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The Effect of Business Process Representation Type on Assessment of Business and Control Risks: Diagrams versus Narratives

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ABSTRACT: The Sarbanes-Oxley Act (SOX) (U.S. House of Representatives 2002) mandates the assessment of internal controls over financial reporting, and many organizations are using diagrams to document their internal control processes. While educators regularly stress the effectiveness of diagrammatic representation of process information over textual representation, no prior study has offered convincing evidence that diagrammatic representation leads to improved performance. In an experiment, we examine students' performance on a business process risk and control assessment task using two informationally equivalent methods that are commonly taught in the classroom to document business processes: descriptive narrative (hereafter, textual) and diagrammatic. We also examine whether students' academic achievement and perceptions of their ability (self-efficacy) affect performance by type of representation. First, we find that while the method of representation has no effect on students' accuracy, those receiving the textual representation were more efficient and had a greater weighted-average performance than those receiving the diagrammatic representation. Second, we find academic achievement increases students' accuracy, decreases their efficiency, and has no effect on their weighted-average performance. Third, we find self-efficacy has no effect on students' accuracy, has no effect on their efficiency, and decreases their weighted-average performance. Finally, we find that both self-efficacy and academic achievement interact with the type of representation to affect students' performance. Implications for education and practice are discussed.

Keywords: business process models; business process diagrams; system documentation; audit documentation methods; risk assessment; BPMN; narrative; accuracy; efficiency; self-efficacy.

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Supplemental materials can be accessed by clicking the link in Appendix B.

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INTRODUCTION

Business processes are an important component of managers' and auditors' assessments of the effectiveness of an organization's internal controls over financial reporting (International Auditing and Assurance Standards Board [IAASB] 2006, ISA 315, paras. 30–34). Although there is no convincing evidence pointing to a single most-effective method for documenting business processes for this purpose, auditing and accounting information systems courses typically feature diagrammatic representation as being more effective than narrative representation. This choice appears to emanate from the logic of "A picture is worth a thousand words." Interest in this choice is not limited to accounting. For example, the mode of representing processes is also of concern in other disciplines such as software engineering, e-commerce, and organizational strategy.

The choice of the process representation matters for two reasons. First, the creation and assessment of business process documentation can be a costly activity. Second, representation may have a profound impact on the performance of both practitioners and students. In fact, practitioners and textbook authors have proposed a variety of graphical and diagrammatic techniques, on the grounds that they help managers and auditors document business processes and accurately and efficiently identify areas of risk (Bradford et al. 2007; Jones et al. 2002; Xiong and Martin 2006). More recently, Bierstaker et al. (2009) conclude that auditors are better able to identify missing controls when using a general business process flowchart than when not using a flowchart.

Although these studies support the use of diagrammatic documentation, with the exception of Bierstaker et al. (2009), none consider the comparative value of documentation in the form of a narrative. In fact, there exists evidence that individuals are often uninspired by certain diagrammatic techniques and would prefer simple narrative documentation (Gadh et al. 1993). Further, the absence of controls for informational differences in the business process representations and the small effect size in Bierstaker et al. (2009) raise a question about the practical significance of their finding. While practitioner and academic journals continue to analyze the advantages of various diagrammatic documentation techniques, questions persist as to which of these techniques should be used in practice (Jones et al. 2002), prompting a call for research comparing the effectiveness of various types of representation methods (Bradford et al. 2007).

This study was designed to speak to the choice of representation mode by comparing the accuracy and efficiency of risk assessments made with one of the two types of informationally equivalent representations: diagrammatic and textual.[1] Based on our experiment in an upper-level undergraduate accounting information systems course, we compare the effect of either a narrative or diagrammatic representation of a fictitious company's business processes on three measures of students' performance: *accuracy*, measured as percentage correct out of 24 multiple-choice questions, *efficiency*, measured as the time taken to complete the exam, and a relative *weighted-average* of both. Further, we consider whether academic achievement, measured as course grade out of 100 percent, and participants' self-efficacy, their perception that they are able to succeed on a given task (Bandura 1977), measured prior to completing the exam using a four-question 100-point scale, interact with the method of representation.

First, our results indicate that the method of representation has no effect on students' accuracy on the exam, despite evidence of sufficient power to find an effect. We do, however, find that those receiving the textual representation were more efficient and had a higher weighted-average

[1] With this study, we implicitly assume the purpose of teaching a method of representation is reflected in students' contemporaneous academic assessment. However, it is possible that methods of business process documentation are taught to prepare students for continued learning, either in an academic context or as practitioners. As such, our measures of performance are incomplete. It is beyond the scope of the study to test student performance in subsequent time periods and in other settings. We thank an anonymous reviewer for raising this issue.

performance than those receiving the diagrammatic representation. Second, we find that academic achievement, measured as students' final course grade, was associated with increased accuracy, decreased efficiency, and no effect on weighted-average performance. Third, we find that self-efficacy had no significant effect on accuracy or efficiency, but did have a negative effect on students' weighted-average performance. Finally, we find that both academic achievement and self-efficacy interacted with the mode of representation, such that the effect of the representation on efficiency and weighted-average performance were stronger for those lower in self-efficacy and academic achievement than those higher.

This study contributes to the existing literature in several ways. First, it contributes to the more general literature on external representations and their effect on student problem solving by examining the effects of alternative representations on audit risk and control assessment. It indicates that an informationally equivalent textual representation can possess some of the benefits often associated with diagrammatic representations. This study contributes to curriculum development by providing guidance on whether diagrammatic techniques such as those explored in the study require the emphasis they are given in accounting information systems and auditing courses and textbooks. The results may also contribute to the assessment of techniques that are most useful for auditing. Finally, the results of the study may also help managers and auditors determine how best to document business processes.

The rest of the paper is organized as follows. The next section reviews the literature on business process representations, including studies of the effects of alternative representations on judgment and decision making. This is followed by the development of research hypotheses. The study's research method and participants are then described, followed by analysis and discussion of the results. We conclude by summarizing the study's findings and its limitations.

PRIOR RESEARCH AND HYPOTHESES DEVELOPMENT

This study is at the nexus of several streams of literature: business process modeling, software engineering, cognitive science, and related studies in accounting and auditing. The business process modeling literature specifies what needs to be modeled to understand a business process, and demonstrates the feasibility of business process modeling. The cognitive science and external knowledge representation literature shows how alternative representations—in particular, diagrammatic versus textual representations—should affect judgment and decision making. Finally, the accounting and auditing literature identifies the practical implications relating to modeling method. We summarize key findings from each of these areas below.

Larkin and Simon (1987) were pioneers in establishing the general importance of external representation of information in its effect on the efficiency and effectiveness of problem solving. While there are many types of external representation, Larkin and Simon (1987) suggest that the greatest distinction among the forms of external representation is between propositional/ sentence-based (referred to as narrative) and diagrammatic representations. The latter is broadly defined as an arrangement of various graphic elements in space (Cheng et al. 2001). Accordingly, we focus on these two extremes to test whether diagrammatic representations, as supported by some prior research and popular trend, might be better suited for decision making relative to textual sentence-based representations for the purpose of making audit risk and control assessments.

Theoretical and Empirical Perspective

Various authors have identified characteristics that are relevant to the determination of when a diagram will be preferable to a textual representation, including characteristics of the diagram and characteristics of the user. Little research considers how characteristics of the task, domain, and task environment might alter the effectiveness of method of representation. Appendix A, based on Alencar et al. (2004), summarizes the issues.

A number of empirical studies have sought to determine when a diagram might be preferable to a textual representation, and *vice versa* (Holliday 1976; Vessey and Weber 1986; Cunniff and Taylor 1987; Dunn and Gerard 2001; Gilmore and Smith 1984). Tasks that have been studied include recall, classification, ordering, recognition, knowledge transfer, search, reasoning/inference, translation into and choice of a particular representation, comprehension, and decision making/ problem solving. These studies offer a number of key findings. First, often, but not always, prior studies have found individual performance using diagrams to be superior to performance using text. There is, however, some mixed evidence regarding the accuracy and efficiency improvement associated with using diagrams relative to textual representation.

Second, these findings tend to focus on the differences in user characteristics, and suggest that in some (but not all) cases, the expertise of the user affects the impact of the representation on performance. Specifically, Dunn and Gerard (2001) find that when there was a high degree of locational indexing,[2] experience was not a factor, but that experience became an increasingly important factor as the degree of locational indexing decreased.

Third, studies on the effects of diagrams for those with apparent expertise (Vessey and Weber 1986; Dunn and Gerard 2001; Scanlan 1989) show that diagrams led to improved performance, with performance being measured in a variety of ways. Proxies for performance include number of errors, less time taken to complete the task, greater satisfaction, and ease of use. Studies on the effects of diagrams when used by novices (Holliday 1976; Guthrie et al. 1993; Cunniff and Taylor 1987; Guri-Rozenblit 1989; Bauer and Johnson-Laird 1993; Gobert and Clement 1999; Brooke and Duncan 1980; Krohn 1983) have also found beneficial effects of diagrams, albeit less convincing. These studies have examined proxies for performance that included correctness and the time to perform the task.

More recently, Jones et al. (2002) hypothesize that the degree of cognitive fit between a task and various representation techniques determines the potential value of a method of representation. "Cognitive fit" is defined as the degree to which a particular diagramming technique is representative of a problem space, and Jones et al. (2002) assume that cognitive fit can be quantified by the correctness of a person's responses to questions about the underlying processes, as well as the length of time taken to complete a response. They empirically examine the cognitive fit between four modeling techniques that are typically part of an AIS course: data flow (DFD), process mapping (PM), resources-events-agents (REA) modeling, and flowchart (FC) diagrams. The strongest results in this study indicated that the PM technique appears to be suitable for tasks requiring an analysis of process, as measured by subjects' scores on 22 questions aimed at testing an understanding of each of these four modeling techniques. Jones et al. (2002) did not, however, extend their study to narrative representations of business processes.

The findings summarized above suggest that while it is often claimed that diagrams are *always* better than textual sentence-based representations (i.e., more natural and intuitive), this is not always the case (Cheng et al. 2001). Judgment and decision making errors can result when domain structures or relationships cannot be represented because of limits in the representational language, or because organization and formatting of the diagram are poorly matched to the cognitive processes relating to searching the representation, finding relevant information, and drawing inferences (Larkin and Simon 1987). The usefulness of diagrams in various contexts, thus, remains an open question.

[2] Locational indexing is the degree to which a representation explicitly captures the spatial relations of the domain. A representation that has a high degree of locational indexing uses appropriate organization and specificity to improve the user's ability to quickly recognize key relationships and make inferences.

External Knowledge Representation and Auditor Judgment

While the research cited above examines external representations of information in general, audit research has examined external representation issues in the context of auditor judgment, given that most audit problems, including risk assessment, are usually ill-structured or semi-structured (Boritz 1981). As a result, there have been various studies examining efforts to improve the structuring of information for audit decision making. Rose (2002) summarizes much of the research related to external representations, which has generally found that organizing information to better suit task or cognitive characteristics improves auditor judgment. As in the more general external representation literature cited earlier, however, there may be tradeoffs in computational complexity and judgment effectiveness. For example, a study by Boritz (1984) examined the effects of information structure on audit judgments by comparing auditors' responses to information cues about internal controls arranged according to a hierarchically structured template versus cues arranged in a simple list. The findings suggested that particular information structures did appear to play a role in auditor judgments, and also contributed significantly to the difficulty of making judgments. Dunn and Gerard (2001) examined auditor judgment contrasting an REA model to a more structured text-based model, and found a diagrammatic representation to be superior. Amer (1993) compared auditor judgment across different representations, including diagrammatic ones, for reviewing accounting transaction processing cycles.

Business Process Modeling for Auditor Assessments of Internal Control

As discussed in the foregoing review of literature, it is generally thought that the use of appropriate methods of representing business processes may help managers and auditors to better document, understand, and efficiently and effectively identify areas of risk. Bradford et al. (2007) report on surveys of textbooks, AIS and auditing instructors, and practitioners with respect to use of various system diagramming techniques. Bradford et al. (2007) note that diagrammatic methods are being used more predominantly for describing business processes, and call for research to compare the effectiveness of various types of methods. Carnaghan (2006) analyzes the attributes of several business process diagramming techniques, and assesses their strengths and weaknesses for meeting auditors' requirements for performing assessments of risks and internal controls. Xiong and Martin (2006) describe how two specific system documentation tools (REA and DFD) can be used to map internal controls, but do not compare them with the use of a narrative representation for the same purpose. Jones et al. (2002) assess student performance across four modeling techniques that are typically part of an AIS curriculum: data flow (DFD), process mapping (PM), resources-events-agents (REA), and flowchart (FC) diagrams. The strongest results in this study indicated that the PM technique appears to be suitable for tasks requiring an analysis of process; however, they do not compare diagrammatic representations to textual representations. Bierstaker et al. (2009) investigated whether client-prepared internal control documentation and business process flowcharts help or hinder an auditor's ability to identify missing controls. They found that providing the flowchart led to a statistically significant, albeit practically very small, improvement in their subjects' identification of missing controls. Bierstaker et al. (2009) did not provide informationally equivalent alternative representations to their participants. Thus, it is not clear whether it was the diagrammatic nature of the flowchart or the additional information contained within it that led to the improved performance.

This study is specifically designed to determine the relative merits of diagrammatic and narrative representations of a business process for use in identifying and assessing control risks, as discussed in International Auditing Standard (IAS) 315 (hereafter, we refer to this process simply as "risk assessment"). We study risk assessment outcomes since we wish to understand the impact of the process representations on the accuracy and efficiency of control risk judgments and conclusions.

Hypotheses Development

While previous studies suggest that diagrammatic representations might improve auditor judgment, none of the published research to date has examined the comparative benefits of using Business Process Modeling Notation (BPMN) for the representation of business processes, and using simple textual narratives in a difficult, but common, audit task requiring the assessment of business and control risks. Interviews that we conducted with Big 4 technical audit partners suggested that difficulties with risk assessment stemmed in part from how the information was documented. We interpreted these difficulties as issues of information presentation, hypothesizing that representation is likely to impact performance on risk assessment.

We consider three measures of performance. First, we consider performance as the level of *Accuracy* in identifying and assessing risks. Accuracy is defined as the comparison of individuals' decisions to a true or correct standard (Bonner 2008). Traditionally, research has focused on this performance criterion because of the significant costs associated with failure to identify risk. Second, we consider performance as the level of *Efficiency* at identifying and assessing risks. Efficiency is defined as the time it takes to complete a task or the time it takes to reach a sufficient answer (Bonner 2008). For auditors, managers, and students, time is a valuable resource. In fact, audit firms typically use the criterion of *Efficiency* when assessing the performance of their employees (Tan and Libby 1997).[3] Finally, we consider performance as a *Weighted-Average Performance* of *Accuracy* and *Efficiency*. This measure reflects the importance of balancing the pressures of *Accuracy* and *Efficiency* in a typical business environment.

Although prior work in cognitive science has established that diagrammatic representations can improve problem solving for particular types of problems relative to textual representations, the prior research provides mixed evidence and has not tested the diagrammatic representation of a business process against an *informationally equivalent* narrative representation of the same business process. Therefore, our first research hypothesis is:

> **H1 (null):** Diagrammatic representation of a business process will result in equal accuracy, efficiency, and weighted-average performance in the assessment of internal control risks as an informationally equivalent textual representation.

As noted in Appendix A, user cognitive processes and expertise can influence users' performance on tasks involving different diagrammatic representations. Scaife and Rogers (1996, 201) stress the importance of the user being able to "read and comprehend the significance of the content of the [diagram] in relation to the other information that is being presented verbally or as text and to assimilate this to their current understanding of the domain." Cheng et al. (2001) raise the possibility that experts may make use of more of the provided functional roles of particular diagrams than do novices, and notes prior research on the importance of compatibility between diagrams and the users' mental models based on work by Lowe (1999). Research on audit expertise (Libby 1995) links performance in judgment and decision making (JDM) tasks such as risk and control assessment to antecedents such as ability. In other words, ability is an important antecedent

[3] Efficiency can be achieved in one of two ways. First, individuals could sacrifice accuracy to complete a task as quickly as possible. Second, individuals with superior resources, such as abilities and tools, are expected to complete a task more quickly. The first way is likely to not differ by condition, making it more difficult to find results. It is through the second way that we expect representation to impact efficiency. See footnote 15 for further analysis.

to any training initiative designed to improve knowledge about and understanding of a particular process representation technique and, ultimately, performance on a JDM task in the auditing domain that depends on that process representation. Abilities can be general reasoning abilities or specific abilities, such as spatial abilities (Bonner 2008). Academic achievement reflects students' general reasoning abilities, as well as their success in learning and performing cognitive tasks such as the risk and control assessment task used in this study. Using academic achievement as a proxy for general reasoning abilities and specific abilities germane to risk assessment leads to the following hypothesis:

> **H2a:** Individuals higher in academic achievement will be more accurate, efficient, and have better weighted-average performance when assessing internal control risks than those lower in academic achievement.

Because those with higher abilities perform at higher levels on JDM tasks (Libby 1995), we expect the type of representation to have less effect on individuals with higher abilities, which is the next hypothesis:

> **H2b:** Academic achievement will interact with business process representation such that the effect of representation on accuracy, efficiency, and weighted-average performance will diminish as academic achievement increases.

We also introduce a relatively unexplored dimension of student ability, self-efficacy, and consider its role in determining the effectiveness of diagrammatic representation relative to textual narrative. Self-efficacy, or task-specific confidence, defines an individual's perception that he or she is able to succeed on a given task (Bandura 1977). Self-efficacy is a key feature of social cognitive theory, which describes the series of personal and behavioral factors that can influence an individual's cognition, ultimately affecting his or her judgments and decisions (Wood and Bandura 1989). Indeed, prior research has shown that individuals' self-efficacy is positively associated with their performance on a number of tasks, and that self-efficacy becomes more important as task complexity increases (Stajkovic and Luthans 1998).

Extending this research to business process representation, we predict participants higher in self-efficacy measured using a four-question 100-point scale[4] will outperform those lower in task-specific confidence. Further, as with students' academic ability, we expect greater self-efficacy will reduce the effect that representation has on individuals' performance. These tendencies lead to the following hypotheses:

> **H3a:** Individuals higher in self-efficacy will be more accurate, efficient, and have better weighted-average performance when assessing internal control risks than those lower in self-efficacy.

> **H3b:** Self-efficacy will interact with business process representation such that the effect of representation on accuracy, efficiency, and weighted-average performance will diminish as self-efficacy increases.

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[4] Self-Efficacy Measures: Students were asked to "Please rate how certain you are that *you can do* the things discussed below": (1) How certain are you that *you can* properly evaluate *the effectiveness of* a business process using the process information that was provided in this case? (2) How certain are you that *you can* properly evaluate *the business risks* in a business process using the process information that was provided in this case? (3) How certain are you that *you can* properly evaluate *the audit risks* in a business process using the process information that was provided in this case? (4) How certain are you that *you can* properly evaluate *the internal controls* in a business process using the process information that was provided in this case?

METHOD

Design

We tested our hypotheses using a between-subjects experiment in which participants made risk assessments for internal control from one of two forms of documentation of a company's business processes: diagrammatic and textual.

Participants

Participants were 144 students in three sections of an upper-level undergraduate accounting information systems course at a large North American university. Participants completed a multiple-choice, 24-question assignment that also served as their midterm exam.[5] All students were informed prior to the exam that only their mark on the exam will count toward their course grade, and that they may choose to answer none, some, or all of the process measures and demographics questions asked within the study. As a result, five students omitted necessary supplemental information and were excluded from further analysis, resulting in a sample size of 139 students.

Motivation

Students' grades on the midterm exam represented 10 percent of their final grade in the course, stressing the importance of accuracy. To further incentivize performance regarding accuracy and to encourage greater efficiency in performance, students also earned lottery tickets toward a draw for one of two prizes of $250. Lottery tickets for the draw were earned based on an equally weighted combination of the student's exam score rank and the inverse of the rank of the time spent to complete the exam relative to other students. That is, the higher a student's mark relative to others, the more lottery tickets earned; the less time a student took to complete the exam relative to others, the more lottery tickets earned.

Experimental Procedure

The institution's Office of Research Ethics approved the experimental procedure, including the associated form for informed consent, which students completed before beginning the exam.

At the start of class, the exam was distributed to students and oral instructions were provided describing the exam, the component of the exam that would directly affect participants' course grades, the lottery to motivate performance on two dimensions, and the option to answer any of the additional process measures relating to the experiment. Participants were informed that their professor would not see any of their responses other than their exam grade. The two versions of the exam (textual or diagrammatic representation) were randomly distributed within each of the three sections of the course. Students were informed that they had a maximum of 75 minutes to complete the exam, although using all the time would result in no lottery tickets earned for the time bonus. After all of the students' questions regarding the exam, the experiment, and the lottery were answered, the exam was administered.

Finally, upon completion of the course, students' *course grade* (on a scale from 0 to 100) was obtained directly from the professor as a measure of their general academic achievement.[6]

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[5] There is no difference in accuracy, efficiency, or weighted-average performance between the three sections of students ($p = 0.42$), nor interactions between condition and section ($p = 0.56$). As a result, section is removed from any further analyses.

[6] The results remain unchanged whether we use total course grade or if course grade excludes students' performance on their midterm exam.

Experimental Task

The exam, adopted from Borthick et al. (2012), asked students to use the documentation of an accounts payable process for a fictitious convenience store chain to answer 24 multiple-choice questions regarding control weaknesses and their potential consequences. The two between-subject conditions regarding the method of documenting the procure-to-pay process within the payable process include a textual or diagrammatic representation. The first condition, referred to as the textual condition, documents the procure-to-pay process through a detailed narrative.

In the second condition, referred to as the diagrammatic condition, students view a BPMN diagram representing the process. BPMN is a common diagrammatic process mapping that is included in many AIS textbooks, AIS courses, and auditing courses, and is used in practice (Bradford et al. 2007). Carnaghan (2006) summarizes the attributes of BPMN and compares it with several other methods for diagramming business processes. We chose the BPMN method to maintain consistency with Borthick et al. (2012) and to remain consistent with the method of diagramming that students were taught earlier, in prior weeks of the course. Both conditions also included a narrative which documented the company's application development approach and access controls.

After examining the documentation of the accounts payable process, but prior to starting the multiple-choice questions, students were asked questions designed to serve as manipulation checks and process measure questions that allow for covariate analysis. The manipulation checks asked about the emphasis of process diagrams, narratives, risk in business process, and internal controls using an 11-point scale, from −5 to +5. Further, participants were asked about the ease of understanding the case and how realistic the case was given their experience. The process measures included participants' self-efficacy regarding identifying internal control weaknesses on a 100-point scale (Bandura 1977, 2006) and their length and type of experience using/preparing/assessing business process documentation.[7]

Students then proceeded to answer the 24 multiple-choice questions of the exam (see Supplemental Materials, Appendix 5). The questions and their order were identical for both conditions. Once they completed the exam, participants responded to exit survey questions (see Supplemental Materials, Appendix 6) on an 11-point scale (−5 to +5) about whether they had sufficient time to complete the exam and how difficult the multiple-choice questions were to answer. After completing these questions, students returned their exams to the front of the room, where time was then recorded.

Performance Variables

Accuracy was measured as the percent correct of the 24 multiple-choice questions. *Efficiency* was the amount of time it took a student to complete the exam, where more efficient was associated with less time. *Weighted-Average Performance* was the weighted-average of each participant's relative accuracy and efficiency.[8] This is the same measure that determined how many lottery

[7] Prior to the exam, students received verbal instructions to proceed through the case sequentially, completing manipulation checks and measures of self-efficacy prior to answering the test questions. Further, each exam explicitly asked students to complete the manipulation checks and measures of self-efficacy prior to any test questions. Finally, an administrator was present during the exam to further encourage students to follow these instructions. With that said, there is a possibility that some students completed the test questions prior to the manipulation check and measures of self-efficacy. We have no reason to expect this behavior to be widespread or to differ between conditions.

[8] The weighted-average of accuracy and efficiency is calculated as participants' combined ranking within all participants on accuracy and efficiency. That is, an individual who is the best of all 139 participants in accuracy (or efficiency) is awarded 139 tickets. The maximum number of tickets possible is 278. All equivalently ranked performance scores are awarded the same number of tickets.

tickets a participant earned and, as such, is included because students are financially incentivized to balance both *Accuracy* and *Efficiency*. We contend this also reflects the typical business environment, where balancing the pressures of accuracy and efficiency are fundamental to the future success of students.

RESULTS

Manipulation Checks and Process Measures

Descriptive results discussed below appear in Table 1. Students in the textual (diagrammatic) condition rated the narrative being stressed as 3.66 (1.29) and the diagram being stressed as −2.67 (−0.05) on a −5 to +5-point Likert scale. Both manipulation checks are significantly different between conditions ($p < 0.01$, two-tailed), indicating that independent variable manipulation was sufficiently applied.

To ensure the two business process representations did not differ in perceptions of information content, confirming the informational equivalence of the two conditions, a number of questions were asked of the participants. The task was found to be equally realistic in both conditions ($p = 0.35$, two-tailed). The representation of the accounts payable process equivalently emphasizes risks in the business process ($p = 0.76$, two-tailed) and the internal controls over the business process ($p = 0.57$, two-tailed). Finally, participants in both conditions found the business process representations equivalent in ease of understanding ($p = 0.23$, two-tailed), the exam questions to be equivalent in difficulty to answer ($p = 0.86$, two-tailed), and equivalent in sufficient time to complete the exam ($p = 0.34$, two-tailed). None of the measured responses above were found to interact with condition type (textual or diagrammatic) when included in regression results, and further, none (individually or in combination) were found to alter regression results or interpretation. As a result, they are excluded as covariates in further analyses below.[9] We include demographic information by condition in Table 2.

Hypotheses Testing

To test our hypotheses, we conducted OLS regressions with independent variables *condition* (narrative or diagrammatic), *Self-Efficacy* (perceived ability), *Course Grade* (academic achievement), the interaction of *condition* with *Self-Efficacy* or *Course Grade*, and dependent variables of *Accuracy* (exam grade), *Inefficiency* (time), and *Weighted-Average Performance* (tickets). The results of these regressions are presented in Tables 3, 4, and 5, respectively.

Testing of H1: Performance

Our first hypothesis predicts that diagrammatic representation will result in different performance than textual representation considering three measures of performance: *Accuracy*, *Inefficiency*, *and Weighted-Average Performance*. First, with regard to *Accuracy*, neither narrative nor diagrammatic representation resulted in participants having more correct responses on the exam (Table 3: $\beta_1 = -8.07$, $p = 0.19$, two-tailed). While the maximum grade on the exam was 24, the average (standard deviation) percentage for the textual and diagrammatic conditions was 53.82 percent (11.07) and 53.44 percent (10.10), respectively. These results indicate that the task was challenging enough, yet did not suffer from ceiling or floor effects. In fact, the high difficulty was

[9] Ease of understanding is highly positively correlated with *Accuracy* on the exam ($p = 0.02$, two-tailed). There is, however, no difference in ease of understanding between-condition when controlling for *Accuracy* ($p = 0.54$, two-tailed).

TABLE 1

Descriptive Means (Standard Deviations)[a,b]

Measure	Textual Representation	Diagrammatic Representation
Number of Complete Responses	74	63
Manipulation Checks:		
Flowchart Emphasized	−2.67	−0.05
	(2.70)	(2.50)
Narrative Emphasized	3.66	1.29
	(1.94)	(2.30)
Risk Emphasized	1.33	1.46
	(2.75)	(2.36)
Internal Controls Emphasized	2.07	1.86
	(2.21)	(2.04)
Ease of Understanding	−1.22	−1.03
	(2.71)	(2.54)
Realism of the Task	1.22	0.88
	(2.21)	(2.23)
Sufficient Time to Complete	2.02	2.24
	(3.11)	(2.73)
Difficulty of Task	3.56	3.45
	(1.80)	(1.31)
Measured Factors:		
Self-Efficacy	59.65	56.37
	(16.68)	(18.84)
Course Grade (Academic achievement)	80.76%	80.99%
	(6.06)	(5.10)
Dependent Variables:		
Percent Accuracy (24 questions)	53.33%	53.67%
	(10.66)	(10.78)
Inefficiency (Minutes to Complete the Task)	47.13	46.26
	(10.30)	(9.67)
Weighted-Average Performance	136.74	131.70
	(58.64)	(56.93)

[a] The variables include participants' percentage score calculated as their raw score on the exam out of 24, the time taken to complete the exam bounded by 60 minutes, average self-efficacy on a scale of 1 to 100, the final percent grade in the course on a scale of 1 to 100, the extent flowcharts, narrative, audit risks, and internal controls were emphasized on a scale of −5 to +5, the ease of understanding the business process on a scale of −5 to +5, how realistic the task is on a scale of −5 to +5, experience with textual and flowchart descriptions of business processes on a scale of 1 to 10, whether there was sufficient time to complete the exam on a scale of −5 to +5, and how difficult the exam was on a scale of −5 to +5.

[b] Results are shown separately based on condition. Textual condition received business process information in the form of a descriptive textual narrative. Diagrammatic condition received business process information in the form of a BPMN diagram. The number of responses differs between the two conditions due to randomization and participants' choice to answer self-efficacy questions.

intended to bias in the direction of finding a difference between conditions, as type of representation has a sufficient opportunity to affect *Accuracy*.

As an additional test of the effect of condition on *Accuracy*, we subdivided the 24-question exam into two groups, based on the questions that relied on the common application narrative received by both conditions (10 questions) and those based on information contained in either the textual or diagrammatic manipulation (14 questions). Similar to the null results regarding the effect

TABLE 2

Demographics Count or Mean (Standard Deviation) by Representation[a,b]

Demographic	Textual Representation	Diagrammatic Representation
Number of Male Participants	32	28
Number of Female Participants	42	35
Prior Work Experience in Months	8.6	9.5
	(2.2)	(4.1)
Experience with Textual Business Process Documentation	4.4	3.4
	(2.5)	(2.6)
Experience with Diagrammatic Business Process Documentation	3.6	3.0
	(2.5)	(2.5)

[a] The variables below by condition include participants' gender, months of prior work experience in accounting, the number of previous accounting courses taken, professional experience with textual and flowchart representations on a 0 to 10 scale.

[b] Results are shown separately based on condition. Textual condition received business process information in the form of a descriptive narrative. Diagrammatic condition received business process information in the form of a BPMN model.

TABLE 3

The Effect of *Representation*, *Course Grade*, and *Self-Efficacy* on *Accuracy* (n = 139)

$$Accuracy_i = [\alpha_i] + \beta_1 Representation_i + \beta_2 Self\text{-}Efficacy_i + \beta_3 Course\ Grade_i + \beta_4 Representation{*}Self\text{-}Efficacy_i + \beta_5 Representation{*}Course\ Grade_i + \varepsilon_i.$$

	Unstandardized Coefficient	Standard Error	t-statistic	p-value[a]
Intercept	2.68	3.85	0.70	0.49
Representation	−8.07	6.12	−1.31	0.19
Self-Efficacy	−0.13	0.02	−0.77	0.22
Course Grade	0.13	0.05	3.00	<0.01
Representation × *Self-Efficacy*	0.01	0.02	0.59	0.29
Representation × *Course Grade*	0.09	0.07	1.23	0.11

$R^2 = 15.9\%$

[a] p-values are shown as one-tailed with the exception of the Intercept and *Representation*.

Variable Definitions:
Representation = dichotomous variable of 0 for those receiving textual representation, and 1 for those receiving diagrammatic representation;
Self-Efficacy = continuous measure calculated as the average response to the four efficacy questions in Appendix 4 (see Appendix B to access the Supplemental Materials) measured on a 0 to 100 scale;
Course Grade = continuous measure calculated as participants' grade on a 0 to 100 scale in their information system course (as provided by the course professor); and
Accuracy = discrete variable and measures participants' accuracy on a scale from 0 to 24.

TABLE 4

The of Effect of *Representation*, *Course Grade*, and *Self-Efficacy* on *Inefficiency*
(n = 139)

$$Inefficiency_i = [\alpha_i] + \beta_1 Representation_i + \beta_2 Self\text{-}Efficacy_i + \beta_3 Course\ Grade_i + \beta_4 Representation{*}Self\text{-}Efficacy_i + \beta_5 Representation{*}Course\ Grade_i + \varepsilon_i.$$

	Unstandardized Coefficient	Standard Error	t-statistic	p-value[a]
Intercept	−3.30	15.87	−0.21	0.84
Representation	56.93	25.44	2.24	0.03
Self-Efficacy	0.06	0.07	0.86	0.19
Course Grade	0.58	0.19	3.14	<0.01
Representation × *Self-Efficacy*	−0.18	0.09	−1.89	0.03
Representation × *Course Grade*	−0.59	0.30	−1.96	0.03

$R^2 = 9.5\%$

[a] p-values are shown as one-tailed with the exception of the Intercept and *Representation*.

Variable Definitions:
Representation = dichotomous variable of 0 for those receiving textual representation, and 1 for those receiving diagrammatic representation;
Self-Efficacy = continuous measure calculated as the average response to the four efficacy questions in Appendix 4 (see Appendix B to access the Supplemental Materials) measured on a 0 to 100 scale;
Course Grade = continuous measure calculated as participants' grade on a 0 to 100 scale in their information system course (as provided by the course professor); and
Inefficiency = discrete variable calculated as the amount of time (to the nearest minute) participants took to complete the task.

of condition on all questions, neither narrative nor diagrammatic representation resulted in participants performing better on the 14 questions (not tabulated: $\beta_1 = -3.58$, p = 0.47, two-tailed).[10] Again, the average (standard deviation) percentage *Accuracy* on the 14 questions for the textual and diagrammatic conditions suggests the task was challenging enough and results do not suffer from ceiling or floor effects.[11]

Failure to reject the null hypothesis (e.g., when *Accuracy* is used as a dependent variable) is often criticized as the result of using a low-powered test. To test power sufficiency, a *post hoc* power analysis is often recommended. This approach, however, is flawed since it is impossible to fail to reject the null hypothesis and maintain high retrospective power (Hoenig and Heisey 2001); that is, there is a 1:1 relationship between p-values and *post hoc* power calculations. Instead, it is recommended that confidence limits on parameters of interest be used to assess whether there is sufficient power to support a null conclusion (Howell 2010; Hoenig and Heisey 2001).

While crude when multiple covariates are included in the analysis, assuming all factors are held fixed, the results of our experiment suggest a 95 percent confidence interval for statistical difference

[10] Further analysis shows that percent accuracy did not differ between application questions and the remaining 14 questions (p = 0.95, two-tailed).
[11] Additional analysis, not tabulated, of the questions identified by the professor of the course as directly containing material covered in class (13 questions) showed significantly higher averages (p < 0.01) of *Accuracy* in both conditions, but, similar to our results, *Accuracy* did not differ between conditions.

TABLE 5

The of Effect of *Representation*, *Course Grade*, and *Self-Efficacy* on *Weighted-Average* (n = 139)

$$Weighted\text{-}Average\ Performance_i = [\alpha_i] + \beta_1 Representation_i + \beta_2 Self\text{-}Efficacy_i + \beta_3 Course\ Grade_i + \beta_4 Representation{*}Self\text{-}Efficacy_i + \beta_5 Representation{*}Course\ Grade_i + \varepsilon_i.$$

	Unstandardized Coefficient	Standard Error	t-statistic	p-value[a]
Intercept	181.82	92.59	1.96	0.05
Representation	−356.62	148.47	−2.40	0.02
Self-Efficacy	−0.58	0.39	−1.47	0.07
Course Grade	−0.18	1.08	−0.17	0.43
Representation × *Self-Efficacy*	1.12	0.54	2.05	0.02
Representation × *Course Grade*	3.67	1.76	2.08	0.02
$R^2 = 7.3\%$				

[a] p-values are shown as one-tailed with the exception of the Intercept and *Representation*.

Variable Definitions:
Representation = dichotomous variable of 0 for those receiving textual representation, and 1 for those receiving diagrammatic representation;
Self-Efficacy = continuous measure calculated as the average response to the four efficacy questions in Appendix 4 (see Appendix B to access the Supplemental Materials) measured on a 0 to 100 scale;
Course Grade = continuous measure calculated as participants' grade on a 0 to 100 scale in their information system course (as provided by the course professor); and
Weighted-Average Performance = discrete variable calculated as the number of lottery tickets earned based on participants' *Accuracy* and *Efficiency* relative to other participants. See further description in the "Method" section.

of *Accuracy* scores between textual and diagrammatic conditions is $-0.884 \leq \mu_1 - \mu_2 \leq 0.801$. This implies that a very small difference in accuracy scores of less than one correct answer would be sufficient to reject the null hypothesis. Further support for this conclusion is found through our completion of a non-parametric run test around the median of *Accuracy* by condition. Results of that test suggest the two conditions are the same across *Accuracy*, as the asymptotic significance for total accuracy and accuracy by question is $p > 0.05$. It appears our test offers sufficient power, yet our results support retaining the null hypothesis of H1 that method of representation has no effect on students' *Accuracy*.

The real improvement, however, in students' performance is found in their efficiency on the exam. Students in the diagrammatic condition were more inefficient at completing the exam than students in the narrative condition (Table 4: $\beta_1 = 56.93$, $p = 0.03$, two-tailed). Given the average (standard deviation) time of completion on the exam for the textual and diagrammatic conditions were 47.13 (10.30) and 46.26 (9.67), respectively, the data indicate that students had sufficient time to complete the exam within the maximum 75 minutes of allotted time.[12]

[12] Consistent with the argument made in footnote 1, we graphed the association between student ability and efficiency and find no evidence of a curvilinear relationship. That is, we find little evidence that it is simply those low and high in academic ability that are completing the task more quickly than others.

Finally, we derived a *Weighted-Average Performance* index based on the number of lottery tickets students earned as described in the method section. The *Weighted-Average Performance* is higher (lower) for those in the textual (diagrammatic) condition (Table 5: $\beta_1 = -356.62$, $p = 0.02$, two-tailed). The maximum weighted-average performance possible was 278, and the average (standard deviation) performance scores on the exam for the textual and diagrammatic conditions were 136.74 (58.6) and 131.7 (56.9), respectively.[13] The results suggest that individuals receiving the textual representation were better able to manage the competing performance demands of accuracy and efficiency compared to those of the diagrammatic condition.

Overall, the results explained above support retaining the null hypothesis that diagrammatic representation results in equivalent *Accuracy* relating to students' assessment of internal control risks as a descriptive narrative. However, when performance is measured as *Inefficiency* or the *Weighted-Average Performance* of *Efficiency* and *Accuracy*, the evidence suggests rejecting the null, supporting the conclusion that students perform better at assessing internal controls when using a textual rather than diagrammatic representation.

Testing of H2a and H3a: Academic Achievement and Self-Efficacy

H2a and H3a predict that participants higher in academic achievement and self-efficacy (perceived ability) will perform better than those lower in either. First, the effect of students' academic achievement on their performance is considered, with academic achievement measured as participants' final grade for the information system course, obtained directly from the course professor.[14] As shown in Table 1, the final average course grade for the textual (diagrammatic) condition is 80.76 percent (80.99 percent). Regression results show that students with higher academic achievement are more *accurate* (Table 3: $\beta_3 = 0.13$, $p < 0.01$, one-tailed) and less *efficient* (Table 4: $\beta_3 = 0.58$, $p < 0.01$, one-tailed) in their assessment of internal control risks than those lower in academic achievement.[15] Academic achievement, however, had no effect on *Weighted-Average Performance* (Table 5: $\beta_3 = -0.18$, $p = 0.43$, one-tailed). It appears students higher (lower) in academic achievement were more likely to sacrifice *Efficiency* (*Accuracy*) for more *accurate* (*efficient*) performance.

Second, H3a considers the effect of self-efficacy on performance. Self-efficacy is measured using four questions asked after the treatment of the independent variable, but prior to performance. Confirmatory factor analysis indicates that the four questions regarding participants' self-efficacy represent a unidimensional construct in our setting, with all factor loadings greater than 0.86 and an eigenvalue (variance explained) of 3.2 (80 percent) (Stevens 1996). As a result, our self-efficacy measure is calculated as the average of all four responses. As shown in Table 1, the average self-efficacy for the textual (diagrammatic) condition is 59.65 (56.36) on a 0–100 scale.

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[13] Across both conditions, there is evidence of a negative correlation between *Efficiency* and *Accuracy* ($r = -0.10$, $p = 0.11$). The correlation of *Efficiency* and *Accuracy* by condition, however, suggests that the positive gain in *Accuracy* through less *Efficiency* ($r = -0.15$, $p = 0.09$) in the textual condition is not found in the diagrammatic condition ($r = -0.05$, $p = 0.34$). Including either of the dependent measures as a covariate while including the other as the dependent measure does not alter the results presented above.

[14] Consistent with ethics approval, all participants included in our study consented to the use of their exam grade and their final grades in the experiment.

[15] In following up on the discussion in footnote 3, we tested for the potential of a curvilinear relationship between academic ability and efficiency. We conducted a similar regression, as reported in Table 4, on a median split of the data based on academic ability. We find that both low (not tabulated: $\beta = 0.36$, $p = 0.19$, two-tailed) and high (not tabulated: $\beta = 0.58$, $p = 0.11$, two-tailed) academic ability groups have a positive, but insignificant, relationship between ability and efficiency. This suggests that there is either a positive linear relationship between academic ability and efficiency, or that our sample contains insufficient variation in either ability or efficiency to detect a curvilinear relationship.

Individuals higher in *Self-Efficacy* are found to not differ in their *Accuracy* (Table 3: $\beta_2 = -0.01$, p = 0.22, one-tailed) or *Efficiency* (Table 4: $\beta_2 = 0.06$, p = 0.20, one-tailed) when compared to those lower in self-efficacy. In fact, when performance is considered as the *Weighted-Average Performance*, those higher in *Self-Efficacy* actually performed worse than those lower in *Self-Efficacy* (Table 5: $\beta_2 = -0.58$, p = 0.07, one-tailed). These findings fail to support H3a and are suggestive that self-efficacy may represent overconfidence, which hurts performance on risk assessments, depending on how performance is measured.

Testing of H2b and H3b: Interactions

H2b and H3b predict individuals' academic achievement and self-efficacy will interact with condition on performance for *Accuracy*, *Efficiency*, and *Weighted-Average Performance*. First, we find academic achievement interacts with condition such that improvements of *Efficiency* (Table 4: $\beta_5 = -0.59$, p = 0.03, one-tailed) and *Weighted-Average Performance* (Table 5: $\beta_5 = 3.67$, p = 0.02, one-tailed) from using a narrative rather than diagrammatic representation are stronger for those lower in academic achievement than those higher in academic achievement. There is no interactive effect of academic achievement and condition on students' *Accuracy* on the exam (Table 3: $\beta_5 = 0.09$, p = 0.11, one-tailed).

Second, we find *Self-Efficacy* interacts with condition such that improvements in *Efficiency* (Table 4: $\beta_4 = -0.18$, p = 0.03, one-tailed) and *Weighted-Average Performance* (Table 5: $\beta_4 = 1.12$, p = 0.02, one-tailed) from using a narrative rather than diagrammatic representation are stronger for those lower in self-efficacy than those higher in self-efficacy. *Self-Efficacy*, however, is found to have no interaction with condition when *Accuracy* is the dependent variable (Table 3: $\beta_4 = 0.01$, p = 0.25, one-tailed).

Given this evidence, it appears that academic achievement and/or self-efficacy affect the effectiveness that method of representation has on performance in the same direction. Interestingly, academic achievement and self-efficacy are uncorrelated in our study (r = −0.07, p = 0.38). That is, individuals' actual academic achievement and their perceived ability prior to the exam are inconsistent, suggesting that academic achievement and self-efficacy affect performance regarding method of representation in different ways. Given our data constraint and the continuous nature of both measures, we are unable to sufficiently test this hypothesis using a three-way interaction.[16]

CONCLUSION AND FUTURE RESEARCH

This study investigates whether the method of representing a business process affects students' accuracy and efficiency of risk and control assessments adjusted for academic achievement and self-efficacy. Specifically, this study compared informationally equivalent versions of business process representations using a simple narrative and a diagram in BPMN.

First, we find that a textual representation of a business process can lead to equivalent, if not better, performance as a diagrammatic representation. This further suggests that curriculum design could profitably incorporate instruction in preparation and use of business process textual narratives in addition to or in place of diagrammatic business process representations. It could be that too much emphasis is being placed on diagrammatic representations of business processes when textual narratives can lead to the same performance.

Second, we find that although students' academic achievement improves their accuracy on the exam, there is an equivalent drop in their relative efficiency, which means there is ultimately no

[16] We transformed the continuous measures of *Course Grade* and *Self-Efficacy* into dichotomous measures using their respective medians. A three-way interaction between condition, *Course Grade*, and *Self-Efficacy* was insignificant across each of the dependent measures (not tabulated: p > 0.47, two-tailed).

effect on performance when measured as a weighted-average of accuracy and efficiency. Further, we find that students' task-specific confidence or self-efficacy has no significant direct effect on their accuracy or efficiency on the exam. In fact, self-efficacy has a marginally negative effect on their weighted-average performance.

Finally, we find that both academic achievement and self-efficacy interact with condition such that the effect of method of representation on efficiency and weighted-average performance is stronger when academic achievement and/or self-efficacy is lower than when they are high.

This study contributes to the existing literature in several ways. First, it contributes to the more general literature on external representations and their effect on problem solving by examining the effects of alternative representations on audit risk and control assessment. This study indicates that an informationally equivalent textual representation can possess some of the benefits often associated with diagrammatic representations. The study is silent, however, on how easy it is to obtain such benefits through deliberate structuring of the textual and diagrammatic presentations. The results may contribute to curriculum development by providing guidance on whether diagrammatic techniques such as those explored in the study require the emphasis they are given in accounting information systems and auditing courses and textbooks. The results may also contribute to the assessment of techniques that are most useful for auditing purposes. Finally, the results of the study may also help managers and auditors determine how best to document business processes.

This study has some potential limitations that should be considered in conjunction with the findings reported in this paper. Although both textual narratives and diagrammatic representations led to the same performance, the performance on the experimental task was generally weak, despite the comparatively strong overall grades in the course. We deliberately chose a diagrammatic format that was used in the accounting information systems textbook used by the students. It may be that the case was too complex or too difficult to capture the benefits of using diagrams. An extension of this study would be to use a simpler case. Another extension of this study would be to provide students with additional representation formats to determine whether performance could be improved.

The task involved the assessment of risks and controls in a business process. The use of a different task could lead to different results; for example, the assessment of risks in a business model involving a different type of diagrammatic representation as in Alencar et al. (2008), or different modes of interaction as summarized in Appendix A. Also, we did not investigate the effects of requiring participants to *create* different representations. Instead, we investigated the impact on participants' risk and control assessments of their use of textual and diagrammatic representations prepared by others. We created a textual representation that was informationally equivalent to the diagrammatic representation of the case company's business process. We did not assess the relative costs, difficulties, and benefits of creating such informationally equivalent representations. An extension of this study would be to have participants create diagrammatic and narrative representations, and have other participants use them to assess risks and controls to determine whether the representations would lead to different results under such circumstances.

Finally, participants were individuals with less than one year of professional experience. We cannot tell whether involving more experienced participants, or even auditors, would result in different outcomes. Thus, an extension of this study would be to have practitioners (auditors and managers) perform the task to compare their accuracy and efficiency with those found here.

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APPENDIX A

THEORY SUPPORTING THE SUPERIORITY OF DIAGRAMMATIC OR TEXTUAL REPRESENTATION

Factor and Explanation

Specificity: A key concept in evaluating the desirability of a diagram is what Stenning and Oberlander (1995) refer to as specificity. The general idea here is that it is easier to use a diagram where the number of possible interpretations is limited because this reduces cognitive load.

Cognitive Load: Cognitive load is also reduced when a diagram represents information in the form into which the user would have to learn to transform information provided in another form. Salomon (1994) suggests that this concept of supplantation (similar to what Scaife and Rogers [1996] refer to as cognitive offloading), thus, reduces mental effort and improves accuracy. A diagram may, thus, compensate in some circumstances for poor mastery of a skill (Brna et al. 2001).

Highlighting: If a particular diagram does not capture the constraints of the problem well, it is unlikely to be of much use. Effective modeling that reduces cognitive load is facilitated by a representation that highlights the more important information and downplays or omits other less-relevant aspects of the problem (thus, reducing noise). Appropriate highlighting includes the idea that important relationships and objects are made explicit in the diagram.

Recognition: This general issue of how well the diagram maps to the important features of the domain corresponds to what Larkin and Simon (1987) refer to as recognition. Stenning and Lemon (2001) refer to this as the availability to the users of the constraints operating within the representation, given the semantic interpretation the user has made. Their point is that the utility of a particular diagram will depend on whether "a user with certain competencies and knowledge may learn to exploit the constraints on expressiveness inherent in the intended interpretation of a diagram" (Stenning and Lemon 2001, 31).

Locational Indexing: Another important consideration in representation choice is that of locational indexing, which implies that task informational needs have been considered in the way that the elements of the representation have been organized. A related point made by Larkin and Simon (1987) is that diagrams can explicitly capture the spatial relations of the domain, while a text representation typically does not. Appropriate organization and specificity should improve the user's ability to quickly recognize key relationships and make inferences.

Concretization: The inherent requirement to reflect properties such as proximity and existence in a diagram capture the "concretization" characteristic referred to by Olivier (2001). Concretization reduces ambiguity, and also helps to rule out potential interpretations by demonstrating that certain configurations of elements cannot physically be created. For example, certain spatial arrangements that may seem plausible in a text representation simply cannot be represented in a diagram, which implies that such an arrangement is impossible.

Inference: The issue of ease of inference needs to be considered. Larkin and Simon (1987) make the point that inference rules to be applied to diagrams may be either more or less powerful than the equivalent rules applied to text. Larkin and Simon (1987) suggest that diagrams will have an advantage when the necessary inferences can rely on perceptual results which can be easily recognized from the diagram (i.e., determining the equilibrium price and quantity and the effects of a change in either of these in a supply and demand relationship represented as a diagram).

Interaction: The user's ability to interact with the representation is likely important, although the theoretical perspectives underlying this view are not well articulated. Even basic acts like underlining and making notations may be an important part of sense-making for users. The construction of the diagram by the user likely represents the extreme form of interaction. The need for interaction may have ramifications for preferred media and for the complexity of the representation notation.

User Cognitive Processes and Expertise: Scaife and Rogers (1996) point out the importance of the users having "operators" that match the representation being used, and note that this suggests that the value of diagrams will depend on the experience and expertise of the user. In particular, a user with lots of experience manipulating representations of a particular type (e.g., text-based) may gain little from having representation translated to a diagrammatic form. Scaife and Rogers (1996, 201) stress the importance of the user being able to "read and comprehend the significance of the content of the [diagram] in relation to the other information that is being presented verbally or as text and to assimilate this to their current understanding of the domain." Cheng et al. (2001) raise the possibility that experts may make use of more of the provided functional roles of particular diagrams than do novices, and notes prior research on the importance of compatibility between diagrams and the users' mental models based on work by Lowe (1999).

Source: Alencar et al. (2004).

APPENDIX B

Experiment Instrument (Business Process_IAE_materials): http://dx.doi.org/10.2308/iace-50144.s1