may only use the diagram that the questionnaire is associated with. Please do not look at other diagrams to answer the questions.

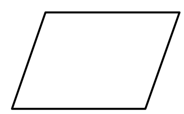
On the Task-Centric [A] Diagram:

7. What do the box with arrow ends mean?
    - It refers to a **Task**.

8. What does a rectangle mean?
    - It refers to a **Resource**.



9. What does parallelogram mean?
    - It refers to an **Information Element**.



10. What do the tasks with objects above them mean?
    - This refers to resources or information elements that control the performance of the task.

11. What do tasks with objects below them mean?
    - This refers to resources or information elements that act as suppliers of the resources or information elements necessary to perform the task.

12. What do solid lines with between tasks mean?
    - This refers to resources or information elements that control the performance of the task.

13. What do the arrows coming in from the left of a task mean?
    - This refers to other tasks or information elements that are inputs required to perform the given task.

14. What do the arrows coming out on the right of a task mean?
    - This refers to either (a) other tasks that must be performed after the given task, or (b) to information elements that act as outputs from the performance of the given task.

15. What does an information element as an input to a task mean versus an information element as a supplier (below) or a control (above) a given task mean?
    - An information element with an arrow on the left of a task means the information element is required as an input to perform the task.
    - An information element with an arrow on the right of a task means the information element is produced by the task and is an output of the task.
    - An information element below a task means the information element is required as a resource in order to perform the task.
    - An information element above a task means the information element is required to control the performance of a task.

16. What do the symbols on T7 and T8 mean?
    - They are tasks. On these diagrams, their flat right side means they are the last task in the process.

17. What does a triangle mean?
    - A decision point in the process. Depending on the decision, the flow of the process going in one direction or another. For example, see the feedback loop from the decision point to T4 on the Task-Centric UML diagram [A].

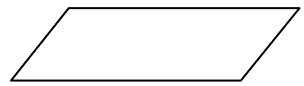
On the Resource-Centric [B] Diagram:

18. What does a solid line mean between resources? 1..1 1..*
    - The solid line means that one resource is directly associated with another resource because of the information elements one provides to another.

19. What do the following numbers on the lines associating the resources mean:
    - (0..1) = is associated with zero or 1 instance of this resource.
    - (1..1) = is associated with 1 and only 1 instance of this resource.
    - (1..*) = is associated with 1 or many instances of this resource.

20. What does the line that starts and ends at the same resource mean?
    - This means that the same resource performs a task that provides some information that is then used in subsequent tasks performed by the same resource.

On the Information-Centric [C] Diagram:



21. What does parallelogram mean?
    - It refers to a specific **information element**.

22. What does the dotted line without the arrow mean?
    - It is an association called a **constraint**. It means that one element acts as a constraint in the calculation or production of another information element. For example, an information element that represents a spending limit of $100 constrains the total amount that can be spent by an individual (another information element).

23. What does the dotted line with an arrow mean?
    - It is called a **dependency**. The arrow points FROM the information element that needs the information TO the information element that is provides the information needed. A dependency does not indicate a process flow, only a relationship between elements. For example, calculation of miles traveled (an information element) depends on the speed at a car traveled.

24. What does a solid line mean between resources? 1..1 1..*
    - The solid line means that one resource <u>is directly associated with</u> another resource because of the information elements one provides to another.

25. What do the following numbers on the lines associating the resources mean:
    - (0..1) = is associated with zero or 1 instance of this resource.
    - (1..1) = is associated with 1 and only 1 instance of this resource.
    - (1..*) = is associated with 1 or many instances of this resource.

I.3 METAGRAPH DIAGRAM FREQUENTLY ASKED QUESTIONS (FAQ) HANDOUT

Metagraph Diagram Frequently Asked Questions (FAQ)

1. What do the words **directly**, **indirectly**, **immediately**, and “**in the entire process**” mean on the questionnaire?

    - The words directly and immediately refer to tasks, resources, or information elements that are related to the object in the question by a line or arrow (pointing into or out of the object in the question). They DO NOT refer to tasks, resources, or information elements that are not directly connected to the object referred to in the question. For example, see question T1.1 in the Training Questionnaire.
    - The words indirectly and “across the entire process” asks you to identify all objects even if they are not directly connected to the object in question. For example, see question CI4.1.

2. What do the words **precede, before,** and **follows** mean on the questionnaire?

    - The words precede or before mean that questions asks you to look for tasks, resources, or information elements that come before the object referred to in the question. For example, see question R2.1.
    - The word follows refers to tasks, resources, or information elements that come after the object referred to in the question. For example, see question T2.1
    - Any of these words can be combined to with the words directly, indirectly, immediately, and “in the entire process.” For example, see question T2.1.

3. What do the words **most utilized, least utilized, “performed the most”, most critical,** and **least critical** mean on the questionnaire?

    - The words most utilized, most critical, or “performed the most” refer to tasks, resources, or information elements that are used by or associated with the most other tasks, resources, or information elements. This is usually indicated by the number of lines connected to the object. For example, see question T3.1.
    - The words least utilized, least critical, or “performed the least” refer to tasks, resources, or information elements that are used by or associated with the fewest other tasks, resources, or information elements. This is usually indicated by the number of lines connected to the object. For example, see question T3.2.

4. Should these maps be read like a flowchart? Should I assume the process "flows" left to right on the maps?

    - Only 1 map should be read as a flow (left to right) - the task-centric [A] map.
    - The resource-centric [B] and information-centric [C] maps should be seen as a "snapshot" or picture of the associations between either resources or information elements. They are not to be read as flowcharts (left to right).

5. What maps can I use for the CI questions?
    - You may use all three diagrams to answer the questions label CI.

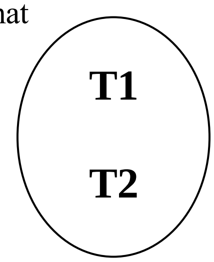
6. Can I use all three maps to answer Task (T), Resource (R), and Information Element (IE) questionnaires?
    - No. You may only use the diagram that the questionnaire is associated with. Please do not look at other diagrams to answer the questions.

7. Should these maps be read like a flowchart? Should we assume the process "flows" left to right on the maps?
    - Only 1 map should be read as a flow (left to right) - the task-centric [A] map.
    - The resource-centric [B] and information-centric [C] maps should be seen as a depiction of "snapshot" or picture of the associations between either resources or information elements. They are not to be read as flows (left to right).

8. What do the letters and numbers mean on a diagram?
    - T# = a specific **Task** identifier
    - R# = a specific **Resource** identifier
    - IE# = a specific **Information Element** identifier

9. Where do I look to find out what a specific task, resource or information element means?
    - There is a key on each diagram. There is also a more detailed key in the experiment instructions.

10. What do circles mean that contain task, resource, or information element identifier?
    - A circle identifies the component or associated components that are either (a) affected by other elements (indicated by an arrowhead that come into or touches the circle), or (b) that are required to work together to produce or affect other components (indicated by an arrow that starts at the circle and ends pointing to another component(s). For example see the R2-R4 circle on the Training Resource diagram [B]



11. What do arrows mean?

- The show that an individual or set of components (tasks, resources, or information elements) affect or are required in order to produce another component or set of components. For example, see question T1.1

12. What does A mean?
    - It refers to the start of the process represented in the diagram.

13. What does B mean"
    - It refers to the end of the process represented in the diagram.

On the Task-Centric [A] Diagram:

14. What does IE#(T#) mean next to the arrows?
    - It means that a specific information element (IE#) is produced by association with a specific task or tasks (T#).

On the Resource-Centric [B] Diagram:

15. What does IE#(T1*,T2) mean?
    - It means that a specific information element (IE#) is produced by task T1* using the resource or resources from which the arrow started.
    - IE# is used in the task (T2*) by the resource or resources where the arrow ends.

On the Information-Centric [C] Diagram:

16. What does T#(R1*, R2*) mean?
    - It means that a specific task (T#) is performed or executed using the information element or information elements from where the arrow started using resources R1* and R2*).
    - Using the beginning information element(s), Task (T#) produces or helps to produce the information element(s) where the arrow ends.

You may refer to this Training FAQ at any time during the experiment.

I.4 TRAINING TASK ASSESSMENT PACKET – UML DIAGRAM USER

Training Questionnaire Assessing Task-Centric UML Diagrams

BPM User Comprehension Components	User Comprehension Training Questions
Task-Centric Questions (T) [Diagram A]	T1.1 Given a task, T4, to execute, what other tasks must be executed immediately before T4 to provide the information needed to execute task T4? (a) T1 (b) T4 (c) T5, T6, T7, T8 (d) T12 only (e) None of the above
	T2.1 If task T1 is disabled, what other tasks will be affected that immediately follow T1 – in other words, what other tasks cannot be executed because T1 is disabled? (a) T12 (b) T5, T7, T7, T8 (c) T4 (d) All of the tasks (e) None of the above
	T3.1 What task is performed the most in the list below? (a) T1 (b) T5 (c) T11 (d) T4 (e) None of the above
	T3.2 What task is performed the least in the list below? (a) T1 (b) T7 (c) T2 (d) T3 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	ANSWERS
Task-Centric Questions (T) [Diagram A]	T1.1 Given a task, <u>T4</u>, to execute, what other <u>tasks</u> must be executed <u>immediately before</u> T4 to provide the information needed to execute task T4? **(a) T1 is the Correct Answer** **Why?:** • The arrow leading from T1 to T4 indicates that task T1 must be executed immediately before T4 can be executed. T2.1 If task <u>T1</u> is disabled, what other tasks will be affected that i<u>mmediately follow</u> T1 – in other words, what other tasks cannot be executed because T1 is disabled? **(c) T4 is the Correct Answer** **Why?:** • The arrow leading from T1 to T4 indicates that task T4 cannot be executed if T1 is disabled. T3.1 What task is performed the <u>most</u> in the list below? **(d) T4 is the Correct Answer** **Why?:** • Although T1 and T4 are listed once in the process, the feedback loop from the decision point at the end indicates that T4 may be executed more than once. Therefore, T4 may be performed more than T1. T3.2 What task is performed the <u>least</u> in the list below? **(a) T1 is the Correct Answer** **Why?:** • Although T1 and T4 are listed once in the process, the feedback loop from the decision point at the end indicates that T4 may be executed more than once. Therefore, T1 is the least performed task in the process.

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Questionnaire Assessing Resource-Centric UML Diagrams

BPM User Comprehension Components	ANSWERS
Resource-Centric Questions (R) [Diagram B]	R1.1 If a resource R1 is unavailable, what other resources that directly follow or are associated with R1 will be affected? (a) All resources (b) R2 only (c) R2, R3 (d) R5, R22 (e) None of the above
	R2.1 What specific resources directly precede or are associated with R5 that provides information for R5 to perform its tasks? (a) R1 (b) R3 (c) R2 (d) R22 (e) None of the above
	R3.1 What is the most utilized resource in the list below? (a) R1 (b) R2 (c) R5 (d) R22 (e) None of the above
	R3.2 What is the least utilized resource(s) in the list below? (a) R1 (b) R2 (c) R5 (d) R22 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	**User Comprehension Training Questions**
Resource-Centric Questions (R) [Diagram B]	R1.1 If a resource <u>R1</u> is unavailable, what other resources that <u>directly follow or are associated with</u> R1 will be affected? **(c) R2, R3 is the Correct Answer** **Why?:** • R2 and R3 are both directly associated with R1. R2.1 What specific resources <u>directly</u> <u>precede or are associated with</u> <u>R5</u> that provides information for R5 to perform its tasks? **(d) R22 is the Correct Answer** **Why?:** • R22 is the only resource associated with R5. R3.1 What is the <u>most utilized resource</u> in the list below? **(d) R22 is the Correct Answer** **Why?:** • R22 is utilized by three other resources as indicated by the three lines associating R22 with R2, R3, and R5. R3.2 What is the <u>least utilized resource(s)</u> in the list below? **(c) R5 is the Correct Answer** **Why?:** • R5 is utilized by only R22. • Also, R5 may or may not be utilizes as indicated by the (0..1) on the association with R22. Therefore, R5 is the least utilized resource.

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Questionnaire Assessing Information-Centric UML Diagrams

BPM User Comprehension Components	User Comprehension Training Questions
Information-Centric Questions (IE) [Diagram C]	IE1.1 Given three information elements, IE10, IE17, IE20, which of them is needed to determine the value of the other(s)? (a) IE10 determine IE17 and IE20 (b) IE10 and IE17 determine IE20 (c) IE22 determine IE10 and IE17 (d) IE10 and IE20 determine IE17 (e) None of the above
	IE2.1 Given two sets of information elements {IE10, IE17} and {IE20, IE21}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? (a) Yes – No other information elements are needed (b) No – unless {IE18} is also included (c) No – unless {IE22} is also dropped from the list (d) No – unless {IE7, IE9} is also included (e) No – the first set does not determine the values of the second set, and the addition of information elements will not change this fact.
	IE3.1 What was the <u>most utilized information element</u> in the process that is listed below? (a) IE10 (b) IE20 (c) IE21 (d) IE22 (e) None of the above
	IE3.2 What was the <u>least utilized information element</u> in the process that is listed below? (a) IE7 or IE9 (b) IE19 (c) IE21 (d) IE22 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	**ANSWERS**
Information-Centric Questions (IE) [Diagram C]	IE1.1 Given three information elements, IE10, IE17, IE20, which of them is needed to determine the value of the other(s)? **(b) IE10 and IE17 determine IE20 – is the Correct Answer** **Why?:** • IE20 is dependent on both IE10 and IE17. Therefore, of the elements listed, IE10 and IE17 are needed to determine the value of IE20. IE2.1 Given two sets of information elements {IE10, IE17} and {IE20, IE21}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? **(d) No – unless {IE7, IE9} is also included – is the Correct Answer** **Why?:** • IE20 is dependent on both IE10 and IE17. Therefore, of the elements listed, IE10 and IE17 are needed to determine the value of IE20. IE3.1 What was the <u>most utilized information element</u> in the process that is listed below? **(b) IE20 is the Correct Answer** **Why?:** • IE20 is associated with three other information elements IE7, IE9, and IE21 (not including the two elements that that IE20 is dependent on). Therefore, IE20 is the most utilized information element. IE3.2 What was the <u>least utilized information element</u> in the process that is listed below? **(a) IE7 or IE9 is the Correct Answer** **Why?:** • IE7, IE8, and IE18 are all associated with or constrain only one other information element.. However, IE 7 and IE9 are listed as only occasionally being associated with IE20 – as indicated with by the (0..1) on the association. • IE18 always constrain IE21. Therefore, IE7 and IE9 are equally the least associated information element.

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Sample Questions Assessing Interactions Between All UML Diagrams

BPM User Comprehension Components	User Comprehension Training Questions
Questions Concerning the Interactions among Components (CI) [Diagrams A, B, and C]	CI1.1 If a resource, R0, is unavailable, which information elements and tasks in the entire process can still be generated and completed? CI2.1 If an information element, IE0, is found to be inaccurate, which resources and tasks are used, directly or indirectly across the entire process, in the calculation or creation of IE0? CI3.1 Given a task, T0, what information elements and resources directly affect the performance of these tasks? CI4.1 What tasks, information elements and resources are needed as inputs, directly or indirectly, to perform T0? CI5.1 What is the single most utilized information element, task, or resource in the process? CI5.2 What is the single least utilized information element, task, or resource in the process?

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

NOTE: No answers are provided for these questions. These are only to give you a preview of the types of questions you will answer about the interactions between the diagrams in the experiment.

Assessment of the Mental Workload You Just Experienced

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you just completed and are now asked to evaluate. Don't think that there is any correct pattern. I am only interested in your opinions. If you have any questions, please ask them now. Otherwise, you may begin.

SCALE TITLES FOR ASSESSMENT OF MENTAL WORKLOAD

TITLE	ENDPOINTS	DESCRIPTIONS
Mental Demand	Low/High	How much mental and perceptual activity is required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required(e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Bad/Good	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

MENTAL WORKLOAD RATING SHEET

Participant Name ______________________ Diagram ID (A, B, or C) ________

Diagram Type: UML or Metagraph (circle one)

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Bad Good

EFFORT

Low High

FRUSTRATION

Low High

SOURCES OF WORKLOAD CARDS: INSTRUCTIONS

The evaluation you are about to perform is a technique that has been developed by NASA to assess the relative importance of six factors in determining how much workload you experienced as a result of performing the task you have just completed. You will be given a series of pairs of rating scale titles (for example, Effort vs. Mental Demands).

1. Please choose between one of the two items within each pair that was more important to your experience of mental workload in the task that you just performed. Each pair of scale titles will appear on a separate box in the matrix below. Please circle your choice.

2. On a scale of 1 to 10, write your rating of the how important the item your selected was to your experience of mental workload compared to the item you didn't select, on a scale of 1 to 10.

    - 1 = Difficult to decide which one was more important because both were almost equally important to my experience of mental workload.

    - 10 = My selection was a great deal more important to my experience of mental workload compared to the other item. It was extremely easy to identify my choice as more important.

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any correct pattern. We are only interested in opinions. If you have any questions, please ask them now. Otherwise, you may begin.

NASA TLX SCORING CARDS

Frustration or Effort	Performance or Mental Demand	Physical Demand or Frustration
Performance or Temporal Demand	Mental Demand or Effort	Physical Demand or Temporal Demand
Mental Demand or Physical Demand	Effort or Physical Demand	Temporal Demand or Mental Demand
Frustration or Mental Demand	Effort or Performance	Temporal Demand or Effort
Physical Demand or Performance	Performance or Frustration	Temporal Demand or Frustration

<u>Self-Efficacy Questionnaire</u>

I COULD COMPLETE THE TASK QUESTIONNAIRES USING THE DIAGRAMS PROVIDED …

		NOT AT ALL CONFIDENT				MODERATELY CONFIDENT					TOTALLY CONFIDENT
1. …if there was no one around to tell me what to do.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
2. …if I had never used these types of diagrams before.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
3. …if I had only the training handouts for reference.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
4. …if I had seen someone else using the diagrams before trying them myself.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
5. …if I could call on someone for help if I got stuck.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
6. …if someone else had helped me get started.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
7. …if I had a lot of time to complete the task for which the training was provided.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
8. …if I had just the materials provided during training for assistance.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
10. …if I had used similar diagrams to do the other tasks before completing this task.	YES…….. NO	1	2	3	4	5	6	7	8	9	10

I.5 TRAINING TASK ASSESSMENT PACKET – METAGRAPH USER

Training Questionnaire Assessing Task-Centric Metagraph Diagrams

BPM User Comprehension Components	User Comprehension Training Questions
Task-Centric Questions (T) [Diagram A]	T1.1 Given a task, T11, to execute, what other tasks must be executed immediately before T11 to provide the information needed to execute task T11? (a) T1, T12 (b) T5, T6 only (c) T5, T6, T7, T8 (d) T12 only (e) None of the above T2.1 If task T11 is disabled, what other tasks will be affected that immediately follow T11 – in other words, what other tasks cannot be executed because T11 is disabled? (a) T12 (b) T5, T7, T7, T8 (c) T1 (d) All of the tasks (e) None of the above T3.1 What task is performed the most in the list below? (a) T1 (b) T5 (c) T11 (d) T12 (e) None of the above T3.2 What task is performed the least in the list below? (a) T1 (b) T7 (c) T2 (d) T3 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	**ANSWERS**
Task-Centric Questions (T) [Diagram A]	T1.1 Given a task, T11, to execute, what other tasks must be executed immediately before T11 to provide the information needed to execute task T11? **(d) T5, T6, T7, T8 is the Correct Answer** **Why?:** • Because the arrows come IN to T11 designate tasks that must be executed immediately before you can execute T11. • Since T5, T6, T7, T8 are included in the circle, and the arrow come OUT from the edge of the circle, all the tasks within the circle must precede T11. • T1 is not correct because it is not executed immediately before T11. T1 would have been part of the answer IF the question had included such a phase as "directly AND indirectly". T2.1 If task T11 is disabled, what other tasks will be affected that immediately follow T11 – in other words, what other tasks cannot be executed because T11 is disabled? **(a) T12 is the Correct Answer** **Why?:** • Because the arrows OUT of T11 designate tasks that follow immediately after T11. T12 is the only task that is attached to arrows from T11. T3.1 What task is utilized the most from the list below? **(a) T1 is the Correct Answer** **Why?:** • Because there are two arrows OUT of T1 to other tasks and one arrow coming into T1. This means that T1 must be executed before Both T11 and T12 can be executed. Therefore, both T11 and T12 must utilize T1. T3.2 What task is utilized the least from the list below? (e) None of the above **Why?:** • Because all tasks have one arrow coming and one arrow coming in, except T1. Therefore, all tasks but T1 appear to be executed or utilized the same number of times. So we cannot determine which task is the least utilized.

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Questionnaire Assessing Resource-Centric Metagraph Diagrams

BPM User Comprehension Components	User Comprehension Training Questions
Resource-Centric Questions (R) [Diagram B]	R1.1 If a resource R4 is unavailable, what other resources that directly follow or are associated with R4 will be affected? (a) All resources (b) R2 only (c) R2, R6 (d) R2, R10, R16 (e) None of the above R2.1 What specific resources directly precede or are associated with R16 that provides information for R16 to perform its tasks? (a) R10 (b) R2 only (c) R2, R6 (d) R2, R4, R6 (e) None of the above R3.1 What is the most utilized resource in the list below? (a) R2 (b) R10 (c) R6 (d) R4 (e) None of the above R3.2 What is the least utilized resource(s) in the list below? (a) R2 (b) R10 (c) R16 (d) R10 and R16 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	ANSWERS
Resource-Centric Questions (R) [Diagram B]	R1.1 If a resource R4 is unavailable, what other resources that directly follow or are associated with R4 will be affected? **(d) R2, R10, R16 is the Correct Answer** **Why?:** • R2 and R4 are grouped in a circle with one arrow going out to another circle that contains R10 and R16. This means that BOTH R2 and R4 are required to produce an information element (IE16) that is required by R10 and R16. • The arrow from the R2-R4 circle indicates that IE16 (listed on the arrow) is produced by the combination of R2 and R4. • Therefore, when R4 is unavailable, R2, R10 and R16 are affected because IE16 can't be produced. R2.1 What specific resources directly precede or are associated with R16 that provides information for R16 to perform its tasks? **(c) R2, R4, R6 is the Correct Answer** **Why?:** • R2 and R6 are grouped in a circle with one arrow going out to R16. • R2 and R4 are grouped in a circle with one arrow going out to a circle that includes R16. • Therefore, R2, R4 and R6 precede R16. R3.1 What is the most utilized resource in the list below? **(a) R2 is the Correct Answer** **Why?:** • R2 is used in conjunction with both R4 and R6 making it the most utilized resource. R3.2 What is the least utilized resource(s) in the list below? **(d) R10 and R16 is the Correct Answer** **Why?:** • R10 and R16 are the only resources that are not used to produce information for another resource. Therefore, they are equally the least used resources.

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Questionnaire Assessing Information-Centric Metagraph Diagrams

BPM User Comprehension Components	User Comprehension Training Questions
Information-Centric Questions (IE) [Diagram C]	IE1.1 Given three information elements, IE19, IE21, IE22, which of them is needed to determine the value of the other(s)? (a) IE19 determine IE21 and IE22 (b) IE19 and IE21 determine IE22 (c) IE22 determine IE19 and IE21 (d) IE19 and IE22 determine IE21 (e) None of the above
	IE2.1 Given two sets of information elements {IE6, IE17} and {IE19, IE21}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? (a) Yes – No other information elements are needed (b) No – unless {IE22} is also included (c) No – unless {IE17} is also dropped from the list (d) No – unless {IE20} is also included (e) No – the first set does not determine the values of the second set, and the addition of information elements will not change this fact.
	IE3.1 What was the <u>most utilized information element</u> in the process that is listed below? (a) IE6 (b) IE19 (c) IE21 (d) IE22 (e) None of the above
	IE3.2 What was the <u>least utilized information element</u> in the process that is listed below? (a) IE6 (b) IE19 (c) IE21 (d) IE22 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	ANSWERS
Information-Centric Questions (IE) [Diagram C]	IE1.1 Given three information elements, IE19, IE21, IE22, which of them is needed to determine the value of the other(s)? **(b) IE19 and IE21 determine IE22 is the Correct Answer** **Why?:** • IE19 and IE21 are grouped in a circle with one arrow going out to IE22. Therefore, IE19 and IE21 determine the value of IE22. IE2.1 Given two sets of information elements {IE6, IE17} and {IE19, IE21}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? **(d) No – unless {IE20} is also included - is the Correct Answer** **Why?:** • IE6, IE17, and IE20 are grouped in a circle with one arrow going out to point at a circle that includes IE19 and IE21. Therefore, if IE 20 is included in the list, IE6 and IE17 are able to determine the values of IE19 and IE21. IE3.1 What was the <u>most utilized information element</u> in the process that is listed below? **(e) None of the above – is the Correct Answer** **Why?:** • All information elements are used just once to produce other information elements. Therefore, it can't be determined if one element is more utilized than another. IE3.2 What was the <u>least used or least critical information element</u> in the process that is listed below? **(e) None of the above – is the Correct Answer** **Why?:** • All information elements are used just once to produce other information elements. Therefore, it can't be determined if one element is the least utilized.

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Sample Questions Assessing Interactions Between All Diagrams

BPM User Comprehension Components	**User Comprehension Training Questions**
Questions Concerning the Interactions among Components (CI) [Diagrams A, B, and C]	CI1.1 If a resource, R0, is unavailable, which information elements and tasks in the entire process can still be generated and completed? CI2.1 If an information element, IE0, is found to be inaccurate, which resources and tasks are used, directly or indirectly across the entire process, in the calculation or creation of IE0? CI3.1 Given a task, T0, what information elements and resources directly affect the performance of these tasks? CI4.1 What tasks, information elements and resources are needed as inputs, directly or indirectly, to perform T0? CI5.1 What is the single most utilized information element, task, or resource in the process? CI5.2 What is the single least utilized information element, task, or resource in the process?

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

NOTE: No answers are provided for these questions. These are only to give you a preview of the types of questions you will answer about the interactions between the diagrams in the experiment.

<u>**Assessment of the Mental Workload You Just Experienced**</u>

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you just completed and are now asked to evaluate. Don't think that there is any correct pattern. I am only interested in your opinions. If you have any questions, please ask them now. Otherwise, you may begin.

SCALE TITLES FOR ASSESSMENT OF MENTAL WORKLOAD

TITLE	ENDPOINTS	DESCRIPTIONS
Mental Demand	Low/High	How much mental and perceptual activity is required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required(e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Bad/Good	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

MENTAL WORKLOAD RATING SHEET

Participant Name ____________________ Diagram ID (A, B, or C) ________

Diagram Type: UML or Metagraph (circle one)

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Bad Good

EFFORT

Low High

FRUSTRATION

Low High

SOURCES OF WORKLOAD CARDS: INSTRUCTIONS

The evaluation you are about to perform is a technique that has been developed by NASA to assess the relative importance of six factors in determining how much workload you experienced as a result of performing the task you have just completed. You will be given a series of pairs of rating scale titles (for example, Effort vs. Mental Demands).

3. Please choose between one of the two items within each pair that was more important to your experience of mental workload in the task that you just performed. Each pair of scale titles will appear on a separate box in the matrix below. Please circle your choice.

4. On a scale of 1 to 10, write your rating of the how important the item your selected was to your experience of mental workload compared to the item you didn't select, on a scale of 1 to 10.

   - 1 = Difficult to decide which one was more important because both were almost equally important to my experience of mental workload.

   - 10 = My selection was a great deal more important to my experience of mental workload compared to the other item. It was extremely easy to identify my choice as more important.

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any correct pattern. We are only interested in opinions. If you have any questions, please ask them now. Otherwise, you may begin.

NASA TLX SCORING CARDS

Frustration or Effort	Performance or Mental Demand	Physical Demand or Frustration
Performance or Temporal Demand	Mental Demand or Effort	Physical Demand or Temporal Demand
Mental Demand or Physical Demand	Effort or Physical Demand	Temporal Demand or Mental Demand
Frustration or Mental Demand	Effort or Performance	Temporal Demand or Effort
Physical Demand or Performance	Performance or Frustration	Temporal Demand or Frustration

Self-Efficacy Questionnaire

I COULD COMPLETE THE TASK QUESTIONNAIRES USING THE DIAGRAMS PROVIDED …

		NOT AT ALL CONFIDENT				**MODERATELY CONFIDENT**					**TOTALLY CONFIDENT**
1. …if there was no one around to tell me what to do.	YES……..1 NO		2	3	4	5	6	7	8	9	10
2. …if I had never used these types of diagrams before.	YES……..1 NO		2	3	4	5	6	7	8	9	10
3. …if I had only the training handouts for reference.	YES……..1 NO		2	3	4	5	6	7	8	9	10
4. …if I had seen someone else using the diagrams before trying them myself.	YES……..1 NO		2	3	4	5	6	7	8	9	10
5. …if I could call on someone for help if I got stuck.	YES……..1 NO		2	3	4	5	6	7	8	9	10
6. …if someone else had helped me get started.	YES……..1 NO		2	3	4	5	6	7	8	9	10
7. …if I had a lot of time to complete the task for which the training was provided.	YES……..1 NO		2	3	4	5	6	7	8	9	10
8. …if I had just the materials provided during training for assistance.	YES……..1 NO		2	3	4	5	6	7	8	9	10
10. …if I had used similar diagrams to do the other tasks before completing this task.	YES……..1 NO		2	3	4	5	6	7	8	9	10

I.6 EXPERIMENTAL TASK SCRIPTS - INTRODUCTION

This experiment consists of two phases: a training phase and an experimental phase. During the training phase, you will be given instruction and allows to practice interpreting simplified diagrams of a business process. During the experimental phase, you will apply what you have learned to the interpretation of diagrams that represent a real-world business process.

Training Phase:

Your training on the metagraph Diagrams used in this experiment will proceed in this order:

(1) You will be presented with a training document that explains and illustrates the metagraph diagrams used in this experiment.

(2) We will read the document that will explain how to read and interpret the symbols on this diagram.

(3) You will be asked to answer some questions that allow you to practice interpreting this type of diagram.

(4) When you have completed the practice questions, you will be asked to fill out a brief survey that assesses the mental workload you experienced during the training exercise.

(5) Once have completed the training and are ready to begin the experimental phase. Make sure the facilitator is aware you are ready to begin so you time performing the task can be accurately recorded.

The experimental phase will proceed in a similar way to the training phase, except (a) the diagrams will be different, (b) you answer the same kinds of questions you answered during the training phase, and (c) you will be asked to complete the mental workload questionnaire after each set of the four sets of questions (instead of only at the end - as in the training phase).

REMEMBER!

During the experiment, you will win the gift certificates if you have BOTH the highest number of correct answers AND the lowest time spent answering the questions. In other words, you are trying to maximize how many questions you answer correctly and minimize the amount of time you take to answer those questions.

Good Luck!!

Experimental Phase:

In order to train you in how to interpret a type of graphical process model (called metagraph diagrams), you will play the role of a new manager in a bank that is trying to understand your bank's loan application process. This business process takes the completed loan application of the customer and performs several tasks that use different types of resources and information, to determine whether an application for a loan is to be accepted or rejected. You have been asked to read and interpret three different graphical process models that depict three different views of the same loan application process:

(a) A task-centric view of the loan application process

(b) A resource-centric view of the loan application process

(c) An information-centric view of the loan application process

I.7 EXPERIMENTAL TASK DESCRIPTION – BANK LOAN APPLICATION BPM

Task Description: The training tasks you are based on a loan approval business process[2]. You represent a manager in this company that has been asked to read and interpret graphical process models that describe different types of BPM task information prior to attending an important meeting to discuss this business process. The loan approval process is modeled as using metagraph diagrams. The following is a key to the abbreviations used in these maps as follows:

- A task is executed when the inputs are used to determine outputs. For example, several types of documents are used in the Credit Rating task (T1) to determine the credit rating (output) of a customer.
- A resource is an entity associated with one or more tasks, and the resource must be available if the tasks are to be executed. Several resources may be associated with a single task, and vice versa. Resources may be a person, a statement of information, piece of software, an information system, or a document (called an 'abstract') in the context of this experiment. For example, to determine the credit rating of the client, a loan officer (R1 – a person resource) and the customer loan application (R10 - an abstract document resource) are required.
- An information element is a single data item. An information element can be a single or a set of numbers, characters, words, images, or icons (as would be found in a document). For example, the information elements needed as inputs to the Credit Rating Task are the applicant's account data (IE1), loan application data (IE2), and credit history (IE3).
- A process is a set of tasks that connects one set of information elements to another set of information elements. All inputs for any task in the process must be either in the form of information elements or from the output of some other task(s) in the system. For example, the loan approval process begins with three information elements serving as inputs to task T1. Task T1's outputs serve as inputs to task T2, as well as produce another information element (IE6).

There are eight tasks in the loan approval process, as follows:

[2] Adapted from Basu and Blanning (2000).

T_1: Credit Risk Rating - The loan officer uses account data, the applicant's credit history, and applicant data to calculate the applicant's credit rating.

T_2: Property Appraisal Task - The property appraiser uses data about the property along with data about comparable properties to calculate the appraised value of the property.

T_3: Risk Assessment Task - The loan officer uses the applicant's credit rating, the appraised value of the property, and the loan amount to calculate the level of risk associated with the loan.

T_4: Loan Amount Reduction Task - If the risk of the loan is determined to be a bad risk, the branch manager uses the appraised value of the property and the level of risk associated with the loan to calculate a new loan amount.

T_5: Risk Exposure Assessment Task - The risk analyst and the property appraiser use the appraised value of the property, the loan amount, and the current bank portfolio of loans to calculate the bank's current risk exposure.

T_6: Acceptable Risk Assessment Task - The system examines the risk associated with the loan and performs the calculations needed to determine whether the risk is acceptable.

T_7: The Loan is Approved - If the level of risk is acceptable, the loan officer uses the risk associated with the loan and the bank's risk exposure to decide whether to approve the loan.

T_8: The Loan is Rejected - If the loan application represents a bad risk, the loan officer rejects the application.

There are six resources used in the loan application process:

- R_1: a property appraiser;
- R_2: the branch manager;
- R_3: a loan officer;
- R_4: a risk analyst;
- R_{10}: a completed loan application from a customer;
- R_{11}: an automated bank information system;

Finally, there are information elements in the loan approval process:

- IE_1: account data of the applicant;
- IE_2: applicant data from the loan application;
- IE_3: credit history of the applicant;
- IE_4: data about the property for which the loan is sought;
- IE_5: data about comparable properties;
- IE_6: applicant's credit rating;
- IE_7: the amount of the loan;
- IE_8: the appraised value of the property;
- IE_9: the current bank portfolio of loans;
- IE_{10}: the bank's level of acceptable risk;
- IE_{11}: the level of risk associated with the loan;
- IE_{12}: the bank's current risk exposure;
- IE_{13}: a statement that the application is approved;
- IE_{14}: a statement that the application is rejected.

You may refer to these descriptions at any time during the experiment.

I.8 EXPERIMENT TASK ASSESSMENT PACKET – BOTH UML & METAGRAPH USER

Questionnaire Assessing Task-Centric Diagrams

BPM User Comprehension Components	Experiment User Comprehension Questions*
Task-Centric Questions (T) [Diagram A]	T1.1 Given a task, T3, to execute, what other tasks must be executed immediately before T3 to provide the information needed to execute task T3? (a) T1, T2, T4 (b) T4 (c) T6 (d) T5 (e) None of the above
	T1.2 Given a task, T7, to execute, what other tasks must be executed immediately before T7 to provide the information needed to execute task T7? (a) T3, T5, T6 (b) T5 only (c) T4, T8 (d) T1, T2 (e) None of the above
	T1.3 Given a task, T1, to execute, what other tasks must be executed immediately before T1 to provide the information needed to execute task T1? (a) T5, T6, T7, T8, T11 (b) T13, T14 (c) T7, T8 (d) T2, T3 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	Experiment User Comprehension Questions
Task-Centric Questions (T) (Continued) [Diagram A]	T2.1 If task <u>T7</u> is disabled, what other tasks will be affected that i<u>mmediately follow</u> T7 – in other words, what other tasks cannot be executed because T7 is disabled? (a) T11. T12 (b) T5, T6, T8 (c) T3, T9 (d) T0, T10 (e) None of the above T2.2 If task <u>T1</u> is disabled, what other tasks will be affected that i<u>mmediately follow</u> T1 – in other words, what other tasks cannot be executed because T1 is disabled? (a) T4 (b) T5 (c) T2, T3 (d) T2 only (e) None of the above T2.3 If task <u>T2</u> is disabled, what other tasks will be affected that i<u>mmediately follow</u> T2 – in other words, what other tasks cannot be executed because T2 is disabled? (a) T3, T4, T5 (b) T1 (c) T5, T6, T7, T8 (d) T1, T2, T3, T4 (e) None of the above T3.1 What task is utilized the <u>most</u> from the list below? (a) T4 (b) T9 (c) T10 (d) T6 (e) None of the above T3.2 What task is utilized the <u>least</u> from the list below? (a) T1 (b) T7 (c) T2 (d) T3 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Assessment of the Mental Workload You Just Experienced

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you just completed and are now asked to evaluate. Don't think that there is any correct pattern. I am only interested in your opinions. If you have any questions, please ask them now. Otherwise, you may begin.

SCALE TITLES FOR ASSESSMENT OF MENTAL WORKLOAD

TITLE	ENDPOINTS	DESCRIPTIONS
Mental Demand	Low/High	How much mental and perceptual activity is required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required(e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Bad/Good	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

MENTAL WORKLOAD RATING SHEET

Participant Name ____________________ Diagram ID (A, B, or C) ________

Diagram Type: UML or Metagraph (circle one)

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Bad Good

EFFORT

Low High

FRUSTRATION

Low High

Questionnaire Assessing Resource-Centric Diagrams

BPM User Comprehension Components	**Experiment User Comprehension Questions**
Resource-Centric Questions (R)	R1.1 If a resource R1 is unavailable, what other resources that directly follow or are associated with R1 will be affected? (a) All resources (b) R4, R10, R11 (c) R2, R3 (d) R4 only (e) None of the above
[Diagram B]	R1.2 If a resource R2 is unavailable, what other resources that directly follow or are associated with R2 will be affected? (a) All resources (b) R1, R3, R4, R11 (c) R3 only (d) R10, R11 (e) None of the above
	R1.3 If a resource R4 is unavailable, what other resources that directly follow or are associated with R4 will be affected? (a) All resources (b) R1, R2, R3 (c) R10, R11 (d) R1 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	**Experiment User Comprehension Questions**
Resource-Centric Questions (R) (Continued)	R2.1 What specific resources <u>directly</u> <u>precede or are associated with</u> <u>R4</u> that provides information for R4 to perform its tasks? (a) R1, R11 (b) R2, R3 (c) R1, R2 (d) R10, R11 (e) None of the above
[Diagram B]	R2.2 What specific resources <u>directly</u> <u>precede or are associated with</u> <u>R11</u> that provides information for R11 to perform its tasks? (a) R1, R2, R3 (b) R10 (c) R4 (d) R2, R3 only (e) None of the above
	R2.3 What specific resources <u>directly</u> <u>precede or are associated with</u> <u>R2</u> that provides information for R2 to perform its tasks? (a) R4 (b) R1 (c) R10 (d) R11 (e) None of the above
	R3.1 What is the <u>most utilized resource</u> in the list below? (a) R2 (b) R10 (c) R11 (d) R1 (e) None of the above
	R3.2 What is the <u>least utilized resource</u> in the list below? (a) R2 (b) R4 (c) R3 (d) R10 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Assessment of the Mental Workload You Just Experienced

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you just completed and are now asked to evaluate. Don't think that there is any correct pattern. I am only interested in your opinions. If you have any questions, please ask them now. Otherwise, you may begin.

SCALE TITLES FOR ASSESSMENT OF MENTAL WORKLOAD

TITLE	ENDPOINTS	DESCRIPTIONS
Mental Demand	Low/High	How much mental and perceptual activity is required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required(e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Bad/Good	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

MENTAL WORKLOAD RATING SHEET

Participant Name ____________________ Diagram ID (A, B, or C) ________

Diagram Type: UML or Metagraph (circle one)

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Bad Good

EFFORT

Low High

FRUSTRATION

Low High

Questionnaire Assessing Information-Centric Diagrams

BPM User Comprehension Components	Experiment User Comprehension Questions
Information-Centric Questions (IE) [Diagram C]	IE1.1 Given three information elements, IE1, IE2, IE6, which of them is needed to determine the value of the other(s)? (a) IE1 determine IE2 and IE6 (b) IE1 and IE2 determine IE6 (c) IE2 determine IE1 and IE6 (d) IE6 and IE2 determine IE1 (e) None of the above IE1.2 Given two information elements, IE11, IE14, which of them is needed to determine the value of the other(s)? (a) IE11 determine IE14 and IE2 (b) IE14 determine IE11 (c) IE2 determine IE11 and IE14 (d) IE11 determine IE14 (e) None of the above IE1.3 Given six information elements, IE1, IE2, IE3, IE4, IE10, IE11, which of them is needed to determine the value of the other(s)? (a) IE1, IE2, IE3, IE4, IE10 determine IE11 (b) IE11 determine IE1, IE2, IE3, IE4, IE10 (c) IE1, IE3, IE10, determine IE2, IE4, IE11 (d) IE2, IE3, IE11 determine IE1, IE4, IE10 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	Experiment User Comprehension Questions
Information-Centric Questions (IE) (Continued)	IE2.1 Given two sets of information elements {IE6 IE7, IE8} and {IE10, IE11, IE12}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? (a) Yes – No other information elements are needed (b) No – unless {IE9} are also included (c) No – unless {IE1 and IE2} are also included (d) No – unless {IE4 and IE5} are also included (e) No – the first set does not determine the values of the second set, and the addition of information elements will not change this fact.
[Diagram C]	IE2.2 Given two sets of information elements, {IE1, IE2, IE3} and {IE11}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? (a) Yes – No other information elements are needed (b) No – unless {IE10, IE12} are also included (c) No – unless {IE7, IE8, IE9} are also included (d) No – unless {IE6, IE7, IE8} are also included (e) No – the first set does not determine the values of the second set, and the addition of information elements will not change this fact.
	IE2.3 Given two sets of information elements, {IE6, IE7, IE8, IE9, IE10, IE11} and {IE13, IE14}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? (a) Yes – No other information elements are needed (b) No – unless {IE1} is also included (c) No – unless {IE12} is also included (d) No – unless {IE4, IE5} are also included (e) No – the first set does not determine the values of the second set, and the addition of information elements will not change this fact.

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	Experiment User Comprehension Questions
Information-Centric Questions (IE) (Continued)	IE3.1 What was the <u>most used or most critical information element</u> in the process that is listed below? (a) IE8 or IE11 (b) IE1 (c) IE5 (d) IE13 (e) None of the above
[Diagram C]	IE3.2 What was the <u>least used or least critical information element</u> in the process that is listed below? (a) IE7 (b) IE13 or IE 14 (c) IE2 (d) IE5 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Assessment of the Mental Workload You Just Experienced

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you just completed and are now asked to evaluate. Don't think that there is any correct pattern. I am only interested in your opinions. If you have any questions, please ask them now. Otherwise, you may begin.

SCALE TITLES FOR ASSESSMENT OF MENTAL WORKLOAD

TITLE	ENDPOINTS	DESCRIPTIONS
Mental Demand	Low/High	How much mental and perceptual activity is required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required(e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Bad/Good	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

MENTAL WORKLOAD RATING SHEET

Participant Name ______________________ Diagram ID (A, B, or C) ________

Diagram Type: UML or Metagraph (circle one)

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Bad Good

EFFORT

Low High

FRUSTRATION

Low High

Questionnaire Assessing Interactions Between All Diagrams

BPM User Comprehension Components	Experiment User Comprehension Questions
Questions Concerning the Interactions among Components (CI) [Diagrams A, B, and C]	CI1.1 If a resource, R3, is unavailable, which information elements and tasks in the entire process can still be generated and completed? (a) All Tasks and Information Elements can be generated and completed. (b) All information elements can still be generated and all tasks can be completed except for {IE12, IE13, IE14} and {T5, T7, T8} (c) All information elements can still be generated and all tasks can be except for {T1, T2, T3} and {IE1, IE2, IE3, IE4, IE5}. (d) No information elements can still be generated or tasks can be completed except for {IE1, IE2} and {T7, T8}. (e) None of the above CI2.1 If an information element, IE6, is found to be inaccurate, which resources and tasks are used, directly or indirectly across the entire process, in the calculation or creation of IE6? (a) All Tasks and Resources. (b) {T2} and {R2, R4, R6, R11, R12} (c) {T5} and {R1, R2, R7} (d) {T1} and {R1, R10} (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	Experiment User Comprehension Questions
Questions Concerning the Interactions among Components (CI) (Continued) [Diagrams A, B, and C]	CI3.1 Given a set of tasks, {T1, T2}, what information elements and resources <u>directly affect</u> the performance of these tasks? (a) All Information Elements and Resources. (b) {R1, R2, R10} and {IE1, IE2, IE3, IE4, IE5} (c) {R1, R3, R10, R12, R14, R21} and {IE5, IE7, IE9, IE11, IE13, IE15, IE17, IE21} (d) {R2, R4, R6, R10, R11, R12, R13, R14, R15, R16} and {IE10, IE11, IE12, IE13, IE14, IE15, IE16} (e) None of the above CI4.1 What tasks, information elements and resources <u>are needed as inputs</u>, <u>directly or indirectly</u>, to perform <u>T5</u>? (a) All Tasks, Information Elements, and Resources. (b) {R1, R2, R3, R4, R10} and {IE1, IE2, IE3, IE4, IE5, IE7, IE8} and {T1, T2, T4} (c) {R1, R2, R3, R10, R11} and { IE1, IE2} and {T1, T4, T6}. (d) {R1, R2, R11} and {IE4, IE5, IE6, IE7} and {T2, T3, T4}. (e) None of the above CI5.1 What is the single <u>most utilized information element, task, or resource</u> in the process - that is included in the list below? (a) R1 (b) IE1 or IE2 (c) T10 (d) All of the above (e) Cannot be determined from these diagrams CI5.2 What is the single <u>least utilized information element, task, or resource</u> in the process - that is included in the list below? (a) IE7 (b) R4 (c) T7 or T8 (d) All of the above (e) Cannot be determined from these diagrams

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

Assessment of the Mental Workload You Just Experienced

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you just completed and are now asked to evaluate. Don't think that there is any correct pattern. I am only interested in your opinions. If you have any questions, please ask them now. Otherwise, you may begin.

SCALE TITLES FOR ASSESSMENT OF MENTAL WORKLOAD

TITLE	ENDPOINTS	DESCRIPTIONS
Mental Demand	Low/High	How much mental and perceptual activity is required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required(e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Bad/Good	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

MENTAL WORKLOAD RATING SHEET

Participant Name ____________________ Diagram ID (A, B, or C) ________

Diagram Type: UML or Metagraph (circle one)

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Bad Good

EFFORT

Low High

FRUSTRATION

Low High

SOURCES OF WORKLOAD CARDS: INSTRUCTIONS

The evaluation you are about to perform is a technique that has been developed by NASA to assess the relative importance of six factors in determining how much workload you experienced as a result of performing the task you have just completed. You will be given a series of pairs of rating scale titles (for example, Effort vs. Mental Demands).

5. Please choose between one of the two items within each pair that was more important to your experience of mental workload in the task that you just performed. Each pair of scale titles will appear on a separate box in the matrix below. Please circle your choice.

6. On a scale of 1 to 10, write your rating of the how important the item your selected was to your experience of mental workload compared to the item you didn't select, on a scale of 1 to 10.

    - 1 = Difficult to decide which one was more important because both were almost equally important to my experience of mental workload.

    - 10 = My selection was a great deal more important to my experience of mental workload compared to the other item. It was extremely easy to identify my choice as more important.

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any correct pattern. We are only interested in opinions. If you have any questions, please ask them now. Otherwise, you may begin.

NASA TLX SCORING CARDS

Frustration or Effort	Performance or Mental Demand	Physical Demand or Frustration
Performance or Temporal Demand	Mental Demand or Effort	Physical Demand or Temporal Demand
Mental Demand or Physical Demand	Effort or Physical Demand	Temporal Demand or Mental Demand
Frustration or Mental Demand	Effort or Performance	Temporal Demand or Effort
Physical Demand or Performance	Performance or Frustration	Temporal Demand or Frustration

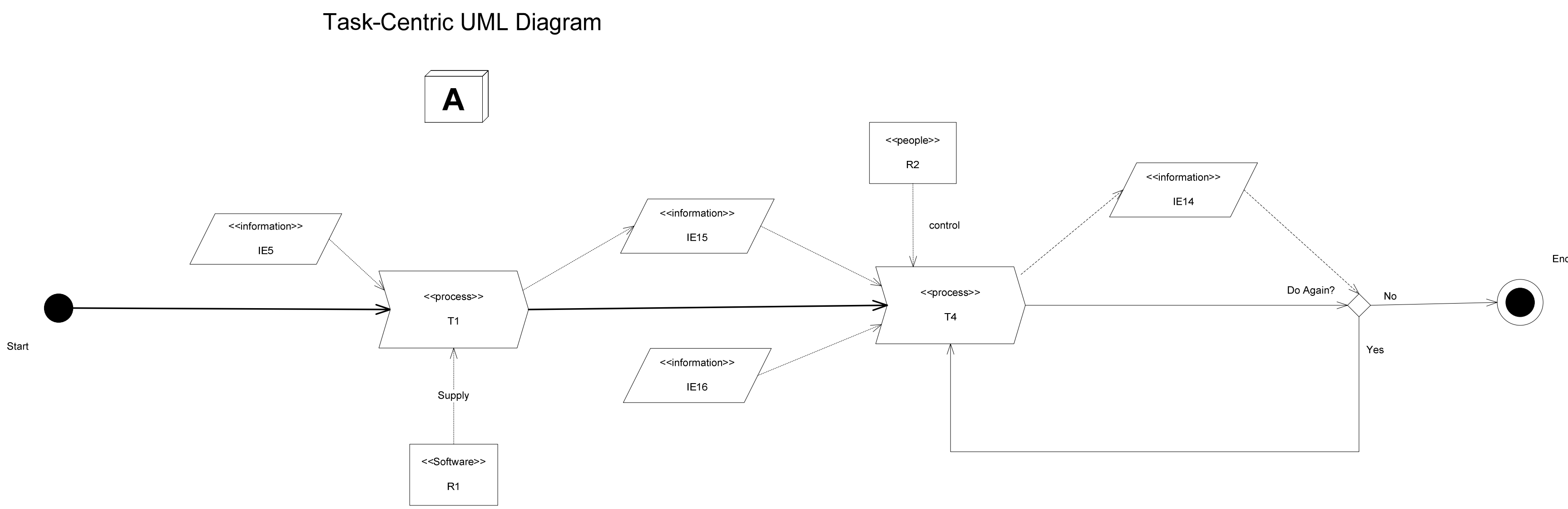
Self-Efficacy Questionnaire

I COULD COMPLETE THE TASK QUESTIONNAIRES USING THE DIAGRAMS PROVIDED …

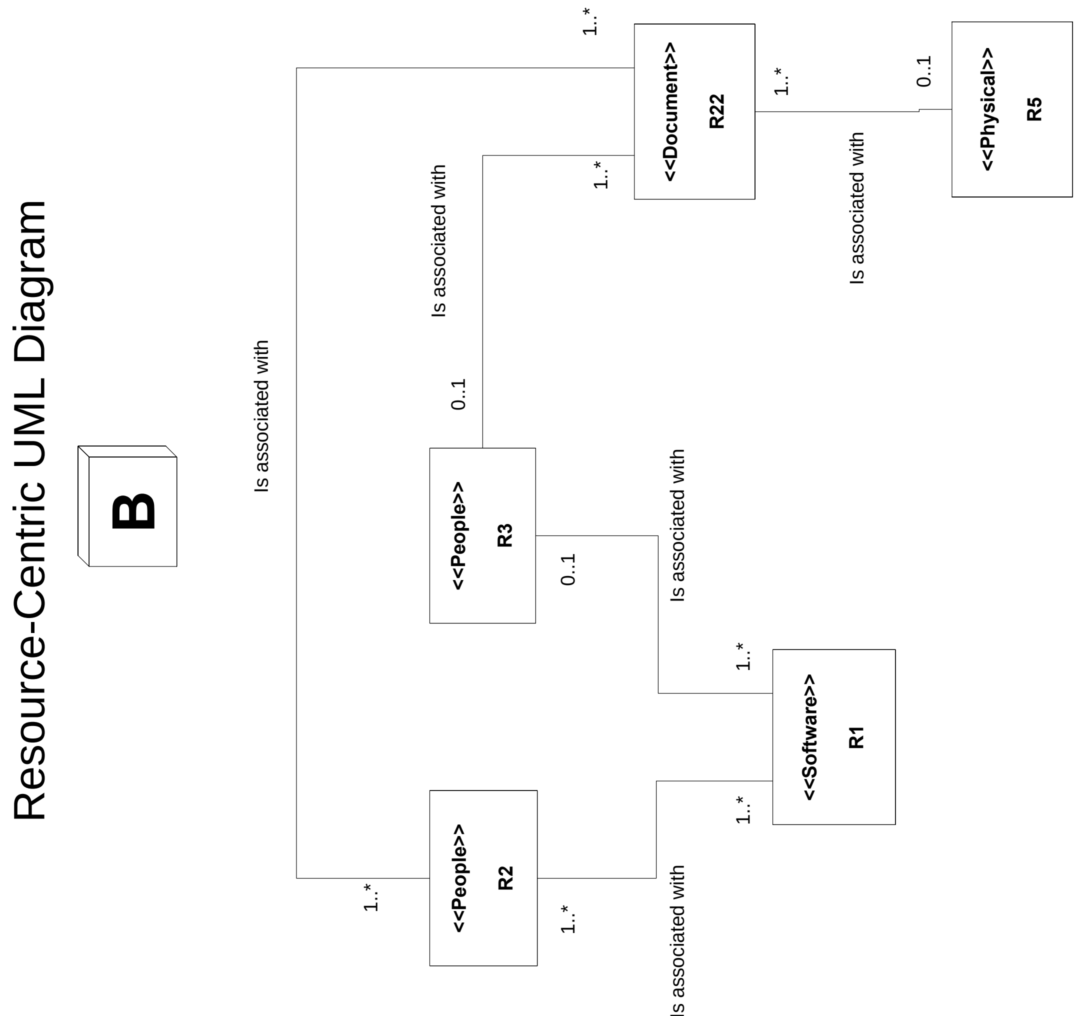
		NOT AT ALL CONFIDENT				MODERATELY CONFIDENT					TOTALLY CONFIDENT
1. …if there was no one around to tell me what to do.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
2. …if I had never used these types of diagrams before.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
3. …if I had only the training handouts for reference.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
4. …if I had seen someone else using the diagrams before trying them myself.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
5. …if I could call on someone for help if I got stuck.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
6. …if someone else had helped me get started.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
7. …if I had a lot of time to complete the task for which the training was provided.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
8. …if I had just the materials provided during training for assistance.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
10. …if I had used similar diagrams to do the other tasks before completing this task.	YES…….. NO	1	2	3	4	5	6	7	8	9	10

J TRAINING TASK UML GRAPHICAL PROCESS MODELS USED IN THE EXPERIMENT

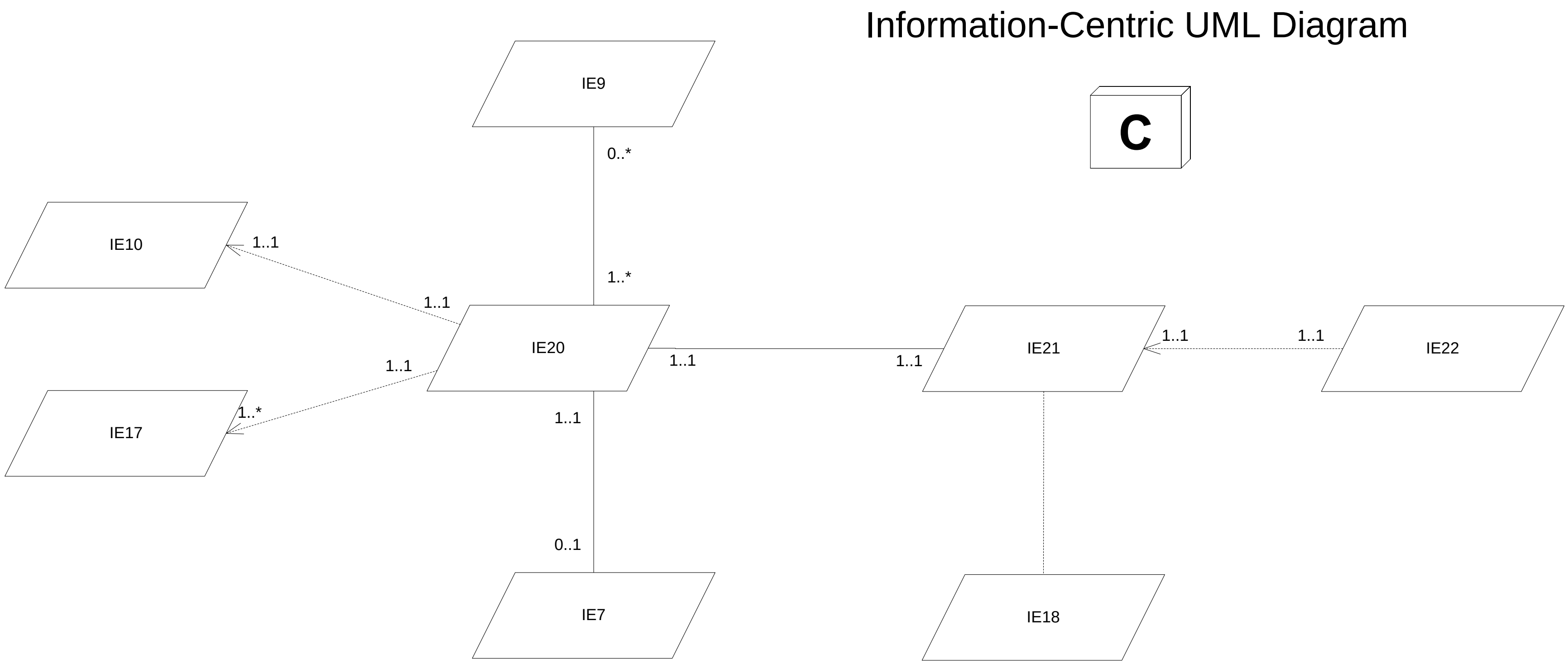
J.1 TRAINING TASK: TASK-CENTRIC UML PRACTICE DIAGRAMS



J.2 TRAINING TASK: RESOURCE-CENTRIC UML PRACTICE DIAGRAMS

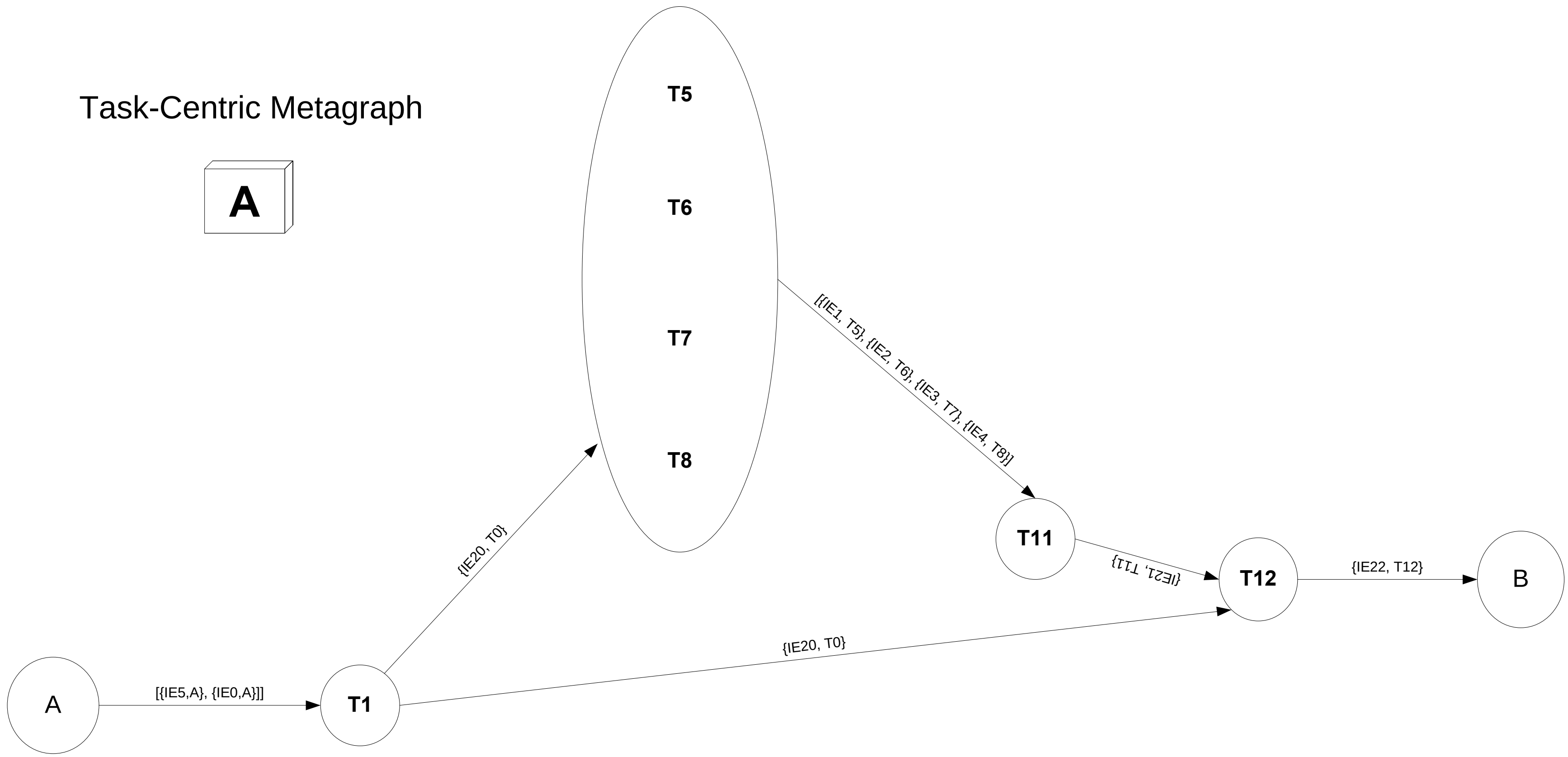


J.3 TRAINING TASK: INFORMATION-CENTRIC UML PRACTICE DIAGRAMS

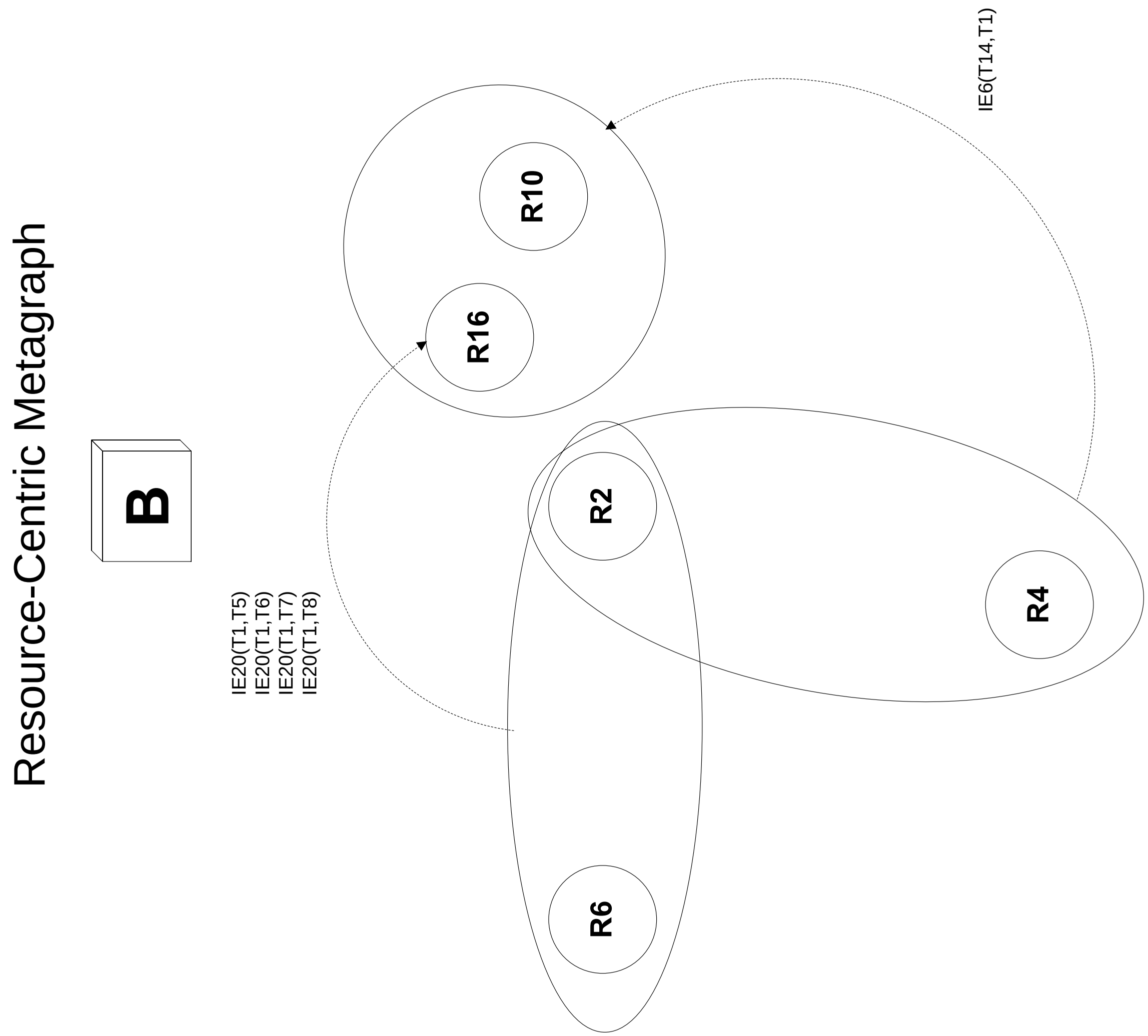


K TRAINING TASK METAGRAPH GRAPHICAL PROCESS MODELS USED IN THE EXPERIMENT

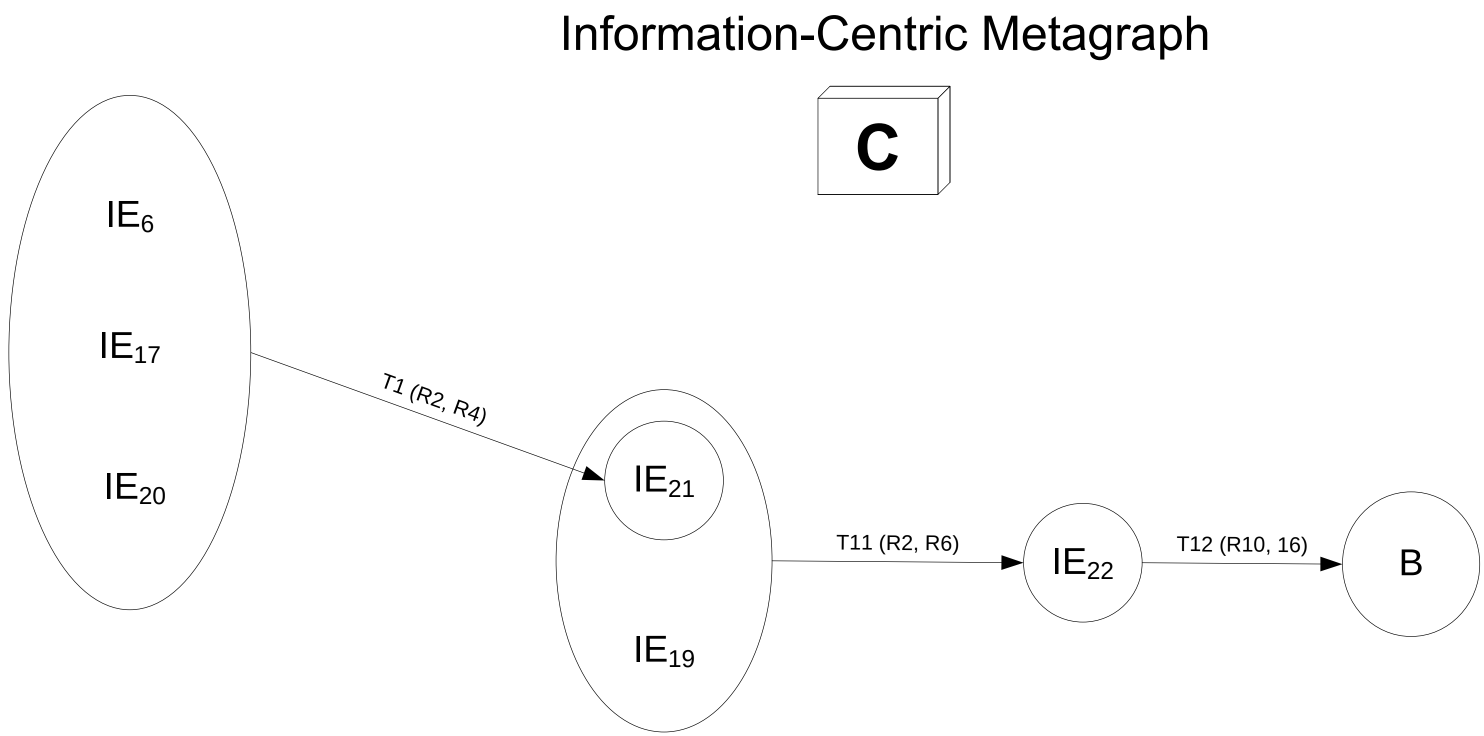
K.1 TRAINING TASK: TASK-CENTRIC METAGRAPH PRACTICE DIAGRAMS



K.2 TRAINING TASK: RESOURCE-CENTRIC METAGRAPH PRACTICE DIAGRAMS



K.3 TRAINING TASK: INFORMATION-CENTRIC METAGRAPH PRACTICE DIAGRAMS



L DATA COLLECTION INSTRUMENTS

L.1 UNIVERSITY A: DEMOGRAPHIC & PRIOR EXPERIENCE QUESTIONNAIRE

Demographic & Prior Experience Questionnaire

- Age: ____
- Gender: M F
- Major:
  - o Industrial and Systems Engineering (ISE)
  - o Business Management (MGT)
  - o Computer Science (CS)
- Have you had any experience in modeling business processes in industry? .Please describe the types of project, the type of information modeled, and software used (if any).

For students majoring in Industrial and Systems Engineering (ISE), which of the following courses have you taken?

- As an Undergraduate:

  - MATH 1114 Linear Algebra
  - MATH 1224 Vector Geometry
  - MATH 2224 Multivariable Calculus
  - ISE 2014 Engineering Economy
  - ISE 2204 Manufacturing Processes
  - ISE 2214 Manufacturing Processes Laboratory
  - ISE 2404 Deterministic Operations Research
  - ENGE 2314 Engineering Problem Solving w/ C++
  - ENGE 2344 Computer-Aided Drafting
  - ESM 2104 Statics
  - ESM 2304 Dynamics
  - ISE 3004 Industrial Cost Control
  - ISE 3014 Work Measurement and Methods Engineering
  - ISE 3214 Facility Planning and Material Handling
  - ISE 3414 Probabilistic Operations Research
  - ISE 3424 Discrete-Event Computer Simulation
  - ISE 3614 Introduction to Human Factors Engineering
  - ISE 3624 Work Design / Industrial Ergonomics
  - ECE 3054 Electrical Theory
  - ISE 4004 Theory of Organization
  - ISE 4005-4006 Project Management and Systems Design
  - ISE 4015 and/or 4016 Management Systems Theory, Application, and Design
  - ISE 4204 Production Planning & Inventory Control
  - ISE 4244 Fundamentals of Computer Integrated Manufacturing
  - ISE 4264 Industrial Automation
  - ISE 4304 Global Issues in Industrial Management
  - ISE 4404 Statistical Quality Control
  - ISE 4414 Industrial Quality Control
  - ISE 4624 Work Physiology
  - ISE 4644 Occupational Safety and Hazard Control
  - STAT 4705 and/or 4706 Statistics for Engineers

For students majoring in Management (MGT), which of the following courses have you taken?

- As an Undergraduate:
  - ACIS 2504: Personal Computers in Business
  - MGT 3324: Organization Behavior
  - MGT 3334: Introduction to Human Resource Management
  - MGT 4344: Productivity and Quality Leadership
  - MGT 3604: E-Management
  - MGT 4064: Innovation, Technology and Entrepreneurial Leadership
  - MGT 4074: Applied Small Business Consulting
  - MGT 3344: Labor-Management and Employee Relations
  - MGT 3424: Human Resource Staffing and Development
  - MGT 4414: Compensation and Performance Management

For students majoring in Computer Science (CS), which of the following courses have you taken? (Check all that apply)

- As an Undergraduate:
  - CS 1 Object 1st Introductory Course I
  - CS 2 Object 1st Introductory Course II

Undergraduate/Graduate College Credits Completed (complete only one of the following two)

- As an <u>undergraduate</u> student, what is the approximate number of Total Credits Completed here at the university?
    - Not Applicable
    - 0 to 30
    - 30 to 60
    - 60 to 90
    - 90 to 120
    - 120 to 150
    - 150 +
- As a <u>graduate</u> student, what is the approximate number of Total Credits Completed here at the university?
    - Not Applicable
    - 0 to 30
    - 30 to 60
    - 60 to 90
    - 90 to 120
    - 120 to 150
    - 150 +

Prior Experience with Graphical Process Models

- Have you been trained in graphical process modeling techniques:
    - Flowcharts
    - Petri nets
    - Metagraphs
    - UML Class Diagrams
    - UML Activity Diagrams
    - Other? ____________________

- What software have you used to model processes? (Please list the names of as many software packages as you can remember.)
    - __________________________________
    - __________________________________
    - __________________________________
    - __________________________________
    - __________________________________

- From the experience you have gained in your education and on industry projects, would you consider yourself a __________ in modeling business processes:
    - Novice
    - Intermediate
    - Advanced

L.2 UNIVERSITY B: DEMOGRAPHIC & PRIOR EXPERIENCE QUESTIONNAIRE

Demographic & Prior Experience Questionnaire

- Name:
- Email:
- Phone:
- Age: ____
- Gender: M F
- Home Country:

- Is English your native language?

  Yes No, My primary language is ________________
- Check the *Department* and *Course Number(s)* you are currently enrolled in:
  - Computer Science (CS) _____ _____ _____
  - Business Management (BUSM) _____ _____ _____

- As an undergraduate student, what is the approximate number of Total Credits Completed here at the university?
  - Not Applicable
  - 0 to 30
  - 30 to 60
  - 60 to 90
  - 90 to 120
  - 120 to 150
  - 150 +

- Have you had any prior experience in modeling business processes in industry?

  [Please briefly describe the projects, the type of business process modeled, the type of information modeled, and the software package used (if any). If needed, please use the back of this paper.]

For students taking **<u>Business Management (BUSM)</u>** courses, which of the following BUSM courses <u>have you completed</u> as an undergraduate? Do not indicate courses you are currently enrolled in. (Check all that apply)

- MATH 221: Principles of Statistics I
- IS 290L: Business Problem Solving with Applications II
- BUSM 242: Ethics and the Legal Environment of Business
- HTM 450: Hospitality and Tourism Law and Ethics (for HTM majors)
- BUSM 300: Leadership Principles
- BUSM 302: Business Finance/Entrepreneurship
- BUSM 304: Marketing/Entrepreneurship
- BUSM 306: Business Communication/Entrepreneurship
- BUSM 499: Strategic Management

For students taking **Computer Science (CS)** courses, which of the following CS courses have you completed as an undergraduate? Do not indicate courses you are currently enrolled in. (Check all that apply)

- CS 101: Beginning Programming
- CS 201: Web Programming
- CS 202: Object-Oriented Programming
- CS 210: Computer Organization
- CS 301: Algorithms and Complexity
- CS 320: Computational Theory
- CS 333: Software Engineering I
- CS 410: Computer Architecture
- CS 415: Operating Systems Design
- CS 420: Programming Languages
- CS 433: Software Engineering II
- CS 440: Intelligent Systems
- CS 421: Algorithmic Lang. and Compilers
- CS 441: Automatic Speech Recognition
- CS 442: Image Proc. and Computer Vision
- CS 451: Advanced Database Topics
- CS 456: Mobile Computing
- CS 461: Computer Graphics
- CS 491-492-493: Seminar I,II,III

<u>Have you completed or are enrolled</u> in any of the following courses? (Check all that apply)

- IS 100: Personal Productivity with IS technology
- IS 110: Introduction to Information Systems
- IS 220: Introduction to Unix or Linux (circle one)
- IS 240: Principles of HTML and Web Development
- IS 250: IT Hardware and Software
- IS 280: Networks and Telecommunications
- IS 300: MOUS certification preparation
- IS 307: Information Systems Analysis and Design
- IS 330: Management Information Systems
- IS 350: Physical Design and Implementation with DBMS Outcomes
- IS 351: Advanced Data Files and Database
- IS 320: Linux Administration (RHCT certification prerequisite)
- IS 409:
- IS 410:
- IS 420: Advanced Linux Administration (RHCE certification prerequisite)
- IS 431: E-Commerce Web Development

<u>Have you completed or are enrolled</u> in any of the following courses? (Check all that apply)

- Math 112: Calculus I (5)
- Math 113: Calculus II (5)
- Math 201: Discrete Mathematics I/Lab
- Math 202: Discrete Mathematics II/Lab
- Math 221 or 321
- Math 343: Elementary Linear Algebra

- ECON 200: Principles of Microeconomics
- ECON 201: Principles of Macroeconomics

- ACCT 201: Introduction to Financial Accounting
- ACCT 203: Introduction to Managerial Accounting
- ACCT 301: Intermediate Accounting I
- ACCT 302: Intermediate Accounting II
- ACCT 312: Managerial Accounting
- ACCT 321: Federal Tax-Individuals**
- ACCT 356: Accounting Information Systems
- ACCT 365: Auditing
- ACCT 386: Advanced Financial Accounting
- ACCT 440: International Acct. and Acct. Research
- ACCT 400: Intermediate Accounting II
- ACCT 401: Advanced Accounting

Prior Experience with Graphical Process Models

- Have you been trained in graphical process modeling techniques (Check all that apply):
  - Flowcharts
  - Petri nets
  - Metagraphs
  - UML Class Diagrams
  - UML Activity Diagrams
  - Other? ____________________

- What software packages have you used to model business processes? (Please list the names of as many software packages as you can remember.)
  - ___________________________________
  - ___________________________________
  - ___________________________________
  - ___________________________________
  - ___________________________________

- From the experience you have gained in your education and on industry projects, would you consider yourself __________ in modeling business processes:
  - A Beginner
  - Adequate
  - Advanced

L.3 TASK ACCURACY QUESTIONNAIRE

L.3.1 QUESTIONNAIRE ASSESSING PROCESS MANAGEMENT TASK-CENTRIC GPMS

Questionnaire Assessing Task-Centric Diagrams

BPM User Comprehension Components	Experiment User Comprehension Questions*
Task-Centric Questions (T) [Diagram A]	T1.1 Given a task, T3, to execute, what other tasks must be executed immediately before T3 to provide the information needed to execute task T3? (a) T1, T2, T4 (b) T4 (c) T6 (d) T5 (e) None of the above
	T1.2 Given a task, T7, to execute, what other tasks must be executed immediately before T7 to provide the information needed to execute task T7? (a) T3, T5, T6 (b) T5 only (c) T4, T8 (d) T1, T2 (e) None of the above
	T1.3 Given a task, T1, to execute, what other tasks must be executed immediately before T1 to provide the information needed to execute task T1? (a) T5, T6, T7, T8, T11 (b) T13, T14 (c) T7, T8 (d) T2, T3 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	Experiment User Comprehension Questions
Task-Centric Questions (T) (Continued)	T2.1 If task <u>T7</u> is disabled, what other tasks will be affected that i<u>mmediately follow</u> T7 – in other words, what other tasks cannot be executed because T7 is disabled? (a) T11. T12 (b) T5, T6, T8 (c) T3, T9 (d) T0, T10 (e) None of the above
[Diagram A]	T2.2 If task <u>T1</u> is disabled, what other tasks will be affected that i<u>mmediately follow</u> T1 – in other words, what other tasks cannot be executed because T1 is disabled? (a) T4 (b) T5 (c) T2, T3 (d) T2 only (e) None of the above
	T2.3 If task <u>T2</u> is disabled, what other tasks will be affected that i<u>mmediately follow</u> T2 – in other words, what other tasks cannot be executed because T2 is disabled? (a) T3, T4, T5 (b) T1 (c) T5, T6, T7, T8 (d) T1, T2, T3, T4 (e) None of the above
	T3.1 What task is utilized the <u>most</u> from the list below? (a) T4 (b) T9 (c) T10 (d) T6 (e) None of the above
	T3.2 What task is utilized the <u>least</u> from the list below? (a) T1 (b) T7 (c) T2 (d) T3 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

L.3.2 QUESTIONNAIRE ASSESSING RESOURCE-CENTRIC GPMS

Questionnaire Assessing Resource-Centric Diagrams

BPM User Comprehension Components	Experiment User Comprehension Questions
Resource-Centric Questions (R)	R1.1 If a resource R1 is unavailable, what other resources that directly follow or are associated with R1 will be affected? (a) All resources (b) R4, R10, R11 (c) R2, R3 (d) R4 only (e) None of the above
[Diagram B]	R1.2 If a resource R2 is unavailable, what other resources that directly follow or are associated with R2 will be affected? (a) All resources (b) R1, R3, R4, R11 (c) R3 only (d) R10, R11 (e) None of the above
	R1.3 If a resource R4 is unavailable, what other resources that directly follow or are associated with R4 will be affected? (a) All resources (b) R1, R2, R3 (c) R10, R11 (d) R1 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	**Experiment User Comprehension Questions**
Resource-Centric Questions (R) (Continued) [Diagram B]	R2.1 What specific resources directly precede or are associated with R4 that provides information for R4 to perform its tasks? (a) R1, R11 (b) R2, R3 (c) R1, R2 (d) R10, R11 (e) None of the above R2.2 What specific resources directly precede or are associated with R11 that provides information for R11 to perform its tasks? (a) R1, R2, R3 (b) R10 (c) R4 (d) R2, R3 only (e) None of the above R2.3 What specific resources directly precede or are associated with R2 that provides information for R2 to perform its tasks? (a) R4 (b) R1 (c) R10 (d) R11 (e) None of the above R3.1 What is the most utilized resource in the list below? (a) R2 (b) R10 (c) R11 (d) R1 (e) None of the above R3.2 What is the least utilized resource in the list below? (a) R2 (b) R4 (c) R3 (d) R10 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

L.3.3 QUESTIONNAIRE ASSESSING INFORMATION-CENTRIC GPMS

Questionnaire Assessing Information-Centric Diagrams

BPM User Comprehension Components	Experiment User Comprehension Questions
Information-Centric Questions (IE) [Diagram C]	IE1.1 Given three information elements, IE1, IE2, IE6, which of them is needed to determine the value of the other(s)? (a) IE1 determine IE2 and IE6 (b) IE1 and IE2 determine IE6 (c) IE2 determine IE1 and IE6 (d) IE6 and IE2 determine IE1 (e) None of the above IE1.2 Given two information elements, IE11, IE14, which of them is needed to determine the value of the other(s)? (a) IE11 determine IE14 and IE2 (b) IE14 determine IE11 (c) IE2 determine IE11 and IE14 (d) IE11 determine IE14 (e) None of the above IE1.3 Given six information elements, IE1, IE2, IE3, IE4, IE10, IE11, which of them is needed to determine the value of the other(s)? (a) IE1, IE2, IE3, IE4, IE10 determine IE11 (b) IE11 determine IE1, IE2, IE3, IE4, IE10 (c) IE1, IE3, IE10, determine IE2, IE4, IE11 (d) IE2, IE3, IE11 determine IE1, IE4, IE10 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	Experiment User Comprehension Questions
Information-Centric Questions (IE) (Continued)	IE2.1 Given two sets of information elements {IE6 IE7, IE8} and {IE10, IE11, IE12}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? (a) Yes – No other information elements are needed (b) No – unless {IE9} are also included (c) No – unless {IE1 and IE2} are also included (d) No – unless {IE4 and IE5} are also included (e) No – the first set does not determine the values of the second set, and the addition of information elements will not change this fact.
[Diagram C]	IE2.2 Given two sets of information elements, {IE1, IE2, IE3} and {IE11}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? (a) Yes – No other information elements are needed (b) No – unless {IE10, IE12} are also included (c) No – unless {IE7, IE8, IE9} are also included (d) No – unless {IE6, IE7, IE8} are also included (e) No – the first set does not determine the values of the second set, and the addition of information elements will not change this fact.
	IE2.3 Given two sets of information elements, {IE6, IE7, IE8, IE9, IE10, IE11} and {IE13, IE14}, is it possible to determine the values of the second set from the elements in the first set, and if not, are there any additional information elements that would make it possible to do so? (a) Yes – No other information elements are needed (b) No – unless {IE1} is also included (c) No – unless {IE12} is also included (d) No – unless {IE4, IE5} are also included (e) No – the first set does not determine the values of the second set, and the addition of information elements will not change this fact.

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	Experiment User Comprehension Questions
Information-Centric Questions (IE) (Continued)	IE3.1 What was the <u>most used or most critical information element</u> in the process that is listed below? (a) IE8 or IE11 (b) IE1 (c) IE5 (d) IE13 (e) None of the above
[Diagram C]	IE3.2 What was the <u>least used or least critical information element</u> in the process that is listed below? (a) IE7 (b) IE13 or IE 14 (c) IE2 (d) IE5 (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

L.3.4 QUESTIONNAIRE ASSESSING INTERACTIONS BETWEEN THREE BPIS AT ONCE

Questionnaire Assessing Interactions Between All Diagrams

BPM User Comprehension Components	Experiment User Comprehension Questions
Questions Concerning the Interactions among Components (CI) [Diagrams A, B, and C]	CI1.1 If a resource, R3, is unavailable, which information elements and tasks in the entire process can still be generated and completed? (a) All Tasks and Information Elements can be generated and completed. (b) All information elements can still be generated and all tasks can be completed except for {IE12, IE13, IE14} and {T5, T7, T8} (c) All information elements can still be generated and all tasks can be except for {T1, T2, T3} and {IE1, IE2, IE3, IE4, IE5}. (d) No information elements can still be generated or tasks can be completed except for {IE1, IE2} and {T7, T8}. (e) None of the above CI2.1 If an information element, IE6, is found to be inaccurate, which resources and tasks are used, directly or indirectly across the entire process, in the calculation or creation of IE6? (a) All Tasks and Resources. (b) {T2} and {R2, R4, R6, R11, R12} (c) {T5} and {R1, R2, R7} (d) {T1} and {R1, R10} (e) None of the above

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

BPM User Comprehension Components	Experiment User Comprehension Questions
Questions Concerning the Interactions among Components (CI) (Continued) [Diagrams A, B, and C]	CI3.1 Given a set of tasks, {T1, T2}, what information elements and resources <u>directly affect</u> the performance of these tasks? (a) All Information Elements and Resources. (b) {R1, R2, R10} and {IE1, IE2, IE3, IE4, IE5} (c) {R1, R3, R10, R12, R14, R21} and {IE5, IE7, IE9, IE11, IE13, IE15, IE17, IE21} (d) {R2, R4, R6, R10, R11, R12, R13, R14, R15, R16} and {IE10, IE11, IE12, IE13, IE14, IE15, IE16} (e) None of the above
	CI4.1 What tasks, information elements and resources <u>are needed as inputs</u>, <u>directly or indirectly</u>, to perform <u>T5</u>? (a) All Tasks, Information Elements, and Resources. (b) {R1, R2, R3, R4, R10} and {IE1, IE2, IE3, IE4, IE5, IE7, IE8} and {T1, T2, T4} (c) {R1, R2, R3, R10, R11} and { IE1, IE2} and {T1, T4, T6}. (d) {R1, R2, R11} and {IE4, IE5, IE6, IE7} and {T2, T3, T4}. (e) None of the above
	CI5.1 What is the single <u>most utilized information element, task, or resource</u> in the process - that is included in the list below? (a) R1 (b) IE1 or IE2 (c) T10 (d) All of the above (e) Cannot be determined from these diagrams
	CI5.2 What is the single <u>least utilized information element, task, or resource</u> in the process - that is included in the list below? (a) IE7 (b) R4 (c) T7 or T8 (d) All of the above (e) Cannot be determined from these diagrams

*Assume that the answers listed are complete – in other words, if an item is not listed, it is not part of the listed answer.

L.4 TASK TIMELINESS

Stopwatch

L.5 NASA TASK-LOAD INDEX (TLX)

Assessment of the Mental Workload You Just Experienced

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you just completed and are now asked to evaluate. Don't think that there is any correct pattern. I am only interested in your opinions. If you have any questions, please ask them now. Otherwise, you may begin.

SCALE TITLES FOR ASSESSMENT OF MENTAL WORKLOAD

TITLE	ENDPOINTS	DESCRIPTIONS
Mental Demand	Low/High	How much mental and perceptual activity is required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required(e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Bad/Good	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

MENTAL WORKLOAD RATING SHEET

Participant Name ____________________ Diagram ID (A, B, or C) ________

Diagram Type: UML or Metagraph (circle one)

MENTAL DEMAND

Low High

PHYSICAL DEMAND

Low High

TEMPORAL DEMAND

Low High

PERFORMANCE

Bad Good

EFFORT

Low High

FRUSTRATION

Low High

SOURCES OF WORKLOAD CARDS: INSTRUCTIONS

The evaluation you are about to perform is a technique that has been developed by NASA to assess the relative importance of six factors in determining how much workload you experienced as a result of performing the task you have just completed. You will be given a series of pairs of rating scale titles (for example, Effort vs. Mental Demands).

7. Please choose between one of the two items within each pair that was more important to your experience of mental workload in the task that you just performed. Each pair of scale titles will appear on a separate box in the matrix below. Please circle your choice.

8. On a scale of 1 to 10, write your rating of the how important the item your selected was to your experience of mental workload compared to the item you didn't select, on a scale of 1 to 10.

    - 1 = Difficult to decide which one was more important because both were almost equally important to my experience of mental workload.

    - 10 = My selection was a great deal more important to my experience of mental workload compared to the other item. It was extremely easy to identify my choice as more important.

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any correct pattern. We are only interested in opinions. If you have any questions, please ask them now. Otherwise, you may begin.

NASA TLX SCORING CARDS

Frustration or Effort	Performance or Mental Demand	Physical Demand or Frustration
Performance or Temporal Demand	Mental Demand or Effort	Physical Demand or Temporal Demand
Mental Demand or Physical Demand	Effort or Physical Demand	Temporal Demand or Mental Demand
Frustration or Mental Demand	Effort or Performance	Temporal Demand or Effort
Physical Demand or Performance	Performance or Frustration	Temporal Demand or Frustration

Subject #: _______________

NASA TLX Scoring - Sources of Workload

Task #: ______ Document: ______ Condition: _______

Scale title	Tally	Weight	Raw rating	Adjusted Rating (Weight X Raw)
Mental Demand				
Physical Demand				
Temporal Demand				
Performance				
Effort				
Frustration				

Total Count = ____ (no weight can be greater than 5; total count can’t be > 15).
Write the sum of the adjusted rating column _______. Weighted rating = Sum of adjusted ratings/15

L.6 WONDERLIC PERSONNEL TEST

The Wonderlic Personnel Test (WPT) Form A was used to assess participants' *General Cognitive Abilities* (GCA). Form A is administered with a 12 minute time limit. A copy of the WPT Form A is available upon request. The following are samples of WPT test questions from the Wonderlic, Inc. website: http://www.wonderlic.com/products/selection/wpt/sampleQuestions.asp

Sample Wonderlic Personnel Test (WPT)

Directions: In only 2 minutes, correctly answer as many questions as you can.

1. Look at the row of numbers below. What number comes next?
8, 4, 2, 1, 1/2, 1/4 ?
- o 4
- o 1/2
- o 1/8
- o 1/4
- o 1

2. Assume the first two statements are true.

The boy plays football. All football players wear helmets. The boy wears a helmet.

Is the final statement:
- o True?
- o False?
- o Not Certain

3. How many of the five pairs of items below are exact duplicates?

Nieman, K.M.	**Neiman, K.M.**
Thomas, G.K.	**Thomas, C.K.**
Hoff, J.P.	**Hoff, J.P.**
Pino, L.R.	**Pina, L.R.**
Warner, T.S.	**Wanner, T.S.**

- o 1
- o 2
- o 3
- o 4
- o 5

4. RESERVE | PRESENT -- Do these words

- o have similar meanings?
- o have contradictory meanings?
- o mean neither the same nor opposite?

5. One of the numbered figures in the following drawing is most different from the others. What is the number in that figure?

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5

6. The ninth month of the year is

- o October
- o January
- o June
- o September
- o May

7. Which number in the following group of numbers represents the smallest amount?

- o 7
- o .8
- o 2
- o 31
- o .33

8. The hours of daylight and darkness in SEPTEMBER are nearest equal to the hours of daylight and darkness in:

- o June
- o March
- o May
- o November

9. Assume the first two statements are true.

Bill greeted Beth. Beth greeted Ben. Bill did not greet Ben.

Is the final one:

- o True?
- o False?
- o Not Certain

L.7 DIFFERENTIAL ATTENTIONAL PROCESSES INVENTORY (DAPI)

Differential Attentional Processes Inventory (DAPI)

This questionnaire is an assessment of individual differences in the abilities to selectively attend and to carry out several tasks simultaneously. These abilities are NOT related to general intelligence. Describe your experiences in terms of frequency:

NEVER	VERY RARELY	RARELY	OCCASIONALLY	OFTEN	VERY OFTEN	ALWAYS
0	1	2	3	4	5	6

____ 1. Can you concentrate on reading or studying while in a noisy room?

____ 2. Can you get so involved in an activity that you don't have extraneous thoughts (don't think about other things)?

____ 3. Can you block out advertising commercials on TV or radio?

____ 4. Have you ever had the experience of not hearing or not remembering what a person said to you while you are involved in an activity and yet found yourself acting upon that person's statement at a later time?

____ 5. Can you lose yourself in thought so that you are hardly aware of the passage of time?

____ 6. Can you ignore or reduce pain (without drugs) if you want to?

____ 7. Can you ignore music when you are reading or studying?

____ 8. Can you shift your attention away from bothersome noises or distractions in a room so that they no longer bother you?

____ 9. Can you concentrate easily on reading or studying when music is playing in the same room?

____ 10. Can you lose yourself easily in thought?

____ 11. Can you doodle at the same time that you are having a conversation with another person?

____ 12. Can you attend to music easily and not hear conversations going on nearby in the same room?

____ 13. When you are at a party, can you attend to one conversation and ignore another one which is close by and audible?

____ 14. Do you ever miss or arrive late for appointments or class because you were so involved in something that you forgot the time?

____ 15. Can you drift off into your own thoughts or daydreams and still attend to someone else's conversation at the same time?

NEVER	VERY RARELY	RARELY	OCCASIONALLY	OFTEN	VERY OFTEN	ALWAYS
0	1	2	3	4	5	6

____ 16. While walking can you become so engrossed in thought that you do not recall the people or places you have passed?

____ 17. Can you forget that someone else is in the room with you?

____ 18. Can you ignore the discomfort of being in an environment that is too hot or too cold (within reasonable limits)?

____ 19. Can you “loose” a period of time where you cannot remember what you did?

____ 20. When you are at a play or movie, can you ignore or be unaware of disruptive movements or noises made by others around you?

____ 21. Can you write easily while at the same time listen to a conversation?

____ 22. Can you wander off into your own thoughts while doing an activity so that you actually forget what you were doing, and then find a few minutes later that you have finished the job without even being aware of having finished it?

____ 23. Can you daydream so deeply that you do not hear someone talking to you?

____ 24. Can you be so involved in reading or studying that when someone talks to you, you do not hear them?

____ 25. If you want to take a nap, can you easily ignore others conversing in the same room?

____ 26. Can you write easily while at the same time listen to the radio or TV?

____ 27. Can you be so involved in reading or studying that when someone talks to you, you do not hear them at the time yet later realize that they have spoken to you?

____ 28. Can you be so involved in dancing that you are almost not aware of your surroundings?

____ 29. Can you carry out a moderately complex activity at the same time that you are having a conversation with another person?

____ 30. Can you talk on the telephone while doing some other physical activity?

____ 31. Can you read or study easily while at the same time listen easily to a conversation?

____ 32. Can you read or study easily while at the same time listen to the talking of the radio or TV?

____ 33. Can you read or study easily while at the same time listen to music?

____ 34. Can you write easily while at the same time listen to music?

NEVER	VERY RARELY	RARELY	OCCASIONALLY	OFTEN	VERY OFTEN	ALWAYS
0	1	2	3	4	5	6

____ 35. Can you carry out a physical activity easily while listening to a conversation?

____ 36. Can you carry out a physical activity easily while listening to someone talking on radio or TV?

____ 37. Can you carry out a physical activity easily while listening to music?

____ 38. Can you wake up at night at some predetermined time during the night? (e.g., know you have to wake up at 4 AM and do so without any external help, such as an alarm clock)

____ 39. Can you read or study easily while actively involve in conversation?

____ 40. Can you listen to a conversation, be writing or studying at the same time, and also carry on some other internal thoughts unrelated to the first two at the same time?

L.7.1 DAPI SCORING

DAPI Construct: *Moderately Focused Attention Scale*
Items = ATT1 + ATT3 + ATT7 + ATT8 + ATT9 + ATT26 + ATT33 + ATT34

DAPI Construct: *Extremely Focused Attention Scale*
Items = ATT4 + ATT5 + ATT10 + ATT14 + ATT16 + ATT17 + ATT19 + ATT22 + ATT23 + ATT24 + ATT27 + ATT28

DAPI Construct: *Dual Cognitive-Physical Attention Scale*
Items = ATT11 + ATT30 + ATT35 + ATT36 + ATT37

DAPI Construct: *Dual Cognitive-Cognitive Attention Scale*
Items = ATT31 + ATT32 + ATT39 + ATT40

L.8 MYERS-BRIGGS TYPE INDICATOR

The Myers-Briggs Type Indicator (MBTI) Form F was used in this study.

L.9 GPM SELF-EFFICACY INSTRUMENT

Self-Efficacy Questionnaire

I COULD COMPLETE THE TASK QUESTIONNAIRES USING THE DIAGRAMS PROVIDED …

		NOT AT ALL CONFIDENT				MODERATELY CONFIDENT					TOTALLY CONFIDENT
1. …if there was no one around to tell me what to do.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
2. …if I had never used these types of diagrams before.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
3. …if I had only the training handouts for reference.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
4. …if I had seen someone else using the diagrams before trying them myself.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
5. …if I could call on someone for help if I got stuck.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
6. …if someone else had helped me get started.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
7. …if I had a lot of time to complete the task for which the training was provided.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
8. …if I had just the materials provided during training for assistance.	YES…….. NO	1	2	3	4	5	6	7	8	9	10
10. …if I had used similar diagrams to do the other tasks before completing this task.	YES…….. NO	1	2	3	4	5	6	7	8	9	10

M PRELIMINARY DATA ANALYSIS METHODS

Several preliminary analyses are required to test the underlying assumptions that permit parametric statistical analyses of this dataset. Parametric assumptions and analyses discussed in this section include:

1. Random Sampling and Interval Data: Random sampling of the population is required and measured at least at the interval level (see Appendix M.1).
2. Normality: for ANOVAs, the dependent variables are normally distributed within each group. For MANOVAs, the assumption is that the dependent variables (collectively) have multivariate normality within groups (see Appendix M.2).
3. Homogeneity of Variance/Covariance. Because this multivariate dataset has unequal cell sizes across groups, the data is not robust to violations of homogeneity of variance. Consequently, homogeneity of variance assumptions are used to test for sphericity in the repeated measures of accuracy, timeliness, and TLX mental workload (see Appendix M.3).
4. Tests of Independence: Since this is a multivariate dataset, it is likely there is a high correlation between these dependent variables. Therefore, these data require multivariate hypothesis testing procedures be conducted to test for independence of the dependent variables prior to conducting univariate statistical analyses in order to protect the validity of the results (see Appendix M.4).
5. Scale Reliability Analyses of the Differential Attentional Processes Inventory (DAPI): Reliability analyses were also used to evaluate the scale reliability of DAPI constructs for further analysis (see Appendix M.5).
6. Evaluation of the Balance of Participant Cognitive Styles within Treatment Groups (see Appendix M.6).

M.1 INTERVAL DATA AND RANDOM SAMPLING

The selection of participants was by primarily by volunteering and not completely random. Students were chosen based on their class standing (at least a rising junior-standing in their major) and the current classes from which they were recruited. All IE students were from one university, were all members of a single summer term course, and were required by their professor to participate in the experiment for course credit. MGT and CS student participants were volunteers, were from various courses, and were from two different universities. Lastly, the order all participants were exposed to different types of BPI could not be completely randomized, but the order was balanced by design so that approximately equivalent groups of students were exposed to different types of BPI. The design of this experiment sampled participants and randomized the order of the different types of BPI as much as possible.

Both interval and continuous data were collected according to the measures described earlier in the chapter. Interval data were collected for measures of self-efficacy. Continuous data were collected for timeliness and TLX subjective mental workload. Task accuracy data were evaluated as count data for each participant and then converted to a percent correct. Percent correct data are treated as continuous data in this experiment.

M.2 NORMALITY

Multivariate normality is a prerequisite for most of the univariate and multivariate statistical analyses used in this study. Normality is evaluated most effectively by plotting histograms of the data and visually evaluating it. Skewness and Kurtosis results also help determine normality (cf. Field, 2005; Rencher, 2001).

M.3 HOMOGENEITY OF VARIANCE

For ANOVAs, the required assumption is that variances are equal across groups. For MANOVAs, the requirement is that there is homogeneity across covariance matrices. This means that the homogeneity of variance assumption holds for each dependent variable and that the correlation between any two dependent variables is the same in all groups. Levene's and Box's tests are used to evaluate this assumption. Box's test evaluates the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups, and has added robustness compared to Levene's test. Lastly, sphericity is used to test that variances are equal across repeated measures data taken from the same participant. Barlett's and Mauchly's tests are used to test the sphericity. Significant results for any of these results indicate a violation of this assumption. If these assumptions are violated, there are corrections that can sometimes be made to the analyses to give more reliable results (cf. Field, 2005; Rencher, 2001). See Appendix A.2 for results.

M.4 TESTS OF INDEPENDENCE

Observations in the dataset should be statistically independent. Since this is a multivariate dataset, it is likely there is a high correlation between these dependent variables. Therefore, these data require multivariate hypothesis testing procedures be conducted to test for independence of the dependent variables prior to conducting univariate statistical analyses in order to protect the validity of the results. These multivariate hypothesis tests protect against inflation in the overall experimentwise error rate and subsequent misinterpretations of univariate analyses when results for a variable are significant at the $p < 0.05$ level of significance. When a multivariate hypothesis test is non-significant (i.e., the null hypothesis is true, H_0: $\mu_{Accuracy} = \mu_{Time} = \mu_{MentalWorkload} = \mu_{Self-Efficacy}$) any subsequent analytic results are highly suspicious because any significance must be a Type I error.

M.4.1 THE NEED FOR MULTIVARIATE VS. UNIVARIATE HYPOTHESIS TESTS

Rencher (2001, pp. 112-113) discusses four arguments for a multivariate approach to hypothesis testing as opposed to a univariate approach:

1. The use of p univariate tests inflate the Type I error rate, α , whereas the multivariate tests preserves the exact α -level. If an *f*-test is made on each of the p variables regardless of whether the overall multivariate analysis of variance (MANOVA) test of H_0: $\mu_1 = \mu_2 = \mu_3 = ...\mu_X$ rejects H_0, then the overall α -level will increase beyond the nominal value because we are making p tests. For example, if we do $p = 10$ separate univariate tests at the $\alpha = 0.05$ level, the probability of at least one false rejection is greater than $\alpha = 0.05$. If the variables are independent, we will have under H_0.

   $$P \text{ (at least one rejection)} = 1 - P \text{ (all 10 tests accept } H_0)$$
   $$= 1 - (0.95)^{10} = 0.40$$

   The resulting overall α is not an acceptable error rate. Typically, the 10 variables are correlated, and the overall α lies somewhere between 0.05 and 0.40.

2. Univariate tests completely ignore the correlations among the variables, whereas the multivariate tests make direct use of the correlations.

3. Multivariate test is more powerful in many cases. The power of a test is the probability of rejecting H_0 when it is false. In some cases, all p of the univariate tests fail to reach

significance, but the multivariate test is significant because small effects on some of the variables combine to jointly indicate significance. However, for a given sample size, there is a limit to the number of variables a multivariate test can handle without losing power.

4. Many multivariate tests that involve comparing group means have, as a byproduct, the construction of linear combinations of variables revealing more about how the variables combine to reject the hypothesis.

The probability of rejecting one or more of univariate tests on *p* variables when H_0: $\mu_1 = \mu_2 = \mu_3 = \ldots\mu_X$ is true is called the overall α or experimentwise error rate. If only univariate tests are performed on individual variables, without using multivariate hypothesis tests, then the overall error rate is overinflated. Yet, when the same testing is performed only after the multivariate tests reject H_0, the error rates of individual variable tests are close to the nominal rate. Rencher (2001, pp. 126-128, 183-185) cites several examples of research studying the experimentwise error rate for univariate tests following rejection of H_0 by the multivariate tests. Using α = 0.05 in calculation of the multivariate T^2 statistic, univariate *t*-tests are performed only if the T^2-test rejected H_0. The result yielded an overall α between 0.017 and 0.050, which is acceptably close to the nominal 0.05. When compared to the same procedure performed without a prior T^2-test, the resulting overall α was found to be too high (between 0.077 to 0.348). In another study, univariate *F*-tests are conducted following a Wilk's Lambda multivariate test. The resulting values ranged from 0.022 to 0.057, which is close to the target value of 0.05. Without first performing the Wilk's Lambda test, the probability for rejecting one or more univariate tests when H_0 is true varied from 0.09 to 0.31, far above the target value of 0.05. If a univariate *F*-test or *t*-test is made on each of the *p* variables regardless of whether the overall MANOVA test rejects H_0: $\mu_1 = \mu_2 = \mu_3 = \ldots\mu_X$, then the overall α-level will increase beyond the nominal value because we are making *p* tests.

Thus, when testing multivariate data, multivariate hypothesis tests should be conducted before any univariate tests. When univariate tests are conducted only after rejection of the overall multivariate tests, the experimentwise error rate is close to the desired α-level. When the probability of rejection for the tests on individual variables is reduced, these tests become more conservative. If H_0 is rejected, further univariate tests on individual variables and variable interactions can go on. If H_0 does not reject, then further univariate tests are not advised because they will not yield valid and reliable results. In this way, the results will "protect" against the inflation of the experimentwise error rate by performing tests on individual variables only if the overall MANOVA test rejects *H₀*: $\mu_1 = \mu_2 = \mu_3 = ...\mu_X$ (cf. Rencher, 2001, pp. 112-117, 126-128, 168-170, 183-185).

M.4.2 THE FOUR MULTIVARIATE HYPOTHESIS TESTS USED IN A MANOVA

A MANOVA is recommended for data analysis from this experiment because the independent variables are both fixed and categorical (Rencher, 2001). However, prior to proceeding with the MANOVA, it is important to perform four multivariate hypothesis tests prior to performing univariate statistical analyses. The four multivariate test statistics include:

the Wilk's Lambda (Λ),

$$\Lambda = \prod_{i=1}^{s} \frac{1}{1+\lambda_1} \tag{3.1}$$

Roy's Largest Root (θ),

$$\theta = \frac{\lambda_1}{1+\lambda_1} \tag{3.2}$$

Pillai Statistic ($V^{(s)}$),

$$V^{(s)} = \sum_{i=1}^{s} \frac{\lambda_1}{1+\lambda_1} \tag{3.3}$$

and the Lawley-Hotelling test statistic ($U^{(s)}$).

$$U^{(s)} = \sum_{i=1}^{s} \lambda_i \tag{3.4}$$

However, as can be seen from the equations above, the four tests are not equivalent. In a given sample, they may lead to different conclusions, even when H_0 is true and some tests reject H_0 while other tests accept H_0.

There are several reasons why four different multivariate hypothesis tests are needed. All four are exact tests. This means when H_0: $\mu_1 = \mu_2 = \mu_3 = ...\mu_X$ is true, all the mean vectors are at the same point. Consequently, all four MANOVA test statistics have the same Type I error rate α ;

meaning all tests have the same probability of rejection when H_0 is true. Using all four tests contribute to assuring the researcher that further tests on multivariate data will maintain an acceptable error rate.

Four different multivariate test statistics are used because different situations make one test statistic more powerful than another. As a result, there is a considerable amount of disagreement in the statistics community as to which statistic is best. According to Rencher (2001), this disagreement is primarily a result of many statisticians not understanding the increased complexities of multivariate statistics. Because of this debate, the most reliable conclusion is obtained when all four tests agree on the independent variable being tested. When all four tests agree, the multivariate dataset clearly meets the requirements of multivariate independence, and, therefore, significant statistical results in further analyses can be trusted because the overall experimentwise error rates are preserved. The following sections detail these four multivariate test statistics.

The differences between the four MANOVA test statistics are due to the multidimensional nature of the space in which the multivariate mean vectors lie. The argument supporting the use of multiple test statistics is that each test is more sensitive to different types of variation in multivariate *s*-dimensional space. Consequently, the mean vectors lie in *s*-dimensional subspace of the *p*-dimensional space of the observations - meaning they may occupy a subspace of *s*-dimensions. For example, the points may be confined to a line (one dimension) or a plane (three dimensions).

The pattern of the mean vectors is indicated by the eigenvalues (λ_i) of the $\mathbf{E}^{-1}\mathbf{H}$ matrix. If there is one large eigenvalue, then the vectors lie close to a line. If there are two or more large eigenvalues and the others are small, then the mean vectors lie mostly in a plane. Since the power of a test is the probability of rejecting H_0 when it is false, in terms of power, the tests are ordered, $\theta \geq U^{(s)} \geq \Lambda \geq V^{(s)}$ for collinear mean vectors, and $V^{(s)} \geq \Lambda \geq U^{(s)} \geq \theta$ for diffuse mean vectors. This means that for multivariate data with multivariate mean vectors, Roy's Largest Root is the most powerful test but is the least powerful test for multidimensional data, where the Pillai statistic is the most powerful test. Wilk's Lambda and Lawley-Hotelling statistics provide good overall power in both cases. Therefore, using all four tests helps identify potential problems and lends reliability and validity to further statistical analyses on the data (see Rencher (2001, pp. 176-179) for further discussion).

M.5 Scale Reliability Analysis of the Differential Attentional Processes Inventory

Preliminary analysis of the DAPI items evaluated the scale reliability of its constructs. Cronbach's α was calculated for each of the four DAPI construct subscales:

- Moderate Focus Subscale: 8 items (DAPI items 1, 3, 7, 8, 9, 26, 33, 34)
- Extreme Focus Subscale: 12 items (DAPI items 4, 5, 10, 14, 16, 17, 19, 22, 23, 24, 27, 28)
- Dual Cognitive-Physical Task Focus Subscale: 5 items (DAPI items 11, 30, 35, 36, 37)
- Dual Cognitive-Cognitive Task Focus Subscale: 4 items (DAPI items 31, 32, 39, 40)

If DAPI constructs are reliable, the Cronbach $\alpha \geq 0.8$.

M.6 Evaluation of the Balance of Participant Cognitive Styles in Treatment Groups

Participants' *cognitive styles* (i.e., extraversion-introversion and sensing-intuition abilities) were evaluated to understand their distributions within treatment groups. Counts of participants MBTI extroversion, introversion, sensors, and intuitive styles are arranged and analyzed by the type of between-subject independent variables used in this study: the type of graphical process model (GPM) and the type of User Educational Training (UET).

N PRELIMINARY ANALYSES OF THE DATASET

Several preliminary analyses were performed to test the underlying statistical assumptions prior to performing analyses testing the hypotheses. Results of parametric statistical assumptions that were tested are included in this section: multivariate normality, homogeneity of variance/covariance, multivariate hypothesis tests of independence, scale reliability analyses of the DAPI, and evaluation of the balance of participant cognitive styles in the treatment groups.

N.1 NORMALITY

Normality is evaluated most effectively by plotting histograms of the data and visually evaluating it. Skewness and Kurtosis results also help determine normality. The data in this experiment was plotted and analyzed in these ways.

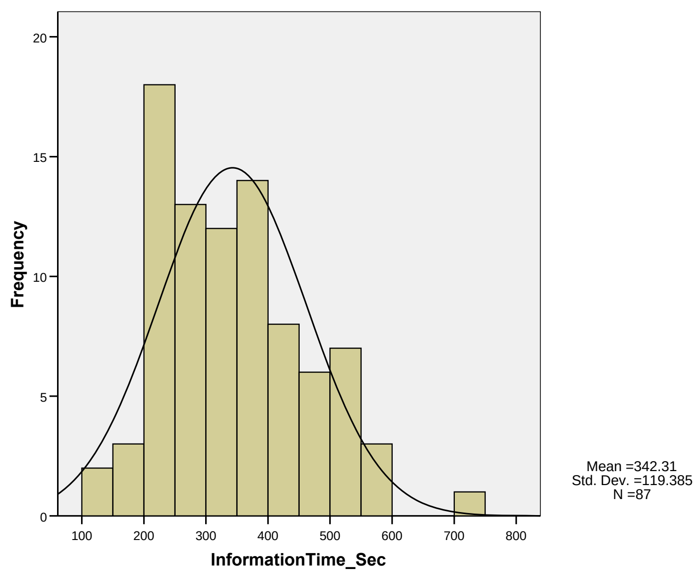


Figure N-1. Histogram of the time participants took to interpret information-related BPI.

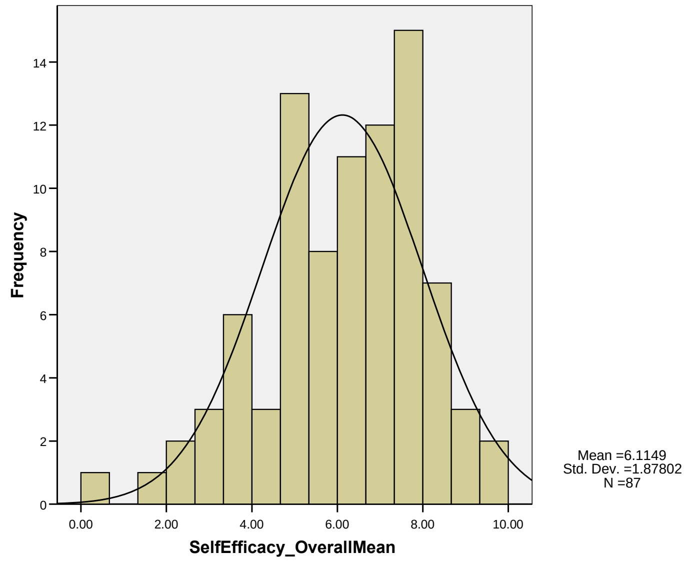


Figure N-2. Histogram of participants' self-efficacy results.

Table N-1. Skewness and Kurtosis results for the dependent variables.

	N	Range	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Accuracy - Task Knowledge (% Correct)	87	63	-.260	.258	-.915	.511
Accuracy - Resource Knowledge (% Correct)	87	80	.102	.258	-1.066	.511
Accuracy - Information Knowledge (% Correct)	87	86	-.341	.258	-.145	.511
Time - Task-related Process Knowledge (Seconds)	87	383	.814	.258	.668	.511
Time - Resource-related Process Knowledge (Seconds)	87	708	1.883	.258	6.420	.511
Time - Information-related Process Knowledge (Seconds)	87	582	.623	.258	-.090	.511
NASA TLX *Mental Workload* for interpreting Task-related BPI	87	85.20	.024	.258	.383	.511
NASA TLX *Mental Workload* for interpreting Resource-related BPI	87	89.73	-.090	.258	.521	.511
NASA TLX *Mental Workload* for interpreting Information-related BPI	87	95.07	-.396	.258	.718	.511
Average *Self Efficacy* Score	87	10.00	-.558	.258	.364	.511

Of all the histograms, Figures N-1 and N-2 are the only two that are suspicious as to their normality. They show skewness to one tail or another and some evidence of being bimodal. Skewness and Kurtosis results are shown in Table N-1. In Table N-1, the three *timeliness* scores show which deviations from normality.

N.2 Post Hoc Statistical Power Analyses

Post hoc analyses of the multivariate data revealed the statistical power (1-β) of the experiment was sufficient to detect large effects on all dependent variables across all independent variables. SPSS statistical analysis reveal possible problems in the observed power in:

- All multivariate hypothesis tests associated with the type of UET (see the observed power column in Table N-2).
- The subjective mental workload results associated with the type of GPM (see the observed power column in Table N-4).
- All dependent variables associated with the type of UET (see the observed power column in Table N-4).
- All dependent variables associated with the type of BPI (see the observed power column in Table N-5).

Further investigation revealed problems with the way the a priori power analysis was conducted. Post hoc power analyses also was able to provide evidence and justification for the statistical power of these analyses.

N.2.1 Problems with A Priori Power Analysis

As discussed in Section 3.6.1, the sample size and power level was determined using Figure 2.1 in Lipsey (1990, p. 44). This figure assists in the determination of power levels and sample sizes for one-way ANOVAs, and was recommended as appropriate to use, at the time, because individual ANOVAs are the basis of MANOVAs and because of inconsistent recommendations for determining power in multivariate data from in prior statistical literature. However, it was discovered during post hoc analysis of the data that the recommended sample size recommended by

Lipsey's figure should have been interpreted as the sample size of each treatment group instead of the total sample size of 72.

Also, using ANOVA power tables to determine power and sample size for a multivariate dataset was also a mistake. One reason for the lack of literature on power analysis of multivariate data is that multivariate power analysis is often ignored or misunderstood in the statistical literature (D'Amico, Neilands, & Zambarano, 2001). As a result, mistakes are common in reporting of *ES*, sample sizes, and power-levels for multivariate data. What statistical literature there is on the topic reports that multivariate power analysis cannot be conducted a priori based on typical ANOVA charts and algorithms because there is not a direct connection between univariate and multivariate statistical power statistics (D'Amico et al., 2001; Faul, Erdfelder, Lang, & Buchner, In Press). Statistical literature recommends the only reliable ways of determining a priori power levels and sample size for multivariate experiments is to perform post hoc power analyses (1) on previous results from prior literature or (2) experiment with sample data based on prior research.

N.2.2 RESULTS OF POST HOC POWER ANALYSES

Post hoc power analysis was conducted on the multivariate data set using G*Power 3.0 software (Faul et al., In Press) based on procedures recommended in (D'Amico et al., 2001; Faul et al., In Press). The first step in investigating the low SPSS observed power results were to calculate the observed effect sizes and recalculate the observed power using the SPSS results for the partial η^2 and the multivariate hypothesis test statistics using G*Power software. G*Power is a statistical power analysis software capable of performing power analyses on various types of univariate and multivariate data. It gives the option of calculating power based on the Muller and Peterson (Muller, LaVange, Landesman-Ramey, & Ramey, 1992; Muller & Peterson, 1984) algorithm or the or O'Brien and Shieh algorithm (Shieh, 2003). The Muller and Peterson algorithm has found widespread application in statistical software, including SPSS, but recently O'Brien and Shieh algorithm has been shown to be more accurate and less conservative (Faul et al., In Press; Shieh, 2003).

Next, revised effects sizes and power were calculated based on Cohen's (1988) recommendations: *ES* = 0.15 for detecting small effects, *ES* = 0.25 for detecting medium effects, and *ES* = 0.40 for detecting large effects. After adjusting the effect sizes, power was demonstrated to be at least powerful enough to detect large effects for all dependent variables across all independent variables at the level of $(1-\beta) \geq 0.80$ (see Tables N-2, N-3, N-4, and N-5 – only effect sizes or observed power statistics that were suspicious were revised). Subsequent research should increase the sample size of the treatment groups to be capable of detecting medium or smaller effect sizes.

Table N-2. Post hoc power analyses of multivariate hypothesis tests of between-subject effects for both between and within-subjects independent variables and interactions.

Between Subjects Effect			Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Observed Effect Size (e)	Observed Power (a)	Revised Effect Size(e)	Revised Power(e)
Between Subjects Variable	Intercept	Pillai's Trace	.99	2514.41(b)	3.00	79.00	.00	.99		1.00		
		Wilks' Lambda	.01	2514.41(b)	3.00	79.00	.00	.99		1.00		
		Hotelling's Trace	95.48	2514.41(b)	3.00	79.00	.00	.99		1.00		
		Roy's Largest Root	95.48	2514.41(b)	3.00	79.00	.00	.99		1.00		
	GPM Type	Pillai's Trace	.44	20.62(b)	3.00	79.00	.00	.44	.89	1.00	.40	.81
		Wilks' Lambda	.56	20.62(b)	3.00	79.00	.00	.44	.89	1.00	.40	.81
		Hotelling's Trace	.78	20.62(b)	3.00	79.00	.00	.44	.89	1.00	.40	.81
		Roy's Largest Root	.78	20.62(b)	3.00	79.00	.00	.44		1.00		
	User Educational Training Type	Pillai's Trace	.16	2.25	6.00	160.00	.04	.08	.43	.78 or .87(e)	.40	.81
		Wilks' Lambda	.85	2.23(b)	6.00	158.00	.04	.08	.42	.77 or .85(e)	.40	.81
		Hotelling's Trace	.17	2.22	6.00	156.00	.04	.08	.41	.77 or .83(e)	.40	.81
		Roy's Largest Root	.12	3.06(c)	3.00	80.00	.03	.10		.70		
Within Subjects Variable	BPI Type	Pillai's Trace	.38	7.64(b)	6.00	76.00	.00	.38		1.00		
		Wilks' Lambda	.62	7.64(b)	6.00	76.00	.00	.38		1.00		
		Hotelling's Trace	.60	7.64(b)	6.00	76.00	.00	.38		1.00		
		Roy's Largest Root	.60	7.64(b)	6.00	76.00	.00	.38		1.00		
	BPI Type X GPM Type	Pillai's Trace	.06	.80(b)	6.00	76.00	.57	.06		.30		
		Wilks' Lambda	.94	.80(b)	6.00	76.00	.57	.06		.30		
		Hotelling's Trace	.06	.80(b)	6.00	76.00	.57	.06		.30		
		Roy's Largest Root	.06	.80(b)	6.00	76.00	.57	.06		.30		
	BPI Type X	Pillai's Trace	.22	1.59	12.00	154.00	.10	.11		.82		

Between Subjects Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Observed Effect Size (e)	Observed Power (a)	Revised Effect Size(e)	Revised Power(e)
User Educational Training Type	Wilks' Lambda	.79	1.61(b)	12.00	152.00	.10	.11		.82		
	Hotelling's Trace	.26	1.61	12.00	150.00	.09	.12		.82		
	Roy's Largest Root	.21	2.68(c)	6.00	77.00	.02	.18		.84		
BPI Type X GPM Type X User Education Type	Pillai's Trace	.13	.88	12.00	154.00	.57	.07		.50		
	Wilks' Lambda	.88	.88(b)	12.00	152.00	.57	.07		.50		
	Hotelling's Trace	.14	.87	12.00	150.00	.58	.07		.49		
	Roy's Largest Root	.10	1.17(c)	6.00	77.00	.33	.08		.44		

a Computed using Muller and Peterson (Muller et al., 1992; Muller & Peterson, 1984) algorithm and alpha = .05
b Exact statistic
c The statistic is an upper bound on F that yields a lower bound on the significance level.
d Design: Intercept+GPMType+UserEducationType+GPMType * UserEducationType
Within Subjects Design: BPIType
e Calculated using the O'Brien & Shieh (Shieh, 2003) algorithm in post hoc power analysis

Table N-3. Post hoc power analyses of multivariate hypothesis tests of with-subject effects for within-subjects independent variables and interactions.

Within Subjects Effect		Value	F	Hypothesis df	Error df	Sig.	Effect Size(f)	Observed Power(a)	Revised Effect Size(f)	Revised Power(f)
BPI Type	Pillai's Trace	0.22	6.49	6.00	322.00	0.00	0.52	.99 or .99(f)	0.34	0.80
	Wilks' Lambda	0.79	6.75(b)	6.00	320.00	0.00	0.52	.99 or .99(f)	0.34	0.80
	Hotelling's Trace	0.27	7.01	6.00	318.00	0.00	0.52	1.00 or .99(f)	0.34	0.80
	Roy's Largest Root	0.25	13.22©	3.00	161.00	0.00		1.00		
BPI Type X GPM Type	Pillai's Trace	0.03	0.86	6.00	322.00	0.52		0.34		
	Wilks' Lambda	0.97	.86(b)	6.00	320.00	0.53		0.34		
	Hotelling's Trace	0.03	0.86	6.00	318.00	0.53		0.34		
	Roy's Largest Root	0.03	1.46(c)	3.00	161.00	0.23		0.38		
BPI Type X User Educational Training Type	Pillai's Trace	0.12	1.70	12.00	486.00	0.06		0.87		
	Wilks' Lambda	0.88	1.70	12.00	423.61	0.06		0.81		
	Hotelling's Trace	0.13	1.70	12.00	476.00	0.06		0.86		
	Roy's Largest Root	0.08	3.35(c)	4.00	162.00	0.01		0.84		
BPI Type X GPM Type X User Educational Training Type	Pillai's Trace	0.06	0.87	12.00	486.00	0.58		0.52		
	Wilks' Lambda	0.94	0.87	12.00	423.61	0.58		0.45		
	Hotelling's Trace	0.07	0.87	12.00	476.00	0.58		0.51		
	Roy's Largest Root	0.04	1.75(c)	4.00	162.00	0.14		0.53		

a Computed using Muller and Peterson (Muller et al., 1992; Muller & Peterson, 1984) algorithm and alpha = .05
b Exact statistic
c The statistic is an upper bound on F that yields a lower bound on the significance level.
d Design: Intercept+GPMType+UserEducationType+GPMType * UserEducationType
Within Subjects Design: BPIType
e Tests are based on averaged variables.
f Calculated using the O'Brien & Shieh (Shieh, 2003) algorithm in post hoc power analysis

Table N-4. Post hoc power analyses of univariate ANOVAs of between-subject independent variables and interactions.

Transformed Variable: Average

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Observed Effect Size(b)	Observed Power(a)	Revised Effect Size(b)	Revised Power(b)
Intercept	Accuracy	1145197.31	1.00	1145197.31	3086.49	0.00	0.97		1.00		
	Time	23198976.21	1.00	23198976.21	1204.61	0.00	0.94		1.00		
	MWL	1088364.98	1.00	1088364.98	2043.07	0.00	0.96		1.00		
GPM Type	Accuracy	15420.83	1.00	15420.83	41.56	0.00	0.34	0.72	1.00	0.29	0.80
	Time	337171.15	1.00	337171.15	17.51	0.00	0.18	0.47	.99 or .99(b)	0.33	..802
	MWL	1837.91	1.00	1837.91	3.45		0.04	0.21	.45 or .34(b)	0.35	0.81
User Educational Training	Accuracy	2208.76	2.00	1104.38	2.98	0.06	0.07	0.27	.56 or .73(b)	0.29	0.80
	Time	43710.18	2.00	21855.09	1.14	0.33	0.03	0.17	.24 or .24(b)	0.33	0.80
	MWL	3525.18	2.00	1762.59	3.31	0.04	0.08	0.29	.61 or .68(b)	0.35	0.81
GPM Type X User Educational Training Type	Accuracy	877.04	2.00	438.52	1.18	0.31	0.03		0.25		
	Time	65593.62	2.00	32796.81	1.70	0.19	0.04		0.35		
	MWL	2169.93	2.00	1084.96	2.04	0.14	0.05		0.41		
Error	Accuracy	30053.89	81.00	371.04							
	Time	1559935.88	81.00	19258.47							
	MWL	43149.67	81.00	532.71							

a Computed using alpha = .05
b Calculated using the O'Brien & Shieh (Shieh, 2003) algorithm in post hoc power analysis

Table N-5. Post hoc power analyses of univariate ANOVA results of within-subject independent variables and interactions.

Source	Measure	Sphericity Correction	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Effect Size(b)	Observed Power(a)	Revised Effect Size(b)	Revised Power(b)
BPI Type	Accuracy	Huynh-Feldt	1293.518	1.93	670.14	2.29	0.11	0.03	0.17	.45 or.81(b)	0.17	0.80
	Time	Sphericity Assumed	203676.36	2.00	101838.18	17.94	0.00	0.18	0.47	1.00	0.15	0.89
	MWL	Sphericity Assumed	954.32	2.00	477.16	5.19	0.01	0.06	0.25	.82 or .99(b)	0.15	0.95
BPI X GPM Type	Accuracy	Huynh-Feldt	318.63	1.93	165.07	0.56	0.56	0.01		0.14		
	Time	Sphericity Assumed	3750.26	2.00	1875.13	0.33	0.72	0.00		0.10		
	MWL	Sphericity Assumed	303.17	2.00	151.59	1.65	0.20	0.02		0.34		
BPI X UET Type	Accuracy	Huynh-Feldt	1175.30	3.86	304.45	1.04	0.39	0.03		0.32		
	Time	Sphericity Assumed	28679.85	4.00	7169.96	1.26	0.29	0.03		0.39		
	MWL	Sphericity Assumed	1198.06	4.00	299.52	3.26	0.01	0.07		0.83		
BPI X GPM X UET Type	Accuracy	Huynh-Feldt	509.69	3.86	132.03	0.45	0.77	0.01		0.15		
	Time	Sphericity Assumed	19068.67	4.00	4767.17	0.84	0.50	0.02		0.26		
	MWL	Sphericity Assumed	520.37	4.00	130.09	1.42	0.23	5.66		0.43		
Error(BPI Type)	Accuracy	Huynh-Feldt	45765.93	156.35	292.72							
	Time	Sphericity Assumed	919765.56	162.00	5677.57							
	MWL	Sphericity Assumed	14898.61	162.00	91.97							

a Computed using alpha = .05
b Calculated using the O'Brien & Shieh (Shieh, 2003) algorithm in post hoc power analysis

N.3 HOMOGENEITY OF VARIANCE AND COVARIANCE

Results for Levene's test on the dependent variables (Table N-6) and Box's test show that the dataset does not violate the assumption of homogeneity of variance and covariance. Levene's test results only showed the *timeliness* results for task-related BPI violated this assumption, $F(5,81)=4.734$, $p = 0.001$. Levene's test for unequal group sizes is not as consistent and it does not take into account covariance between groups. Box's test results take into account this shortcoming. Box's test of equality of covariance matrices is non-significant at $p < 0.05$, but not by much, Box's M=370.156, $F(225,8114)=1.137$, p =0.080.

Table N-6. Levene's Test of Equality of Error Variances (a)

	F	**df1**	**df2**	**Sig.**
Accuracy - Task Knowledge (% Correct)	1.80	5	81	.12
Accuracy - Resource Knowledge (% Correct)	1.98	5	81	.09
Accuracy - Information Knowledge (% Correct)	.27	5	81	.93
Time - Task-related Process Knowledge (Seconds)	4.73	5	81	**.001***
Time - Resource-related Process Knowledge (Seconds)	2.02	5	81	.09
Time - Information-related Process Knowledge (Seconds)	2.12	5	81	.07
NASA TLX Mental Workload for interpreting Task-related BPI	1.90	5	81	.10
NASA TLX Mental Workload for interpreting Resource-related BPI	1.25	5	81	.30
NASA TLX Mental Workload for interpreting Information-related BPI	2.20	5	81	.06

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a Design: + GPM Type + User Educational Training Type + GPM Type*User Educational Training Type
Within Subjects Design: BPI Type

Table N-7. Bartlett's Test of Sphericity (a)

Effect		Likelihood Ratio	Approx. Chi-Square	df	Sig.
Between Subjects		.000	356.207	5	**.000*****
Within Subjects	*BPI Type*	.000	660.609	5	**.000*****

Tests the null hypothesis that the residual covariance matrix is proportional to an identity matrix.
a Design: + GPM Type + User Educational Training Type + GPM Type*User Educational Training Type
Within Subjects Design: BPI Type

Within-subjects sphericity results of Bartlett's test, which tests the null hypothesis that the residual covariance matrix is proportional to an identity matrix, are highly significant both within and between subjects (see Table N-7). Results of Mauchly's test of sphericity shows that task accuracy violates this assumption (see Table N-8). Timeliness and TLX mental workload data do not violate sphericity. Table N-8 also indicates how to correct for this violation in the analyses of the experimental hypotheses. Since the Greenhouse-Geisser correction is greater than 0.75, $\varepsilon = 0.89$, the Huynh-Feldt correction should be used to correct the degrees of freedom for task accuracy in subsequent MANOVA and MANCOVA analyses (Field, 2005; Rencher, 2001).

Table N-8. Mauchly's Test of Sphericity (b)

Within Subjects Design: BPI Type

Within Subjects Effect	**Measure**	**Mauchly's W**	**Approx. Chi-Square**	**df**	**Sig.**	**Epsilon (a)**		
						Greenhouse-Geisser	Huynh-Feldt	Lower-bound
BPI Type	Accuracy	.88	10.52	2	**.005****	.89	.965	.50
	Time	.96	3.45	2	.18	.96	1.00	.50
	Mental Workload	.98	1.74	2	.42	.98	1.00	.50

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.
a May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects Table.
b Design: + GPM Type + UET Type + GPM Type X UET Type

N.4 TESTS OF INDEPENDENCE

Multivariate hypothesis tests were conducted using the four multivariate test statistics in order to test for the independence of the dependent measures. These multivariate tests protect against inflation of the overall experimentwise error rate and subsequent misinterpretations of univariate analyses when results for a variable are significant at the $p < 0.05$ level of significance. When the test is non-significant (i.e., the null hypothesis is true, H_0: $\mu_{Accuracy} = \mu_{Time} = \mu_{MentalWorkload} = \mu_{Self-Efficacy}$) then any subsequent analyses are ignored because any significance must be a Type I error.

Table N-9 and N-10 report the results of multivariate hypothesis tests show that the three independent variables are clearly significant for all four of the test statistics below the $p < 0.05$ level of significance. Therefore, the assumption of independence is preserved and significance results of subsequent statistical analyses can be trusted.

N.5 Reliability Analyses of the Differential Attentional Processes Inventory

Preliminary analysis of the Differential Attentional Processes Inventory (DAPI) items evaluated the scale reliability of its constructs. Scale reliability analysis of these constructs revealed the following:

- Moderate Focus Subscale: Cronbach's $\alpha = 0.897$, 8 items
- Extreme Focus Subscale: Cronbach's $\alpha = 0.830$, 12 items
- Dual Cognitive-Physical Task Focus Subscale: Cronbach's $\alpha = 0.790$, 5 items
- Dual Cognitive-Cognitive Task Focus Subscale: Cronbach's $\alpha = 0.835$, 4 items

All DAPI constructs show Cronbach's α are ≥ 0.8, and, consequently, subsequent participant means of DAPI constructs are justified in future analyses (Field, 2005).

Table N-9. Multivariate hypothesis test results of between- and within-subjects independent variables and interactions.

Effect	Variable & Interactions	Multivariate Tests	Value	F	Hypothesis df	Error df	Sig.
Between Subjects	Intercept	Pillai's Trace	0.99	2514.41(a)	3.00	79.00	.000
		Wilks' Lambda	0.01	2514.41(a)	3.00	79.00	.000
		Hotelling's Trace	95.48	2514.41(a)	3.00	79.00	.000
		Roy's Largest Root	95.48	2514.41(a)	3.00	79.00	.000
	GPM Type	Pillai's Trace	0.44	20.62(a)	3.00	79.00	**.000*** **
		Wilks' Lambda	0.56	20.62(a)	3.00	79.00	**.000*** **
		Hotelling's Trace	0.78	20.62(a)	3.00	79.00	**.000*** **
		Roy's Largest Root	0.78	20.62(a)	3.00	79.00	**.000*** **
	User Educational Training Type	Pillai's Trace	0.16	2.25	6.00	160.00	**.041***
		Wilks' Lambda	0.85	2.23(a)	6.00	158.00	**.043***
		Hotelling's Trace	0.17	2.22	6.00	156.00	**.044***
		Roy's Largest Root	0.12	3.06(b)	3.00	80.00	**.033***
	GPM Type X User Educational Training Type	Pillai's Trace	0.11	1.49	6.00	160.00	.185
		Wilks' Lambda	0.90	1.49(a)	6.00	158.00	.186
		Hotelling's Trace	0.11	1.48	6.00	156.00	.187
		Roy's Largest Root	0.09	2.51(b)	3.00	80.00	**.065**
Within Subjects	BPI Type	Pillai's Trace	0.38	7.64(a)	6.00	76.00	**.000*** **
		Wilks' Lambda	0.62	7.64(a)	6.00	76.00	**.000*** **
		Hotelling's Trace	0.60	7.64(a)	6.00	76.00	**.000*** **
		Roy's Largest Root	0.60	7.64(a)	6.00	76.00	**.000*** **
	BPI Type X GPM Type	Pillai's Trace	0.06	.80(a)	6.00	76.00	.570
		Wilks' Lambda	0.94	.80(a)	6.00	76.00	.570
		Hotelling's Trace	0.06	.80(a)	6.00	76.00	.570
		Roy's Largest Root	0.06	.80(a)	6.00	76.00	.570
	User Educational Training Type X BPI Type	Pillai's Trace	0.22	1.59	12.00	154.00	**.099**†
		Wilks' Lambda	0.79	1.61(a)	12.00	152.00	**.095**†
		Hotelling's Trace	0.26	1.62	12.00	150.00	**.092**†
		Roy's Largest Root	0.21	2.67(b)	6.00	77.00	**.021***
	GPM Type X User Education Type X BPI Type	Pillai's Trace	0.13	0.88	12.00	154.00	.565
		Wilks' Lambda	0.88	.88(a)	12.00	152.00	.574
		Hotelling's Trace	0.14	0.87	12.00	150.00	.583
		Roy's Largest Root	0.09	1.17(b)	6.00	77.00	.329

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

a Exact statistic

b The statistic is an upper bound on F that yields a lower bound on the significance level.

c Design: +GPM Type + User Educational Training Type + GPM Type*User Educational Training Type
Within Subjects Design: BPI Type

Table N-10. Multivariate hypothesis tests of within-subjects independent variables and interactions.

Within Subjects Effect	Multivariate Hypothesis Tests	Value	F	Hypothesis df	Error df	Sig.
BPI Type	Pillai's Trace	0.22	6.49	6.00	322.00	**.000*** **
	Wilks' Lambda	0.79	6.75(a)	6.00	320.00	**.000*** **
	Hotelling's Trace	0.27	7.01	6.00	318.00	**.000*** **
	Roy's Largest Root	0.25	13.22(b)	3.00	161.00	**.000*** **
BPI Type X GPM Type	Pillai's Trace	0.03	0.86	6.00	322.00	.523
	Wilks' Lambda	0.97	.86(a)	6.00	320.00	.525
	Hotelling's Trace	0.03	0.86	6.00	318.00	.527
	Roy's Largest Root	0.03	1.46(b)	3.00	161.00	.228
BPI Type X User Educational Training Type	Pillai's Trace	0.12	1.70	12.00	486.00	**.063**†
	Wilks' Lambda	0.88	1.70	12.00	423.61	**.064**†
	Hotelling's Trace	0.13	1.70	12.00	476.00	**.064**†
	Roy's Largest Root	0.08	3.35(b)	4.00	162.00	**.012***
BPI Type X GPM Type X User Educational Training Type	Pillai's Trace	0.06	0.87	12.00	486.00	.576
	Wilks' Lambda	0.94	0.87	12.00	423.61	.580
	Hotelling's Trace	0.07	0.87	12.00	476.00	.584
	Roy's Largest Root	0.04	1.75(b)	4.00	162.00	.141

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$
a Exact statistic
b The statistic is an upper bound on F that yields a lower bound on the significance level.
c Design: +GPM Type + User Educational Training Type + GPM Type*User Educational Training Type
Within Subjects Design: BPI Type
d Tests are based on averaged variables.

N.6 Evaluation of the Balance of Participant Cognitive Styles in Treatment Groups

The MBTI was used to assess two dimensions of the cognitive styles of the participants: (1) extraversion vs. introversion and (2) sensing vs. intuition. Table N-11 show different balances of participants preferring different cognitive styles across both the type of GPM and the type of UET. IE students using UML diagrams that were sensors (9) vs. intuitives (3) was quite different from those using metagraphs (5 sensors vs. 7 intuitives). IE students had a similar numbers of extroverts vs. introverts using UML vs. metagraphs, but there is a difference between the numbers of sensors vs. intuitives.

MGT student extroverts and introverts showed differences between those who used UML diagrams vs. metagraphs. The number of MGT student extroverts using UML diagrams (10) vs. metagraphs (7) were opposite of MGT student introverts using UML diagrams (8) vs. metagraphs

(10). MGT sensors (11 vs. 12) vs. intuitives (7 vs. 5) were similar for both groups of participants using different type of GPMs. CS students had different distributions of extroverts (9 using UML diagrams vs. 5 using metagraphs); while there were seven introverts for both types of GPMs.

CS sensors vs. intuitives were quite different for the two Types of GPMs: Sensors using UML diagrams (7) vs. metagraphs (9), and intuitives using UML diagrams (9) vs. 3 metagraphs. There is a discrepancy between CS students using UML vs. metagraphs both on the extraversion vs. introversion and sensing vs. intuition cognitive styles.

Table N-11. Counts of the MBTI Cognitive Styles of the participants grouped by the between-subject independent variables.

Moderating Variable: *Cognitive Styles* (MBTI)

Factor: *Type of GPM*	**Factor: *Type of User Educational Training***	**MBTI Extrovert (E) Count**	**MBTI Introvert (I) Count**	**MBTI Sensor (S) Count**	**MBTI Intuitive (N) Count**
UML Diagrams	IE: Industrial Engineering	7	5	9	3
	MGT: Management	10	8	11	7
	CS: Computer Science	9	7	7	9
	Total	26	20	27	19
Metagraphs	IE: Industrial Engineering	8	4	5	7
	MGT: Management	7	10	12	5
	CS: Computer Science	5	7	9	3
	Totals	20	21	26	15
Experiment Totals	N = 87	46	41	53	34

Additionally, there is a discrepancy in the overall total of *extraversion* vs. *introversion* using UML diagrams vs. metagraphs. Figure N-3 and N-4 further illustrate these distributions and statistics.

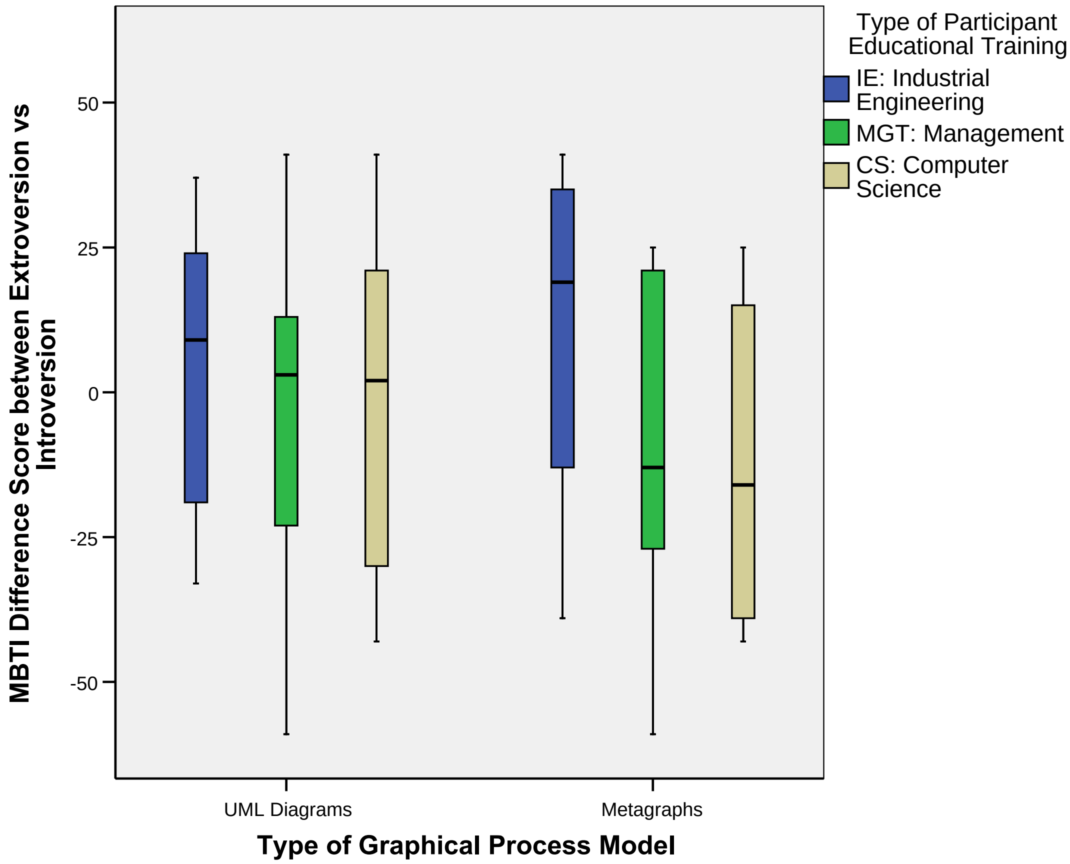


Figure N-3. Box plots of continuous *extrovert vs. introvert* scores (+ scores = Extroverted tendencies; - scores = Introverted tendencies). by the *Type of GPM* and *Type of User Educational Training.*

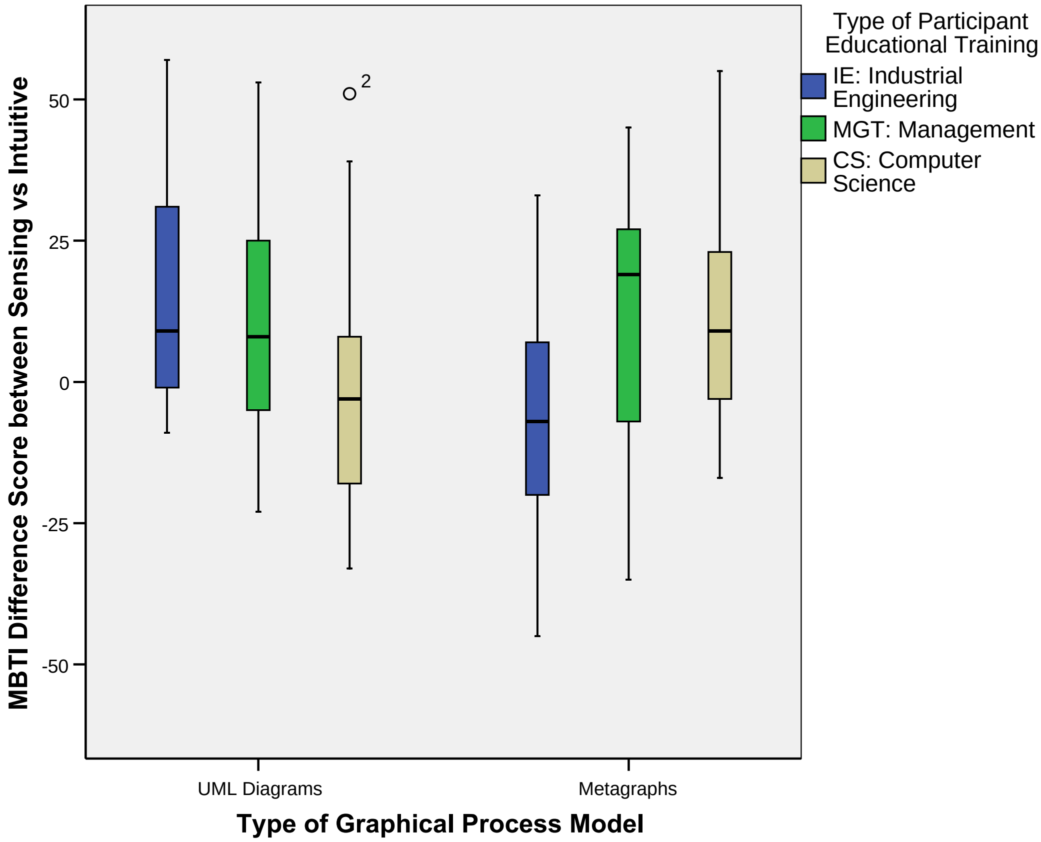


Figure N-4. Box plots of continuous *sensing vs. intuitive* scores (+ scores = Sensing tendencies; - scores = Intuitive tendencies). by the *Type of GPM* and *Type of User Educational Training*

In summary, the preliminary analyses showed that the four parametric assumptions seem to be upheld for most of the dataset. Also, DAPI constructs are sufficiently reliable to be used in future analyses. Where there appears to be a problem with *accuracy* sphericity, a statistical correction can be made. Some questions seem to remain about the normality of *timeliness* results. Yet, based on the other preliminary statistical analyses, it was determined that further analyses testing the experimental hypotheses and conducting exploratory analyses was reasonable.

O EXPLORATORY DATA ANALYSES

In addition to testing the research hypotheses, several additional analyses were conducted that explored other interesting relationships in the dataset. An exploratory factor analysis was conducted to reveal underlying components of participants' evaluations of subjective *mental workload* (Appendix O.1). General Cognitive Abilities, Attentional Abilities, and Cognitive Style covariate effects were also explored in Sections O.2, O.3, and O.4. Finally, sections O.5 through O.9 explores correlations and effects of key demographics that could or do play an important role in this experiment.

O.1 EXPLORATORY FACTOR ANALYSIS OF SUBJECTIVE MENTAL WORKLOAD

In processing TLX *mental workload* subscales, it was apparent that ratings of individual subscales did not appear to be independent and many were highly correlated. Therefore, an exploratory factor analysis was conducted to look for underlying factors that are influencing TLX ratings of subjective mental workload.

The selection of the appropriate number of factors (*m*) is based on interpretation of agreement of four criteria (Rencher, 2002, pp. 427-430), since the selection of *m* cannot be objectively determined with one criteria:

1. Choose *m* equal to number of factors necessary for the variance to explain pre-determined percentage of the total variance explained. In this case, 70-80% is chosen as it represents approximately ¾ of the total variance.
2. Choose *m* equal to the number of eigenvalues greater than the average value. Using the correlation matrix (**R)** the average value is 1.
3. Use the scree test to plot the eigenvalues of **R** (or **S**). If the graph drops sharply, followed by a near straight line with a much smaller slop, choose *m* equal to the number of eigenvalues before the near straight line begins.
4. Test the hypothesis that *m* is the correct number of factors, H_0: $\Sigma = \Lambda\Lambda' + \Psi$ where Λ is *p* x *m*.

Method 1 given $m = 3$ because Table O-1 reveals that three factors explain 74.340 percent of the total variance (tr(**R**)). Method 2 gives $m = 3$ since $\lambda_3 = 0.956$ (=1.048 rotated) and $\lambda_4 = 0.625$.

For Method 3, the scree plot in Figure O-1 reveals a clear break between and leveling off of the slope after λ_3. Method 4 was not determined as necessary because of the clear agreement of the other three Methods. Therefore, the clear choice of the number of factors was selected as $m = 3$.

Table O-1. Exploratory Factor Analysis of TLX Mental Workload subscales revealing three underlying factors explaining close to 75% of the total variance.

Component (i.e., Underlying Factors)	**Initial Eigenvalues**			**Varimax Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	2.223	37.055	37.055	2.153	**35.877**	35.877
2	1.282	21.360	58.415	1.260	**21.004**	56.880
3	.956	15.925	74.340	1.048	**17.460**	**74.340**
4	.625	10.420	84.760			
5	.512	8.539	93.300			
6	.402	6.700	100.000			

Extraction Method: Principal Component Analysis.

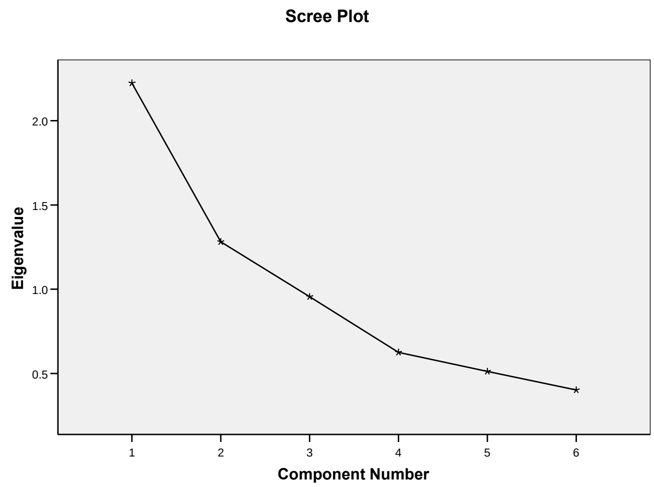


Figure O-1. Scree plot revealing a clear break on Method 3 between λ_3 and λ_4.

This exploratory factor analysis revealed that there were three underlying components (i.e., factors) that made up slightly less that 75% of the total variation in the TLX mental workload constructs. Table O-2 shows that five of the six TLX subscales appear to load cleanly and highly (above 0.6) onto one of these three factors. Frustration appeared to load almost evenly on Factor #1 (0.606) and #2 (0.585). Although frustration is almost equally loading on two factors, usually confusing the interpretation, it is loading relatively high on both factors so its influence should not be discounted.

Factor #1, explaining a 35.9% of the variation (Table O-1) is made up of the TLX subscales: mental demand (0.816), mental effort (0.798), temporal demand (0.670), and frustration (0.606) (Table O-2). Factor #2, explaining 21% of the total variation, is made up of the TLX subscales: frustration (0.585) and perception of performance (0.891). And Factor #3, explaining 17.5% of the total variation is made up of the TLX subscale: physical demand (0.976).

Table O-2. Exploratory Factor Analysis showing the loadings of the three components (i.e., factors) underlying TLX *mental workload* results ($n = 261$).

TLX Mental Workload Construct	**Component (i.e., Factors)**		
	1	**2**	**3**
Mental Demand	**.816**	-.025	-.023
Mental Effort	**.798**	-.332	-.015
Temporal Demand	**.670**	.114	.295
Frustration	**.606**	**.585**	.081
Perception of Performance	-.169	**.891**	-.009
Physical Demand	.072	.004	**.976**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 5 iterations.

Factor #1 reveals that participants saw external demands (temporal and mental) as highly related to both their internal exertions (mental effort) and emotions (frustration). As they reported these external demands increasing, they reported their internal efforts and frustrations increasing. Thus, Factor #1 represents external and internal burdens on participants' subjective mental workload.

Factor #2 is an interesting, almost single variable factor. It represents participants' perception of performance. Frustration was related to performance perception, but, interestingly, the directionality seems counterintuitive. This factor reveals that as perception of performance increases, participants' frustration increases. This suggests that as participants' tried hard and perceived that they performed well, they were also more frustrated; possibly because they experienced such high subjective mental workload in order to achieve what they perceived as high performance on the task.

Factor #3 reflects the accurate perception of participants that physical demand was unrelated to the other impacts of subjective mental workload. The experimental task was not physically demanding, therefore it makes sense that the TLX physical demand subscale is not related, and has the least impact on subjective mental workload.

It is important to note, as a reminder, that the TLX mental workload scores used the analyses of the hypotheses are not solely an aggregation of these TLX subscales. TLX scores are calculations of these six TLX subscales and separate pairwise comparisons weightings of these scales. Nevertheless, these six subscales underlie individual assessments of different aspects of subjective mental workload.

In the context of this experiment, the three factors identified in this exploratory factor analysis illustrate that the six TLX subscales do not actually assess six different aspects of subjective mental workload as the NASA TLX suggested.

O.2 Covariate Effects of General Cognitive Abilities

An interesting finding of *General Cognitive Abilities* analyses, that was not hypothesized, is that participants' WPT scores have a significant effect on *accuracy* $F(1,80)=10.902$, $p = 0.001$. Figure O-2 illustrates this significant effect. Participants with lower WPT scores tended to produce lower accuracy results, and participants with higher WPT scores tended to produce higher accuracy results.

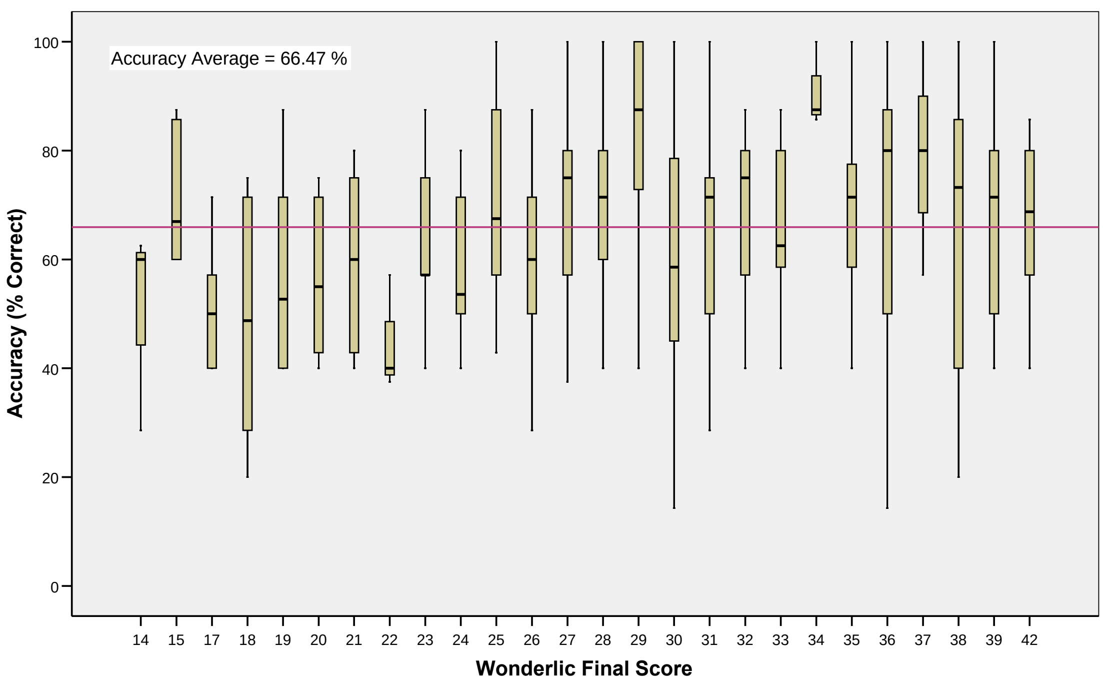


Figure O-2. The *accuracy* of task performance is higher above the average *accuracy* for participants with higher WPT scores.

This result was also seen in the covariate effect of WPT scores on the relationship between the *Type of User Educational Training* and task *accuracy*. The effect of *User Educational Training*

Type on *accuracy* changes from being significant when WPT scores are not included as a covariate ($F(2,81)=3.309$, $p = 0.042$) to be non-significant ($F(2,80)=1.315$, $p = 0.247$) when WPT scores are taken into account.

Furthermore, within-subject MANCOVA results show that, when WPT scores are taken into account, *BPI Type* no longer has a highly significant effect on *timeliness*, $F(2,160)=1.105$, $p = 0.334$, and the impact of subjective *mental workload* is reduced, $F(2,160)=2.506$, $p = 0.085$; compared to the significant effect of the *Type of BPI* on these outcomes ($F(2,162)=17.937$, $p = 0.000$, and $F(2,160)=5.188$, $p = 0.007$ respectively) when WPT scores were not included as a covariate. No other results changed for the other dependent and independent variables when WPT scores are included as a covariate.

These results suggest that the statistically significant effects of the *Type of User Educational Training* and the *BPI Types* on task *accuracy*, *timeliness*, and subjective *mental workload* appear to be due more to covariation with *General Cognitive Abilities* than to the unaccompanied impact of these independent variables.

O.3 ATTENTIONAL ABILITIES COVARIATE EFFECTS

Besides the hypothesized results related to attentional abilities of participants, several covariate effects were discovered in the course of exploratory analyses (Table O-3). Apparently, DAPI constructs have no significant effect on task accuracy. In addition, the DAPI Extreme Focus construct does not have any significant effect on the outcome measures of this experiment. Self-reports of participants' attentional abilities show significant effects of the following:

- *Timeliness:* DAPI Moderate Focus, $F(2,80)=5.785$, $p = 0.018$, and DAPI Dual Cognitive-Physical Task Focus, $F(2,80)=4.678$, $p = 0.034$
- TLX *Mental Workload:* DAPI Dual Cognitive-Physical Task Focus, $F(2,80)=5.219$, $p = 0.025$, and DAPI Dual Cognitive-Cognitive Task Focus, $F(2,80)=8.734$, $p = 0.003$.
- Average *Self-Efficacy:* DAPI Dual Cognitive-Physical Task Focus, $F(2,80)=3.314$, $p = 0.070$, and DAPI Dual Cognitive-Cognitive Task Focus, $F(2,80)=12.827$, $p = 0.037$.

Table O-3. Shows between-subject effects of the covariates for *Attentional Attributes* (DAPI constructs).

Source	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
DAPI Moderate Focus	Accuracy (% Correct)	66.464	1, 80	66.464	.177	.675
	Time (Seconds)	105188.900	1, 80	105188.900	5.785	**.018***
	TLX Mental Workload	1201.697	1, 80	1201.697	2.292	.134
	Average Self Efficacy	.522	1, 80	.522	.159	.691
DAPI Extreme Focus	Accuracy (% Correct)	361.016	1, 80	361.016	.973	.327
	Time (Seconds)	13686.754	1, 80	13686.754	.708	.403
	TLX Mental Workload	294.835	1, 80	294.835	.550	.460
	Average Self Efficacy	3.093	1, 80	3.093	.950	.333
DAPI Dual Task Focus: Cognitive-Physical	Accuracy (% Correct)	183.153	1, 80	183.153	.491	.486
	Time (Seconds)	86183.239	1, 80	86183.239	4.678	**.034***
	TLX Mental Workload	2642.769	1, 80	2642.769	5.219	**.025***
	Average Self Efficacy	14.310	1, 80	14.310	4.596	**.035***
DAPI Dual Task Focus: Cognitive-Cognitive	Accuracy (% Correct)	5.564	1, 80	5.564	.015	.903
	Time (Seconds)	25713.220	1, 80	25713.220	1.341	.250
	TLX Mental Workload	1587.004	1, 80	1587.004	3.055	**.084**†
	Average Self Efficacy	5.745	1, 80	5.745	1.784	.185

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

What is interesting is that the statistically significant effects on *time*, subjective *mental workload*, and average *self-efficacy* have shown that attentional abilities seem to impacts the outcomes of performance rather than accuracy that measures direct task performance.

O.4 Cognitive Style Covariate Effects

Section 4.2 reports *accuracy* and *timeliness* results for the between and within-subject sections of repeated measures MANCOVAs that include extrovert-introvert and sensor-intuitive as covariates. These tables show that neither of the two MBTI cognitive styles had any significant effects on accuracy or timeliness in covariation with the independent variables in this experiment.

O.5 Correlations of Key Demographics

Key demographics were correlated with between-subject components of the accuracy, timeliness, subjective mental workload, and self-efficacy assessments (Table O-4). The *university*, *gender*, and *English* skills show no correlations at a high enough degree, even if statistically significant, to be important.

Table O-4. Between-subject correlations of key demographics.

	University of Participant	Gender	Is English your native language?
Accuracy - Task Knowledge (% Correct)	-0.07	-0.01	-0.15
Accuracy - Resource Knowledge (% Correct)	-0.13	-0.01	-0.14
Accuracy - Information Knowledge (% Correct)	-0.05	-0.02	-0.10
Time - Task-related Process Knowledge (Seconds)	-0.02	-0.03	0.10
Time - Resource-related Process Knowledge (Seconds)	0.05	-0.06	0.10
Time - Information-related Process Knowledge (Seconds)	0.18	-0.01	0.18
Mental Demand on interpreting Task-related Process Information	0.00	0.01	0.03
Physical Demand on interpreting Task-related Process Information	0.11	-0.18	.306**
Temporal Demand on interpreting Task-related Process Information	-0.06	-0.05	-0.08
Perception of Performance on interpreting Task-related Process Information	-0.16	0.09	-0.10
Mental Effort on interpreting Task-related Process Information	0.06	0.09	-0.05
Frustration on interpreting Task-related Process Information	0.02	-0.03	-0.01
Mental Demand on interpreting Resource-related Process Information	-0.06	0.09	-0.08
Physical Demand on interpreting Resource-related Process Information	-0.02	0.00	.240*
Temporal Demand on interpreting Resource-related Process Information	0.00	-0.04	-0.09
Perception of Performance on interpreting Resource-related Process Information	-0.19	0.19	-0.12
Mental Effort on interpreting Resource-related Process Information	0.08	0.01	-0.04
Frustration on interpreting Resource-related Process Information	-0.05	-0.02	-0.05
Mental Demand on interpreting Information-related Process Information	0.09	-0.03	0.09
Physical Demand on interpreting Information-related Process Information	0.07	-0.08	.309**
Temporal Demand on interpreting Information-related Process Information	0.20	-0.07	-0.05
Perception of Performance on interpreting Information-related Process Information	-0.15	0.08	-0.08
Mental Effort on interpreting Information-related Process Information	0.11	0.04	0.11
Frustration on interpreting Information-related Process Information	0.13	-0.04	0.11

	University of Participant	Gender	Is English your native language?
Self-Efficacy-If Alone & No One Was Available to Help	0.03	-.223*	0.14
Self-Efficacy-If Never Used MG or UML Diagrams Before	-0.19	-0.11	-0.02
Self-Efficacy-If Had Only the Training Handouts for Reference	-.273*	0.09	-0.11
Self-Efficacy-If Had Seen Others Using MG or UML Diagrams	0.00	-0.13	0.15
Self-Efficacy-If Could Call on Someone for Help	-0.05	-0.04	-0.09
Self-Efficacy-If Someone Helped You Get Started	-0.03	0.07	-0.06
Self-Efficacy-If Had A lot of Time	0.00	-0.18	0.02
Self-Efficacy-If Had Training Handouts 2	-0.01	0.09	-0.02
Self-Efficacy-If Used MG or UML Diagrams on Similar Tasks	-0.10	0.02	-0.18
Average Self Efficacy Score	-0.09	-0.07	-0.01

$^{\dagger}p < 0.10$ $\quad *p < 0.05$ $\quad **p < 0.01$ $\quad ***p < 0.001$ (2-tailed)

O.6 English as Participants' First Language

Further analyses of experimental variables revealed some interesting findings concerning participants whose native language was something other than English. During the training phase of the experiment, it was observed that participants that learned English later in life had a difficult time understanding the instructions and seemed to take longer to study the handout materials. Therefore, further post hoc analyses were needed to identify the impacts on performance of participants that did not learn English as their first language.

One-way ANOVA results show differences between native and non-native English speakers as significant when using WPT Score as a dependent measure, $F(1,81)=21.592$, $p = 0.000$. Correlations presented in Table O-5 reveal that only one variable was significantly correlated at a level of interest. The WPT scores were negatively correlated with non-native English speakers ($r =$ - 0.450). Participants that did not learn English as their first language appears to do slightly worse on WPT scores than English speakers.

Table O-5. Correlations.

	WPT Score	University currently enrolled in	Gender	Is English your native language?
WPT Score	1	-.341**	-.106	**-.450****
University currently enrolled in		1	-.116	.329**
Gender			1	-.165
Is English your native language?				1

†$p < 0.10$ *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$ (2-tailed)

MANCOVA analyses reveal *that English abilities* do not have a direct effect on *accuracy* ($F(1,80)=2.028$, $p=0.158$), time ($F(1,80)=1.014$, $p=0.317$), nor TLX mental workload ($F(1,80)=0.988$, $p=0.323$). Interestingly, it does have a significant covariate effect on the time it takes participants' to interpret different Types of BPI. When English is taken into account as a covariate, the effect of the Type of BPI on time changes from being significant ($F(2,81)=3.309$, $p = 0.042$) to be non-significant ($F(2,80)=1.315$, $p = 0.247$). Figure L-32 illustrates the effect of English as a covariate on the Type of BPI. No other MANCOVA results were impacted when English is included as a covariate.

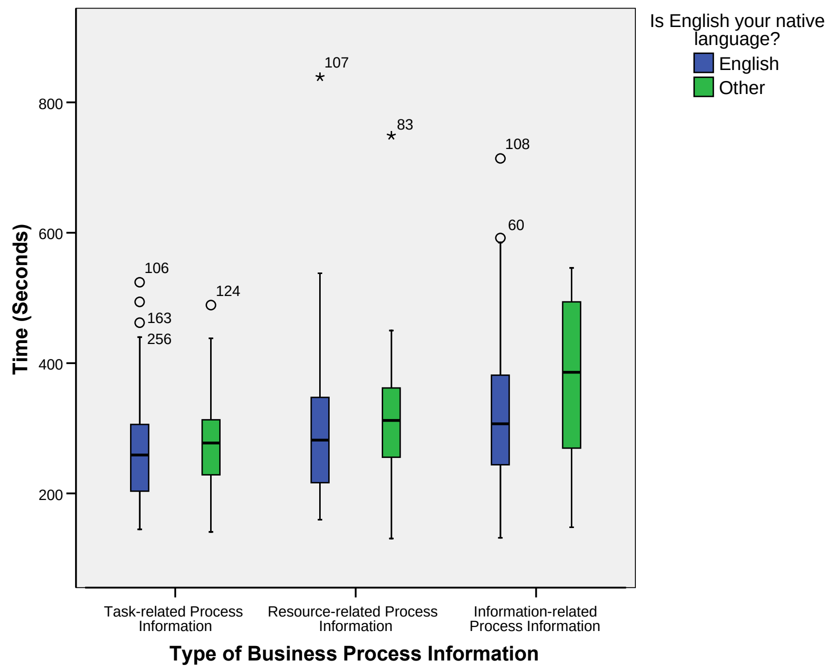


Figure O-3. Box plot showing the relationships timeliness to the *Type of Business Process Information* for native English-speaking participants vs. participants that did not learn English as their first language.

Figure O-3 illustrates the impacts of BPI Type on timeliness results based on native vs. non-native English-speaking users. Additionally, one-way ANOVAs testing the *English* demographic variable on between-subject variables revealed multiple significant results:

- *Time* on Information-related BPI, $F(1,85)=2.767$, $p = 0.100$.
- DAPI Dual Cognitive-Physical Task Focus, $F(1,85)=7.032$, $p = 0.010$.
- TLX Physical Demand on Task-related BPI, $F(1,85)=8.811$, $p = 0.004$.
- TLX Physical Demand on Resource-related BPI, $F(1,85)=5.214$, $p = 0.025$.
- TLX Physical Demand on Information-related BPI, $F(1,85)=8.941$, $p = 0.004$.

Apparently, there is a significant difference in the time it took native vs. non-native English speakers to interpret information-related BPI ($p < 0.10$). It also appears from the above results that native English vs. non-native English speakers reported differences due to the physical demands of the tasks. None of these results reported correlations between these or other performance results as significant, but there is obviously a perception of mental workload and attentional abilities are impacted by physical demands explained, at least partially, by the English demographic variables.

O.7 UNIVERSITY OF PARTICIPANTS

The university of the participants appears to have some effects on several moderating variables. The only highly significant result is that the WPT scores differed between the two universities that participants were recruited, $F(1,85)=11.196$, $p = 0.001$. Figure O-4 shows that University B has significantly lower WPT scores overall than University A participants. Figure O-4 also reveals the ranges of WPT scores are broader for University B as compared to University A. Another potential contributor to this statistical significance that can be seen in Figure O-5 is that all industrial engineering participants came from University A (University B did not have an industrial engineering program).

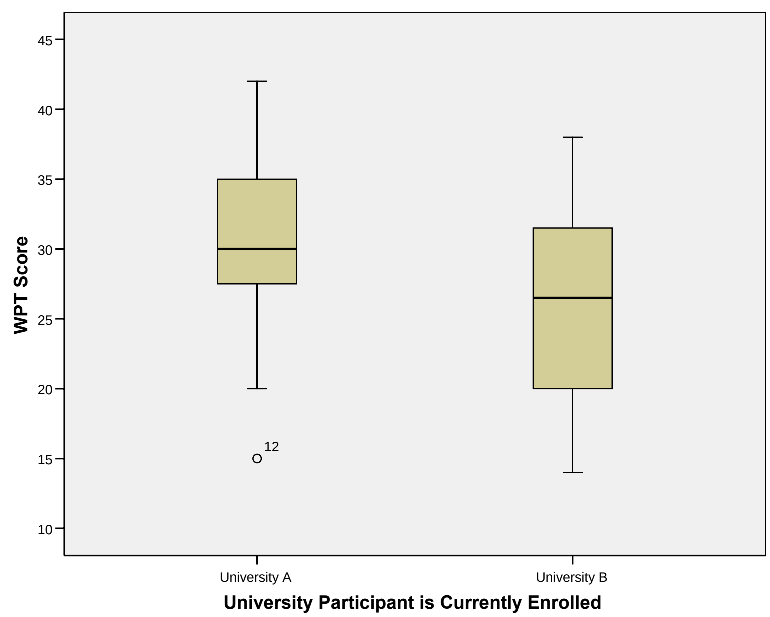


Figure O-4. Box plot showing the difference between WPT scores and the university from which participants were recruited.

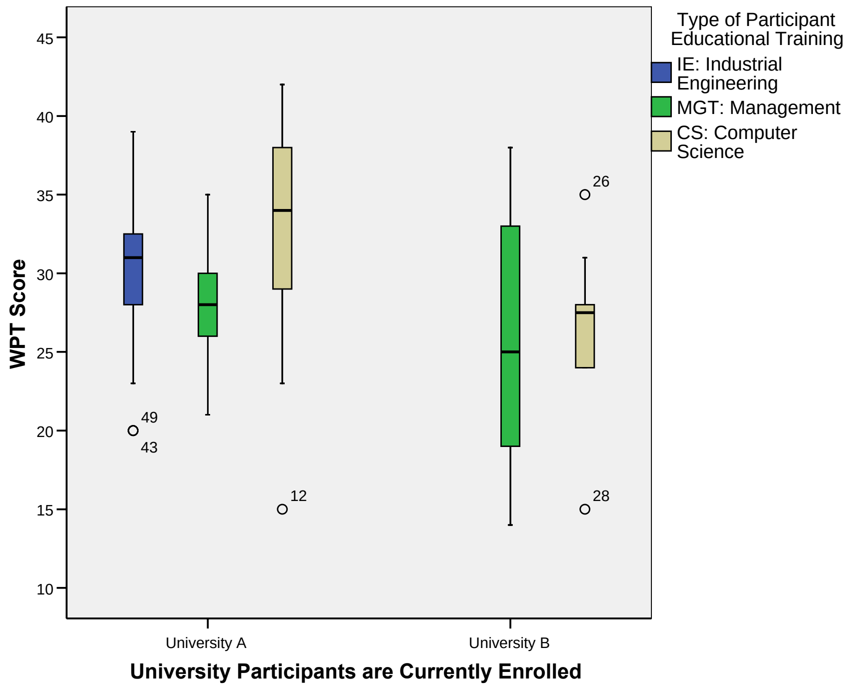


Figure O-5. Box plot further splitting differences between the universities by the Type of User Educational Training.

Although no other significant effects appear related to participant's performance in this experiment, the following effects were found from one-way ANOVAs on between-subject effects:

- MBTI Extroversion vs. Introversion, $F(1,85)=3.887$, $p = 0.093$.
- DAPI Dual Cognitive-Physical Task Focus, $F(1,85)=3.329$, $p = 0.072$.
- TLX Perception of Performance on Resource-related BPI, $F(1,85)=3.265$, $p = 0.074$.
- TLX Temporal Demand on Information-related BPI, $F(1,85)=3.484$, $p = 0.065$.

Additionally, several MBTI, DAPI, and TLX assessments are statistically significant at the p <0.10 level. While not highly significant, it is an indicator that the university from where students are recruited can affect experiment results and should be watched in future research.

O.8 GENDER OF PARTICIPANTS

The gender of participants did not have major effects on this experiment. The only gender difference that was statistically significant is between male and female participants in terms of their self-report assessments of their own DAPI Dual Cognitive-Physical Task Focus, $F(1,85)=5.605$, $p = 0.020$. Figure O-6 reveals that males said their have less problem focusing on dual cognitive-physical tasks, but this figure shows that these results are also so small that the statistical difference may be insignificant practically.

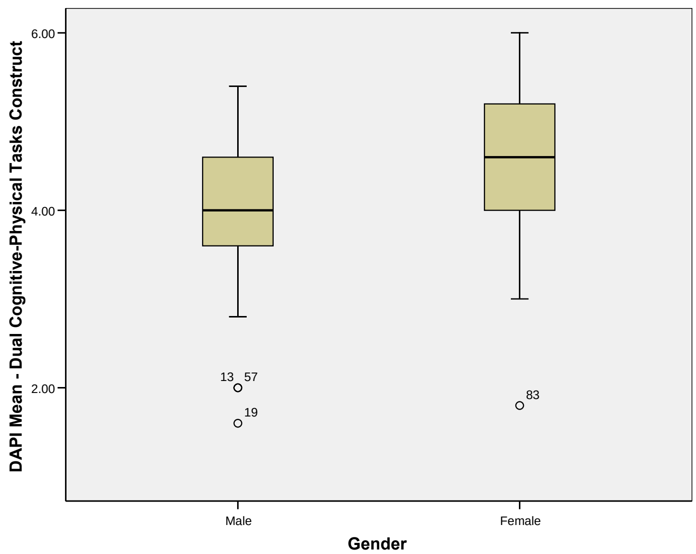


Figure O-6. Box plot of gender differences between DAP Dual Cognitive-Physical Task Focus self-reports.

Two other statistical differences in gender exist at the $p < 0.10$ level of significance, but their impact does not appear to affect other aspects of this experiment:

- TLX Perception of Performance on Resource-related Process Information, $F(1,85)=3.243$, $p = 0.075$.
- TLX Physical Demand on Task-related BPI, $F(1,85)=2.816$, $p = 0.097$.

O.9 AGE OF PARTICIPANTS

The age of participants does not seem to play a significant role in the analyses of this experiment. The only significant difference due to age is in participants' MBTI Sensing vs. Intuitive scores, $F(1,85)=2.124$, $p = 0.028$. Figure O-7 shows the distribution of ages of participants in this experiment. This figure suggests that the statistical significance can mostly be due to the heavily skewed distribution of participants in their early 20s that participated in this experiment.

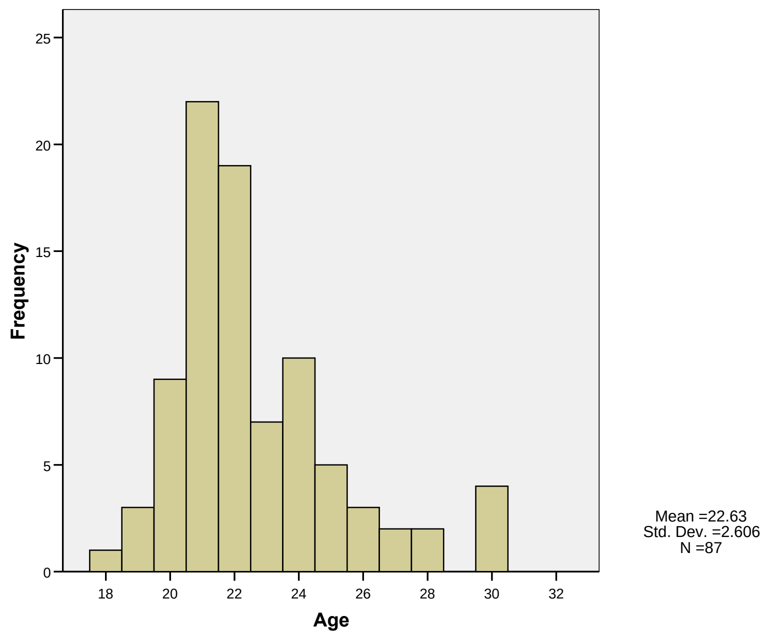


Figure O-7. Distributions of the ages of participants in this experiment.

Table O-6. Exploratory Factor Analysis of GPM Self-Efficacy questions revealing two underlying factors explaining 69% of the total variance ($n = 87$).

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.903	54.476	54.476	3.347	37.184	37.184
2	1.312	14.578	69.054	2.868	31.871	69.054
3	.645	7.167	76.222			
4	.588	6.532	82.754			
5	.478	5.310	88.063			
6	.379	4.213	92.276			
7	.302	3.357	95.633			
8	.247	2.742	98.375			
9	.146	1.625	100.000			

Extraction Method: Principal Component Analysis.

O.10 Factor Analysis of GPM Self-Efficacy

Exploratory factor analysis revealed two underlying factors explaining 69% of the variation underlying the correlations between the GPM self-efficacy question constructs in the data (see Table O-6 and Figure 0-8). These factors loaded cleanly and appear to meet the criteria for justifiable factor analysis results (Rencher, 2001). The first factor in Table O-7 includes most self-efficacy questions associated with receiving help from others to interpret GPMs. The second factor associated questions with the user being alone when interpreting GPMs. These results suggest participants self-efficacy is greatly influenced by whether their receive help from others when comprehending these GPMs.

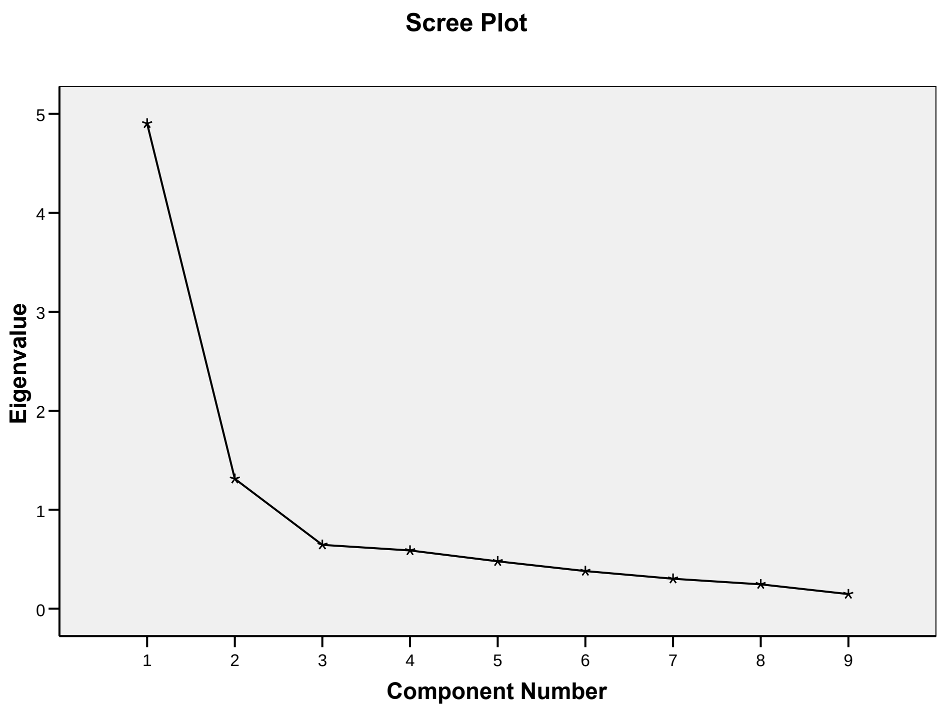


Figure O-8. Scree plot revealing a clear break for between λ_2 and λ_3.

Table O-7. Rotated factor loadings for the two factors underlying GPM Self-Efficacy (*n* = 87).

	Component	
	1	2
Self-Efficacy-If Someone Helped You Get Started	**.852**	.207
Self-Efficacy-If Could Call on Someone for Help	**.784**	.292
Self-Efficacy-If Had A lot of Time	**.780**	.114
Self-Efficacy-If Used MG or UML Diagrams on Similar Tasks	**.775**	.212
Self-Efficacy-If Had Seen Others Using MG or UML Diagrams	**.620**	.526
Self-Efficacy-If Never Used MGor UML Diagrams Before	.102	**.875**
Self-Efficacy-If Alone & No One Was Available to Help	.139	**.857**
Self-Efficacy-If Had Only the Training Handouts for Reference	.407	**.698**
Self-Efficacy-If Had Training Handouts 2	.466	**.647**

a Rotation converged in 3 iterations.

VITA

Bret R. Swan was born in Burley, ID. He graduated from Brigham Young University with a Bachelor of Science degree in Mechanical Engineering and a Masters of Science degree with a minor in Statistics. He was awarded his Ph.D. in Management Systems Engineering from the Grado Department of Industrial and Systems Engineering at Virginia Tech on March 26, 2007. He is a member of both Alpha Pi Mu, the national Industrial Engineering honor society, and Upsilon Pi Epsilon, the international honor society for Computing and Information Sciences. While at Virginia Tech, he worked as a research consultant, research faculty, or graduate research assistant for the Center for Organizational and Technological Advancement, University Leadership Development, the Enterprise Engineering Lab, and the Center for the Scientific Visualization of Organizations. Since 2005, he holds the position of Assistant Professor of Information Systems in the School of Computing at Brigham Young University in Hawaii.

He has consulted for over 15 years for several business, professional, government, and university entities in Utah, Virginia, New Jersey, Hawaii, and the South Pacific – such as AT&T Consumer Process Operations Center, AT&T Electronic Bill Presentment & Payment, AT&T Client Care Center, AT&T Charlotte Bill Print Center, StorageTek, Morton-Thiokol, Utah Pharmaceutical Association, BYU-Hawaii Records Management, and the Pacific Islands Private Sector Organization. His research and consulting interests center on the alignment of business processes and information technology and include the scientific visualization of organizations, the management of knowledge-intensive businesses, performance measurement, information visualization, knowledge management, distributed cognition in HCI, training system development, and the cross-cultural impacts of information technology in developing economies and organizations.