Process Innovation as Creative Problem-Solving: An Experimental Study of Textual Descriptions and Diagrams

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Abstract

The use of process models to support business analysts' idea-generation tasks has been a longstanding topic of interest in process improvement. We examine how two types of representations of organizational processes – textual and diagrammatic – assist analysts in developing innovative solutions to process-redesign tasks. The results of our study clarify the types of process-redesign ideas generated by analysts who work with text vs. those who work with models. We find that the volume and originality of process-redesign ideas do not differ significantly but that appropriateness of ideas varies. We discuss the implications of these findings for research and practice in process improvement.

Keywords: Process Innovation, Business Process Models, Business Process Reengineering, Creative Problem-Solving, Diagrams

Introduction

When analyzing and/or designing information systems, analysts frequently use process models to document and analyze current organizational operations. These models help business personnel understand the work domain and identify improvement opportunities in the business processes and related information systems [35]. This exercise typically involves developing process models that capture the current organizational reality and then giving them to analysts in the hope that the models will stimulate creative ideas about how the processes can be improved. However, whether process models actually assist analysts in their idea generation tasks, i.e., in finding innovative solutions for future processes, or limit them to narrow ways of thinking remains in doubt. This question is far from trivial. For example, some claim that process modeling focuses on the shortcomings of an existing solution, so model-based process innovation centers on overcoming existing problems rather than achieving inspirational new goals [69]. Others suggest that good process models can be an important determinant in process improvement success [41].

We study whether and how various ways of modeling organizational processes aid process innovation. We conceptualize process innovation as creative problem-solving, where analysts generate appropriate and original ideas for how processes could be redesigned. We draw on problem-solving and visual representation theory [e.g. 26, 43, 88, 91, 92] to hypothesize how textual and diagrammatic process models affect the creativity and type of redesign solutions. Then we report an experiment in which we tested our hypotheses.

Our study contributes to the extant literature in three primary ways. First, it adds to the body of knowledge on the use of process modeling in practice. The literature to date tends to explain how analysts *understand* visual models of organizational systems and processes [e.g., 53, 67] but not how the *use* of such models may influence the type and creative quality of ideas in process redesign initiatives. However, input to process redesign remains the main outcome expected from process modeling [35]. Second, our study contributes to the literature on process redesign [66, 81] by evaluating the types of creative solutions analysts generate by working with various types of process models. Third, we offer a new methodology for evaluating process redesign ideas in terms of their originality, appropriateness, impact, and locus of change.

For industry, our study provides an answer to two deceptively simple questions: Do the outcomes of process redesigns vary with the process models analysts' use? What type of representation format should analysts use based on the objective of process improvement?

Background

Our study relates to three streams in the literature: (i) how business process redesign is conducted and how creative problem-solving is part of these efforts, (ii) how information about organizational processes can be represented, and (iii) how process representations can act as stimuli for creative redesign. We discuss each stream in turn.

Business Process Redesign and Creative Problem-Solving

Business processes are sets of logically related organizational tasks that are performed to achieve defined business outcomes [17]. Organizations often document their business processes in order to understand where weaknesses and performance deficiencies in processes manifest and to generate ideas about how new processes, supported by existing or future information systems, could be enacted.

Process-innovation projects tend to unfold in a set pattern [40]: After a process-innovation project is initiated, the diagnosis phase begins with evaluation of a current process and its attributes. Information representations, such as semi-structured texts, process flowcharts, and other types of diagrams, are employed to capture information about the process [20]. In the subsequent redesign phase, analysts use these process models and creativity-support techniques like brainstorming to envision and choose among possible alternatives. In the reconstruction phase, changes to the process are introduced in the organization, and the new process is evaluated in the evaluation stage.

Our study addresses the redesign stage of process-innovation projects [40], particularly the generation of ideas about a current process in the form of a "future" process model. This task can address several components of a business process:

1. *Changing the control-flow components* of a process by, for example, cutting unnecessary, non-value-adding tasks or inserting additional tasks for quality assurance.
2. *Changing the technology component* on which processes operate by changing the systems, applications, tools, or infrastructure required to execute a process [7]. Examples include changes to manufacturing machines in a production process, the use of new tools and techniques in a decision process, and the use of different digital platforms for communication processes.
3. *Changing the organizational component* of a process by allocating process tasks to organizational actors [e.g., 94] or outside organizations [e.g., 47].
4. *Changing an information system component* of a process by changing how a process is enacted within it or supported by it [e.g., 86]. An example is implementing a workflow solution for supply chain processes [45].
5. *Changing the data component* of business processes by modifying how information is produced or consumed in the course of the process tasks [83] (e.g., through electronic patient records).

The literature on the process of redesign in process innovation, rather than the outcome of redesign, is sparse [66, 85]. Sharp and McDermott state [75, p. 323]: "How to get from the as-is to the to-be [in a process redesign project] isn't explained, so we conclude that during the break, the famous ATAMO procedure is invoked—And Then, A Miracle Occurs."

Since there is no widely accepted theoretical frame for the redesign phase, we conceptualize process redesign as the conjuring of creative changes to a business process, and process innovation as the actual implementation of these changes. Our distinction follows West and Farr [90, p. 10], who distinguish between creativity as "the ideation component of innovation" and innovation as "the proposal and applications of the new ideas."

Following this distinction, we can view process redesign as a creative problem-solving activity—that is, an activity that creates solutions that are both original/novel and worthwhile/valuable [80]. Process redesign as a creative problem-solving task involves three steps: idea generation, composition and evaluation [1]. Typically, a process problem is presented to analysts in the form of information about the current way of working and an objective to introduce changes or overcome issues like bottlenecks or quality concerns. Then analysts develop one or more redesign solutions to the problem, identify one preferred solution, and develop and implement the corresponding future process. Finally, the implemented solution is evaluated for its ability to meet the original objective.

Representing Information about Organizational Processes

To redesign processes to resolve issues, analysts require information about how the processes are currently executed. Current processes are documented using approaches that range from textual documentation, such as policy documents or even emails, to structured texts (e.g., in Excel spreadsheets) and visual approaches like flowcharts and formal diagrams. A global study of process-modeling initiatives in 130 companies [60] showed that 55.9 percent of the organizations documented their processes as text and 31.5 percent as tables. The most popular diagrammatic formats were Business Process Model and Notation (BPMN, 21.3%) and Unified Modeling Language (UML, 15.0%). Table 1 provides real-world examples of textual and diagrammatic representations of business processes used in education, research and industry. In these examples, the text format typically uses sentences and sub-sentences to describe the flow of work, whereas diagrammatic forms use markers like boxes, circles, and diamonds to illustrate the flow of work.

Table 1. Real-world Examples of Text and Diagrammatic Representations.

Sector	Examples
Education	Processes in textbooks about business process management usually provide both textual description and corresponding diagrammatic models [e.g., 21, Example 1.1 and Figure 1.6]. Other textbooks provide both diagrams and structured text models of business processes [e.g., 33, Figures 6.1 and 6.2].
Research	Many experimental studies involving models of business processes provide textual and diagrammatic models. For instance, textual and graphic models are used for the processes of: - creating a software solution [59] - providing financial services [65, p. 97 and p. 100] - providing room service in hotels [44, pp. 66, p.75].
Industry	Business process management information and material provided by industry associations typically include process models (e.g., reference models or best-practice models) both as textual descriptions and diagrams (e.g., system or flowchart diagrams). Examples include: - the American Productivity and Quality Center: http://www.apqc.org/pcf - the American Production and Inventory Control Society: http://www.apics.org/sites/apics-supply-chain-council/frameworks/scor - the Massachusetts Institute of Technology process handbook: http://process.mit.edu/Default.asp

Our study addresses whether and how the representation format—purely text and purely diagram—influences process redesign as a creative problem-solving activity. Because we are primarily interested in the existence and magnitude of the contrasts between representation formats, we consider these two opposing types of representation formats for a methodological reason and a theoretical reason. Methodologically, this choice allows us to focus on strong contrasts between the two end-points of the spectrum of representation formats, from textual to visual, in order to ensure instrumentation validity. To facilitate post-hoc analyses to examine the results' ecological validity, we define a control group that receives an intermediary format, structured text.

As for the theoretic reason, several studies have compared text versus diagram formats [e.g., 25, 59], including unstructured and structured text (such as those in use cases), and traditional diagramming notations, such as flowcharts or BPMN. These studies suggest that diagrammatic representations can help overcome working-memory limitations and improve information acquisition because knowledge put down in models as "external storage" need not be maintained in the working memory [6, 74]. For example, Gemino and Parker [25] found that participants' understanding improved when they had supporting diagrams in addition to textual descriptions. On the other hand, Ottensooser et al. [59] reported that readers' understanding of a process based on a diagrammatic model improved only when they were appropriately trained, while all readers, independent of formal training, profited from textual description.

Our choice is thus motivated by conclusion validity. While the literature reports on a variety of benefits of diagrammatic visualizations, results regarding the combination of textual and diagrammatic process descriptions remain inconclusive. Results also appear to depend on the application and task addressed in the research setting. Our interest lies in the differences between textual and diagrammatic representation formats specifically for the task of process redesign, so our study is situated in an information-processing task setting (e.g., using the information in a problem-solving task). Thus, it extends the prevalent focus of the literature on information acquisition (e.g., developing an understanding of a business process) to task settings [25, 59].

Next, we discuss theoretical viewpoints concerning how representation formats influence process redesign as a creative problem-solving activity.

Process Representations as Stimuli for Creative Redesign

The environment in which a creative design activity takes place can affect the creative performance. McCoy and Evans [49] demonstrated that environmental characteristics like highly complex visual detail and naturalness, may positively influence creativity. In addition, creativity-enhancing techniques like creativity-support systems use external stimuli/triggers to inspire designers in searching design and solution spaces [46]. Such stimuli may be inspirational, support analogical creative problem-solving, and/or help designers to structure mental representations of the problem domain.

The effect of the format of a process representation as a stimulus to trigger creativity in process redesign tasks is particularly important because the representation format may significantly affect the quantity and quality of creative ideas [11]. One likely reason for this effect is related to the effort required to do creative problem-solving, which, similar to other information processing tasks, is constrained by the limits of the working memory [72]. Bilda and Gero [6] demonstrated that, designing blindfolded instead of sketching had a negative effect on idea generation because of the attendant demand on working memory.

It is likely that the demand on working memory during creative problem-solving differs with the process representation format. One stream of the literature suggests that visual representations may be best suited to idea generation tasks related to processes because diagrammed process models may have lower working-memory demands than textual representations do. Working memory provides separate subsystems for storing and manipulating visual and verbal information for cognitive tasks [2]. Purely verbal text involves only one system, while two systems are involved with diagrammatic process models– including visual (symbols and syntax of the modeling language) and verbal information (activity labels). Visual process models may use directed edges ("arrows") to depict the process flow and visualize the relationships among the model's elements, leaving more working memory for idea generation, leading to more and better redesign ideas.

Other research suggests that visual models may support retention of information and their use in problem-solving better than textual models do [48] because "cues to the next logical step in the problem may be present at an adjacent location" [43, p. 65]. One piece of relevant information is located near other relevant information.

Process models may also be closer than text is to the structure of internal human semantic memory (networks with nodes and pathways) [13]. Glenberg and Langston [26] demonstrated that simple process diagrams assist in building mental models because their visual structure is similar to that of the mental model. Therefore, ideas could be generated that are semantically close to the problem at hand.

However, a second stream of research suggests that process models may hinder the development of truly innovative solutions [69]. Diagrammatic and other visual representation formats may evoke fixedness and result in problem solutions that are too similar to the original representation. According to Sarkkinen and Karsten [73, p. 184], "Visual representations are likely to constrain discussions more than verbal representations. Talk and written language construct rather abstract versions of the subject matter, leaving it open to various interpretations. […] A software process diagram with a strict notation constrains the audience's imagination more than, for example, a quite freely drawn rich picture diagram."

Finally, stimuli may influence not only the *quality* and *quantity* of ideas but also the *types* of ideas generated in a creative task. The desired outcomes of process redesign can affect any of the components of a business process—control flow, information systems, data, technology, organizational resources, and so on. Process redesign ideas may address any of these components, depending on the activation cues in the information material. These cues act as anchors upon which analysts can fixate when they generate ideas. For example, visual examples are known to constrain idea generation because designers tend to conform to such examples. Jansson and Smith [37] demonstrated that both students and experienced engineers in a creative problem-solving task tended to become fixated on a particular type of solution when shown a picture of a suboptimal design along with a textual description.

The root cause of the effect of information representation on types of ideas can be found in the associative theory of creativity [50]. This theory states that stimuli facilitate specific cognitive associations when people are creating new ideas because different stimuli activate different concepts in the knowledge structure. This idea is supported by the theory of spreading activation [14], which proposes that activation of one concept in the internal semantic knowledge network in long-term memory spreads to concepts in the neighborhood. Activated concepts are transferred to working memory and may influence idea generation, so diagrams may generate different ideas than text does. As process diagrams are used in the context of information system development, designers' exposure to them might generate redesign ideas in that realm. For instance, process diagrams highlight the flow of work through arrows and rectangles, so analysts exposed to these diagrams may focus primarily on control flow instead of, say, organizational resources in their ideas about process redesign. It is unlikely that such a thematic fixation would occur with textual representations because of text's prevalence in everyday life.

In conclusion, while there is some evidence that visual process representations are more effective than text as a cognitive aids in creative process redesign, there is also evidence to the contrary. Table 2 summarizes the studies discussed here and the relevant implications for our study.

Table 2. Summary of Literature on Representation Formats and Creative Problem-solving.				
Reference	**Independent Variable**	**Dependent Variable**	**Summary of Study**	**Implications for this Study**
Comparison Studies				
[46]	Use of words vs. pictures (e.g. a photograph of a cake) vs. pictures and words as stimuli	Open-ended idea generation for new ice cream flavors. (Creativity score was based on judges' ratings of ideas' novelty and feasibility.)	The independent variable had no effect on the number of ideas, but picture stimuli lead to more creative ideas than words or the combination of words and pictures. Word stimuli might lead to inappropriate "design fixation."	Visual representations of processes might lead to different and increasingly creative—, but not more—process redesign ideas than textual representations do.
[31]	Pictorial and textual (cyclone) distant stimuli	Open-ended generation of ideas about transportation in 2050; drawings with short descriptions (fluency, originality ratings, and type of ideas)	The textual condition outperformed the pictorial condition in terms of the number and originality of ideas. The authors argue that text is underestimated as an inspirational source and that pictures can both stimulate and hamper creativity. Both conditions triggered various categories of ideas. This was also explained with a recency effect (focus on last words of a text).	Counterargument to [46]: Textual representations might lead to more original redesign ideas. Empirical testing will be required to determine which of the two hypotheses hold for process redesign. In addition, textual representations might lead to different types of ideas than visual representations do.
[8]	Pictorial and textual stimuli and a control group without stimulus	Design of a device to pick up a book from a shelf that is out of reach (as many designs as possible)	Neither pictorial nor textual stimuli affected the number of ideas. The pictorial stimuli led to ideas similar to the example (fixation effect), while text led to no more fixation than in the control group.	There might be no discernible difference between representation formats in terms of the number of ideas, but visual process representations might lead to process redesign ideas that are less appropriate than textual representations do.
Studies of visual stimuli only				
[79]	Designs with and without pictorial examples, with textual labels	Open-ended generation of ideas for new toy creatures (sketching and labelling)	The ideas generated conformed closely to the examples presented, and their originality was constrained [79].	Visual process representations might lead to unoriginal process redesign ideas that are also less appropriate.
[37]	Designs with and without pictorial examples	Ill-defined mechanical engineering tasks (as many designs as possible)	Design fixation occurred in the experimental groups that were provided with the pictorial example (conformance to stimulus, reusing parts of the example even when inappropriate).	Visual process representations might lead to inappropriate process redesign ideas.

[9]	Pictures (photographs and architectural drawings) with and without the instruction to use visual analogy	Solving ill-designed architectural design problems (one solution)	Pictorial representations stimulated design solutions even when participants were not explicitly instructed to use visual analogies.	Visual process representations might lead to process redesign ideas that focus on the visually highlighted elements (notably control flow).
Studies of textual stimuli only				
[28]	Designs with and without textual examples	Design of a chair for children or a desk clock (one solution)	Text stimuli led to a higher level of originality than no stimuli did, but practicality was not affected.	Textual process representations might lead to process redesigns that are more original but not more appropriate.
[30]	Textual stimuli with differing levels of abstraction (related, distant – a book excerpt, unrelated text) and control group without stimulus	Open-ended generation of ideas for transportation in 2050	The “appropriate” abstraction level–the distant text—led to a higher number of flexible (ideas in slightly different categories) and more original ideas.	Textual process representations might lead to different types of process redesigns and to ideas that are more original if they have an appropriate abstraction level.
[82]	Designs with and without textual stimuli	Sketching and describing one idea for a chair	Text led to a higher number of creative ideas, and more possibilities were explored, but the overall creative quality did not increase.	Textual process representations might lead to more process redesign ideas, but the ideas might not be more original.

We position our research as follows. Our dependent variables contrast those of prior experiments. Most studies have measured creativity in terms of the number of ideas, raters’ creativity scores, and categorized types of ideas. To these measures we add a process redesign-specific categorization of ideas that capture the wider context of a business process. Most experiments have included open-ended divergent idea/solution-generation tasks for ill-defined design problems of various subject areas in which participants wrote or drew either one solution or as many solutions as possible. While the results of prior studies on design activities can be generalized (to some degree) to generating process redesign ideas, we use a specific categorization so as to ensure that the domain specificity of creativity is included [93]. Our study also differs from extant research in terms of the independent variable, as we use diagrammatic process models to compare to textual models, rather than the pictures, photographs or sketches prior studies have used. Another difference is that we present the problem setting, rather than example solutions, in textual/visual form. Finally, our literature review suggests that clarification is required to resolve inconsistencies. As Table 2 shows, the literature reports both positive and constraining effects of textual and pictorial/visual stimuli on idea generation and that textual representations alone may evoke creative ideas, but not always. Determining whether and how process redesign is affected by textual representations, which are a dominant form of process information in practice, can clarify which representations to suggest for redesign projects. A final verdict on this matter requires an empirical analysis.

Research Model

The debate about the relative merits of information representation formats, together with the dearth of empirical research on idea generation in process-redesign tasks, indicates the absence of theory with which to structure our empirical study. Therefore, we follow a scientific exploratory approach, rather than a purely confirmatory approach. To guide this investigation, we first develop a framework that describes the elements to be included in an empirical research design. Next, we develop two sets of hypotheses with which to investigate the effects of representations of business processes on readers' ability to perform creative problem-solving tasks by generating process-redesign ideas. Figure 1 shows the research model that frames our empirical study.

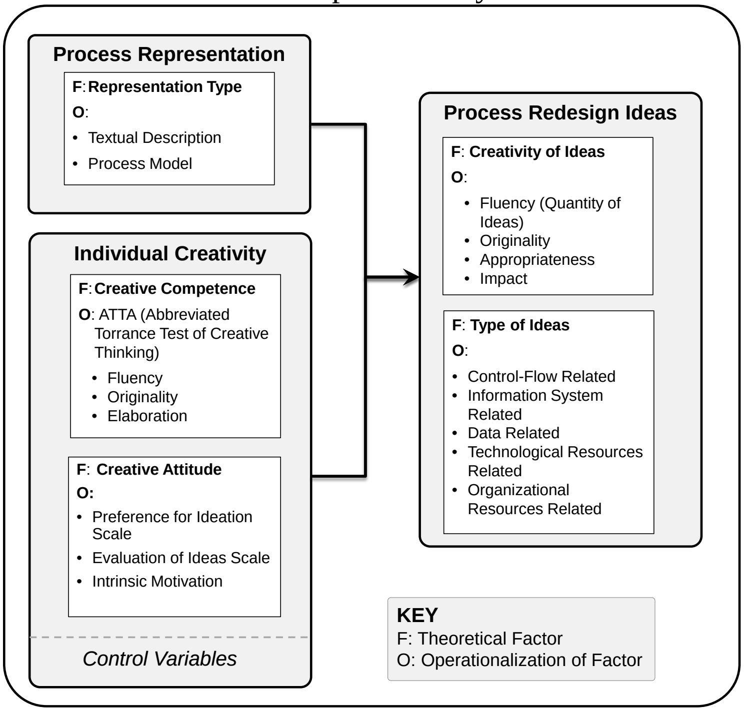


Figure 1. Research Model.

The model shown in Figure 1 frames our primary research interest: the influence of the type of process representation on the *creativity* and *type* of the process-redesign solutions. Based on findings in the literature on how individual characteristics relate to creative problem-solving processes, the model acknowledges the relevance of the individual as a creative person by using creative competence [16] and creative attitude [4] as control variables. Table 3 provides construct definitions for all factors in the model and lists the literature on which the definitions were based.

Table 3. Construct Definitions.

Construct	Definition	Relevant literature
Creativity of process redesign ideas	The number and quality of ideas that are novel and purposeful and that provide an effective solution	[19]
Type of process redesign ideas	The component of a business process that is addressed by the process redesign idea: - control flow (the sequence and order of tasks) - information system (the application software in use in the process) - data (information consumed or produced in the process) - technological resources (technology required to execute the process) - organizational resources (organizational actors involved in the process)	New construct based on theories of control flow components [87] and the wider context of a business process [70]

Type of process representation	The textual or visual notation used to convey information about a business process, including the available graphic or textual symbols and the relevant compositional rules	[59]
Creative competence	The individuals' creative thinking competence in terms of fluency (number of ideas), originality (novelty of ideas), and elaboration (embellishment of ideas with details)	[16, 27]
Creative attitude	The individuals' attitude toward creative problem-solving tasks in terms of intrinsic motivation, preference for ideation, and tendency for premature critical evaluation of ideas	[4]

Based on our model, we present two sets of hypotheses that describe our expectations about the effects of a type of representation in a process-redesign task on the solutions conceived in this task. First, we explore whether the quantity and quality of process-redesign solutions varies. While the literature on the effects of textual and visual stimuli on idea generation has shown both enabling and inhibiting effects of both types of representation, several arguments suggest visual descriptions of process models may be superior to textual descriptions. Research has shown that diagrammatic representations can improve understanding of a business process if readers are sufficiently familiar with the diagrammatic notation [59], as the spatial arrangement of information in diagrammatic models improves information search and reduces the need to store information in the working memory [92], leaving capacity for finding creative solutions. Therefore, we expect that diagrammatic process representations lead users to create more and more creative solutions to the process-redesign task. The creativity literature has typically differentiated the number of solutions (fluency of ideas) found in a creative problem-solving task from their quality (originality and appropriateness) [19]. Accordingly, we suggest:

Hypothesis 1a. Users of diagrammatic process representations develop more solutions to the process-redesign problem than do users of text process representations.

Hypothesis 1b. Users of diagrammatic process representations develop higher-quality solutions to the process-redesign problem than do users of text process representations.

Second, we suggest that the type of process redesign solutions varies. We speculate that textual and diagrammatic process representations activate different kinds of knowledge in the long-term memory, thereby spreading to concepts in different "neighborhoods" of the memory [72]. The difference in the "neighborhoods" is important because the resources that process redesigns require can differ. Organizations typically require to document various resources in their process representations: aside from the sequence of tasks in a process (i.e., control flow components), Patig et al. [60] found that information (i.e., data components), personnel (i.e., organizational components), software (i.e., information systems components) and machines, material, and applications (i.e., technology components) are the process resources listed most frequently.

Which of these resources a process-redesign solution requires depends on the information provided to the analysts because different representations highlight these resources in different ways. For example, if a representation conveys nothing about, say, the software a process uses, then it is unlikely that process redesign solutions will address this component. By contrast, if the representation draws attention to the actors involved in a process, then analysts are more likely to consider solutions that focus on organizational components. Therefore, we suggest that the type of process representation influences the types of process-redesign ideas.

There is no strong theory with which to speculate ex ante which type of process design will feature prominently in process-redesign solutions, but our understanding of the literature leads us to believe two effects will occur. First, we expect that analysts who work with diagrammatic process representations generate more ideas that focus on improving a process's control flow components than other components because the most prominent feature of visual process diagrams is the logical and temporal sequence of activities using boxes and arrows. The spatial arrangement of the predecessor-successor relationships between tasks is likely to facilitate more efficient information processing than does neutral text, where the mind must first identify the activities (e.g., by finding verbs in the text) and then infer their temporal and logical relationships from the text [48]. This added complexity is likely to reduce the amount of working memory available to focus on generating creative solutions. Therefore, we posit:

Hypothesis 2a. Users of diagrammatic process representations develop more process redesign solutions that feature control flow components than do users of text process representations.

Second, we expect that analysts who work with diagrammatic process representations will generate more ideas that focus on improving the organizational resource components of a business process than other components. In visual process diagrams, organizational resources are often modeled using swim lanes, which allow the easy identification of the number of actors involved and their various responsibilities in executing the process [5]. These spatial arrangements are not present in text, so the identification of actors and their roles requires careful reading of the text, which consumes working memory and leaves less for generating ideas. Therefore, we expect:

Hypothesis 2b. Users of diagrammatic process representations develop more process redesign solutions that feature organizational resource components than do users of text process representations.

These two sets of hypotheses help us to evaluate empirically a longstanding assumption about the beneficial use of diagrammatic process representation formats in process-redesign projects–that is, *whether* and *how* types of process models assist analysts in process improvement.

Method

Design

We conducted an experiment to provide evidence about the impact of process models while controlling for other factors. Our research design was motivated more by internal validity than by external validity. We used a controlled repeated measures design with one primary between-groups factor, two covariates and one within-group factor.

The between-groups factor, type of process representation, had three levels: (a) a textual and (b) a diagrammatic representation of information about a pizza-delivery process (Figure 2) and (c) an intermediary representation format "structured text" [88]. The "structured text" group helps us to differentiate the main results from those from a third experimental group for manipulation-check purposes so we can distinguish the factors that cause the differences between text and diagrams (particularly structure vs. use of symbolic vocabulary). Structured texts introduce only structure but no symbolic vocabulary and resemble the process descriptions that are available in tables, which is a third common representation format used in industry [60]. Figure 5 in Appendix A depicts the "structured text" treatment. We report on this data in a post-hoc analysis of the main results below.

Congruent with our research model, we included two types of control variables in the experiment–creative competence and creative attitude—described in the section "Post-Test Evaluation" below.

The within-groups factor, trial, had three levels, operationalized as three creative problem-solving tasks with differing process-improvement objectives. The purpose of multiple trials was to strengthen the external validity of the findings by examining task solutions across three process-redesign objectives.

We employed two categories of dependent variables. First, we measured the solutions' creativity in terms of fluency (number of ideas), appropriateness, and originality, as is common in the creativity literature [e.g. 27], and in terms of their impact [62]. We added the impact dimension in order to relate creative problem-solving solutions back to the original business objective of changing a process (thus to differentiate process redesign solutions that are truly relevant to the business from other creative solutions). Measuring fluency addresses hypothesis 1a, while the other measures relate to hypothesis 1b.

Second, we used a measure we developed for the type of solutions in terms of the locus of change, that is, as affecting the control flow, information systems, or the organizational, technological, , or the data component of a business process. This measure relates to hypotheses 2a and 2b.

Participants

The goal of our study was to ascertain whether different process representation formats would lead to differences in process re-design solutions produced by novice analysts. The population of interest to our study thus consists of business users of process representation formats that would be involved in process-redesign activities. This business cohort is thus wider than BPM practitioners alone, whose tasks typically consist of describing a process in a particular representation format (i.e., process modelers), as it includes process managers, analysts, and domain experts, many of whom do not have method experience [20].

Following recommendations for sample selection [15], we recruited university students from a business school as proxies for future end-users of process representations who have at least some knowledge about business domains and business-process management. Students are also less likely than experienced (and difficult to recruit) practitioners to vary in their knowledge about and experience with modeling methods, creativity, and innovation management. A particular advantage of using a novice sample is that they have not been "brainwashed" into a particular format through years of experience with process-representation formats as industry experts would be; thus, we minimized the chance of bias [23].

Participation incentives included access to a copy of the summarized study results and €15 cash. We used a balanced block-randomization strategy with blocks of variable length to assign the120 students who volunteered to participate in the experiment to the three experimental groups.

Materials and Procedures

We used a paper-based experimentation system. The experiment took place in a daylight computer lab, into which students were invited in lots using the balanced block randomization strategy. Appendix A includes the experimental material used except for the test used to measure creative competence and the scales used to measure creative attitude due to copyright restrictions.

Experimental Tasks

We asked participants to analyze and redesign a business process for a pizza-delivery service business process. We chose this process because it is widely understood and requires little specialized knowledge. We could safely assume that all student participants had some knowledge of pizza delivery from a consumer perspective. We created the process scenario based on a simplified version of the pizza-delivery example given in the BPMN 2.0 standard [57].

All participants were provided with a process description of the pizza-delivery service, either as a textual description or as a diagrammatic process model. The process descriptions for the three experimental groups were created to contain the same information, although the representation format varied (text, diagram, or structured text).

In creating these representations, we started with the text and diagram representations of the process in [58] and then amended them to ensure the information provided in each was equivalent.

The unstructured text uses full sentences (e.g. “the pizza chef checks the oven temperature,” “the delivery person gives change”), which we adapted for the diagram and structured text representations to match established verb-object style conventions [52] (e.g. “prepare dough,” “give change”). In addition, we used vertically arranged swim lanes to group process activities carried out by an actor (pizza costumer, clerk, pizza chef, delivery person), so each actor is mentioned only once, as the label of a swim lane. Next, we replaced textual terms in the unstructured text that indicate the activities’ tempo-logical flow (e.g., “first,” “then,” “next”) with spatial-visual placements in the structured text and with symbolic vocabulary in the diagram [58]. By superimposing printing techniques, we used the same visual layout in the structured text condition that was used in the process diagram but used symbols (routing symbols, start and end symbols, as proposed by BPMN [58]) in the process diagram but pseudocode identifiers (e.g., “Begin,” “If,” “Terminate,” Endif,” “End”) in the structured text [91].The visual process diagram also uses edges to visualize the flow of the process and boxes to visualize the swim lanes. Aside from these changes, we held other variables constant over all three representations to facilitate fair comparison and minimize confounding. All textual elements were set to the twelve-point Arial font, with the representations spanning the width of an A4 page. (Textual description was justified). Finally, we kept the reading direction uniform (left-to-right and top-to-bottom). Figure 2 shows the final text and diagram representations of the pizza-delivery process. The structured text version is provided in Figure 5 in Appendix A.

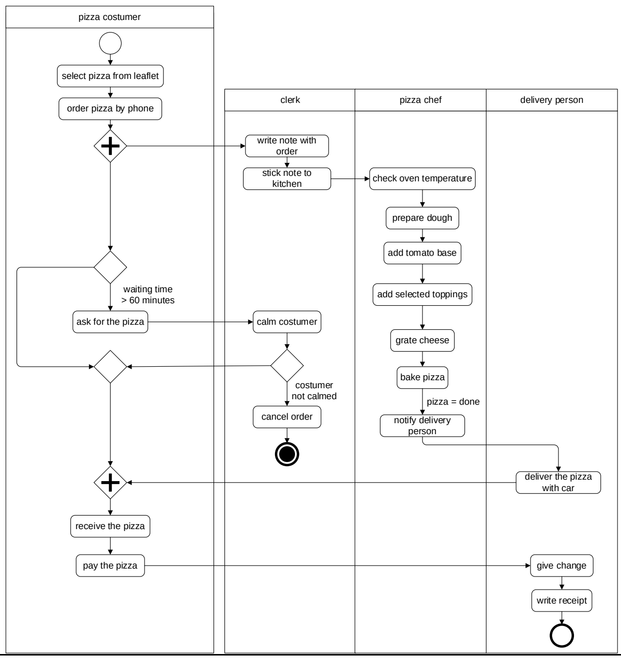
Textual Description of Process	Visual Process Diagram
First, the pizza customer selects a pizza from the leaflet and orders the pizza by phone. The clerk writes a note with the order and sticks the note to the kitchen. Next, the pizza chef checks the oven temperature, prepares the dough, adds tomato base, adds selected topics, grates cheese and bakes the pizza. If the pizza is done, the chef notifies the delivery person. If the waiting time for the pizza customer is longer than 60 minutes, the customer asks for the pizza and the clerk calms the customer. If the clerk is successful at calming down the customer, the client will receive their pizza eventually. Otherwise, the clerk cancels the clients' order and the process terminates. After baking the pizza, the delivery person delivers the pizza by car. Then, the pizza customer receives the pizza and pays for the pizza. Finally, the delivery person gives change and writes a receipt.	

Figure 2. Representations of the Pizza-Delivery Service Process.

Because we wanted to eliminate potentially confounding effects of model complexity [64], we ensured that the chosen business process was represented in a moderately complex, rather than a very simple or very complex, manner. To gauge the level of complexity, we compared the pizza example to the complexity of an average model in the collection of 1400 practitioner models reported in [42], using the complexity metrics defined in [51]. Our case contains more arcs than an average model (28, or 158%) and nodes (27, or 221%) and maintains an approximately average connector degree (3, or 92%). Therefore, it lies between a low-complexity models and a high-complexity model [64]. Its number of tasks (19 vs. 19.1) is similar to the processes examined in [60].

With each participant using one of these three process representations, participants worked on three open-ended problem-solving questions. The objective of these tasks was to identify areas of improvement to the process in terms of efficiency and effectiveness gains, in alignment with a specified process objective. Because of the high-level nature of the process descriptions, participants had to make some appropriate and probable assumptions about the business case.

To avoid mono-method bias in the creativity assessment and determine whether noted effects would differ or be consistent across differing task settings, we used three tasks to measure creativity as the trial levels in our experiment (Table 4). All three tasks focused on idea generation for process innovation. We designed these tasks to allow for variation in the salience of process-improvement ideas and to cover differing approaches to process innovation. Following Shtub and Karni [76], we chose three tasks, corresponding to three types of process innovation procedures (Table 4).

We designed Task 1 as an improvement-invoked procedure, which Shtub and Karni [76, p. 222] indicated requires that designers be cognizant of the improvement objective. We implemented this requirement in the instruction that customers know at all times when their pizzas will arrive.

We designed Task 2 as a pattern-invoked procedure. Specifically, we included pattern no. 26 ("increase the number of performers carrying out a process" [see 76, p. 223]) in the description by asserting that a new employee would be available to assist in the process.

Finally, we designed Task 3 as a measure-invoked procedure: we included in the task description a specific process-quality metric (cost) and the associated objective (cost reduction), thereby adhering to the objective of upgrading process performance in terms of cost, quality, time, or flexibility [76].

Table 4. Idea-Generation Tasks.

Task 1	Improvement-invoked	"The pizza-delivery service wants to improve its processes, so that customers know at all times when their pizza will arrive. How can the process be changed to implement that improvement? Provide as many options as you can think of."
Task 2	Pattern-invoked	"The pizza-delivery service gets a new employee. How could the employee be used most effectively to improve the process? Provide as many options as you can think of."
Task 3	Measure-invoked	"The pizza-delivery service wants to cut down costs. How could the process be changed to most effectively reduce costs? Provide as many options as you can think of."

Result Coding

Three research assistants coded the creativity of process redesign ideas. All had experience in business process management—either through university education or job experience—as well as experience as data coders for research projects and familiarity with the domain of the model from a consumer perspective (ordering pizzas). The research assistants, who were unfamiliar with the purpose of the study, scored all ideas according to a pre-developed coding schema. Instead of relying on a general creativity score, we defined four attributes of creative performance that are predominantly used in creativity research—fluency, originality, and appropriateness [55, 62]—plus impact [62]. To this we added our self-developed categorization of the type of process improvement idea ("the locus of change"). Table 5 summarizes the rationale and the construct definitions for the four dimensions of creativity. We gave the coders an explanation of each dimension and examples (e.g., "using a tissue as a napkin" is less original than "using tissues to make a costume for the next Halloween party (e.g., ghost or fairy)"). Coders rated the dimensions on a five-point scale (whereas 1 = not at all appropriate, 3 = medium appropriateness, and 5= very appropriate), with the exception of fluency, which was coded as the number of solutions provided. The final coding schema is shown in Appendix B.

Table 5. Measurement of Creativity of Ideas.

Attribute	**Measurement**	**Definition**	**Rationale**
Fluency	continuous scale	The number of relevant ideas provided.	This attributes measures ideational fluency as the number of semantically different ideas [32].
Originality	5-point scale (where 1 = not at all original, 3 = medium originality, and 5 = very original)	Something that is original, unexpected, and novel [19].	Originality is the attribute most often used in divergent creativity tests [55] and the most commonly mentioned attribute of creativity [71]. It is defined as resulting in "ideas that are not only rare but that also have the characteristic of being ingenious or imaginative" [19, p. 659].
Appropriateness	5-point scale (where 1 = not at all appropriate, 3 = medium appropriateness, and 5 = very appropriate)	Something that is useful, meets task constraints, and is purposeful.	Appropriateness "refers to the extent to which a proposed solution can satisfy the demands posed in a problem context" [93, p. 31] and determines whether a solution makes sense in its context [36].

Impact	5-point scale (where 1 = no positive impact at all, 3 = medium positive impact, and 5 = very positive impact)	The positive tangible and intangible effects (consequences) of one entity's action or influence upon another.	Impact refers to the benefits that can be derived from implementing a proposed solution—that is, the profit or gain in terms of monetary and/or non-monetary advantages (e.g., in terms of cost or time savings, increased customer or staff satisfaction, or other criteria). The impact or influence of a creative idea differs from its appropriateness and "indicates the extent to which an idea changes a particular domain" [62], which is particularly applicable to the task of innovating a business process.

All coders were instructed on the coding schema, and several iterations with sample data from the participants were used to increase familiarity with the process and the definitions. Once the coders were sufficiently familiar with the criteria and the process, they eliminated responses that were clearly unrelated to the situation (e.g., "costumer called the wrong pizza service"). Three such answers were eliminated. Then they coded all remaining responses against the coding scheme, scoring each response independently. Next, they met to discuss their ratings, which led to revisions to the individual interpretations of the coding scheme and revisions in scoring. This iterative process was repeated to eliminate inconsistencies in the ratings and ensure the reliability of the coding. Therefore, by design, the inter-rater reliability was 100 percent. Table 6 provides illustrative solutions and their final coding.

Table 6. Sample Solutions for Task 1: The pizza-delivery service wants to improve its processes, so that customers know at all times when their pizza will arrive. How can the process be changed to implement this improvement?

Originality (Low, 1)	• Tell them to set an alarm clock.
Originality (Low, 2)	• Promise that the pizza will be delivered in a certain number of minutes. • Oven temperature display near phone.
Originality (High, 5)	• Webcam in the kitchen with livestream. Pizzas get name cards and can be observed while baking. • On the internet there might be an "avatar" chef, etc., where customers can watch a cartoon about the process while waiting: Chef preparing pizza - oven - baking - street delivery. The moment the cartoon delivery person rings the bell, the real one will be there.
Appropriateness (Low, 1)	• Have multiple locations around the city, making the delivery quicker. • Prepare the grated cheese in advance. • Pizza chef and delivery person regularly visit doctors as a precautionary measure. • Keep pizza oven turned on continuously.
Appropriateness (High, 5)	• Each order gets a barcode number. The clerk can then scan it and pass it to the kitchen. The chef scans it when he or she starts to cook, then when it's in the oven, and again when the delivery person gets it. On the website, the customer can look up in which production stage the pizza is now. • GPS-tracking of the delivery car so the customer can watch online where it is right now, see when the pizza is done, etc.
Impact (Low, 2)	• Calculating more time as is needed, so the customer knows before. • Very simple estimation by average times. • An "all for one" option: every pizza is delivered by half an hour after an order is placed. • Customers can order pizza in advance for delivery at a particular time.
Impact (High, 5)	• The pizza-delivery service could buy or order software for the delivery cars that the customers can watch online. At any time the customer could follow the car coming to him or her. Every car could have a number and an option for showing the estimated time until it reaches the target (the customer) • Use web facilities (separate login, where customers can track the status of their pizzas → leads to more playful engagement, where customers can view their pizzas' progress (computer animation of process) from baking to delivery. Delivery will be visualized via GPS sensors on a map so the customer is always informed about the status and location of his or her pizza.

- **Type of process improvement idea (locus of change):**

We also measured the key focus of the proposed improvement solutions—that is, the process component that a solution primarily addressed. Table 7 shows how we coded example answers given for task 3 (cutting costs).

Table 7. Sample Answers for Types of Process Improvement Ideas.

Type	*Characterization*	*Example Answers*
Control flow	the nature, sequence and order of the tasks to be executed in a pizza-delivery service (e.g., prepare dough, bake pizza, select toppings)	• "Take out as many pizzas at the same time as possible (no half empty deliveries!)" • "Receipt-making in the restaurant →saves time" • "The delivery person should be informed before the pizza is ready"
Organizational resources	the staff involved in the pizza-delivery process (e.g., delivery person, pizza chef)	• "Pizza chef is replaced by another cook less well educated – cheaper" • "Cut salary for employees" • "Outsource clerk call center to low-wage country" • "Clerk is let go and pizza chef takes orders as well"
Technological resources	the tools and infrastructure involved in the pizza-delivery process (e.g., oven, fridge, car)	• "Invest in an automatic pizza oven that always has the right temperature, can take more pizzas, and knows when a pizza is ready" • "Delivery by bike on smaller routes"
Information system	any computerized system that might be involved in managing information about the pizza-delivery process (e.g., online ordering system, short messaging services, pizza status dashboard, electronic payment system)	• "Automatic clerk system (standard answers, voice recording of orders)" • "Electronic order service - voice recognition - clerk is not needed, information automatically forwarded to chef" • "Replace the leaflets with a website where you can also place the orders" • "Switch to internet-based order system instead of the phone. More orders can be taken at one time and easily monitored by the clerk. More orders → more pizzas sold"
Data	any input or output information required or created in the pizza-delivery process (e.g., recipe, pizza orders, etc.)	• "Discounts for orders with more than five items" • "Add minimum order-value" • "A higher minimum of the order value"

Post-Test Evaluation: Demographics, Modeling Experience, Creative Competence and Creative Attitude

We collected demographic data and data on task-related (participation in process-improvement initiatives) and domain-related (i.e., ordering pizza as a customer) experience and on experience with process models (how many process models participants had read or created) and let them rate their work intensity with process models on a 5-point scale (from never to always). We also used the three-item process-modeling familiarity scale from Recker [63] to measure their perceived familiarity with process model diagrams.

The participants' last task measured creative competence and creative attitude. This task came last to avoid task-order bias because instruction to be creative can influence creative output [56]. To measure creative competence, we relied on the shortened version of the Torrance Tests of Creative Thinking (TTCT), a widely used instrument [e.g., 10] that measures divergent thinking abilities and assesses the quantity and quality of creative ideas [12]. The test includes verbal and figural subtests, and the scores in the test are based on fluency (number of ideas), originality, and elaboration (the amount of additional details). Two psychologists who had the knowledge and skill required scored the TTCT. The use of certified professionals for psychological test administration is also a legal requirement in Austria, where the study took place. In addition, we wanted to comply with the American Psychological Association's standards for test-user qualifications [84].

We employed three scales to measure creative attitude: the "preference for ideation" scale [4] with the example item "One new idea is worth ten old ones," and the "tendency for premature critical evaluation of ideas" scale [4] with the example item "Quality is a lot more important than quantity in generating ideas." We measured intrinsic motivation to perform the process-redesign activities using items from Davis et al. [18]. Together, these three scales provided a meaningful evaluation of the respondents' creative attitudes.

Results

Data Screening

In examining the data for outliers, we excluded participants who were not currently enrolled in business administration or had already completed a degree in that field because business students score differently on creativity tests than other students do [22]. A variation in areas of study could introduce an experimental bias.

Four participants indicated that they had participated in more than ten process-improvement initiatives, while the rest of participants had participated in five or fewer, so the original sample size of 120 was reduced to 108 to achieve homogeneity. Table 8 summarizes the demographic statistics, including those for the structured text group that we used for a post-hoc analysis of the results.

To screen for differences among the three experimental groups, we computed appropriate statistical tests, shown in Table 8. The results did not suggest significant differences, with the exception of domain-related experience, where the participants who worked with a diagrammatic representation of the process had, on average, less experience ordering pizzas than the other participants did. We did not anticipate any result bias because of this demographic difference.

Table 8. Participants' Demographic Data.							
	Text (n=36)		**Diagram (n=35)**		**Structured Text (n=37)**		**Statistical Test**
	M/ Count	SD/ Percentage	M/ Count	SD/ Percentage	M/ Count	SD/ Percentage	
Age	25.03	3.54	23.43	2.78	24.73	3.57	$T_{df=105}$=-2.32 p=0.10
Gender Male Female	 19 17	 53% 47%	 12 23	 34% 66%	 20 17	 54% 46%	$X^2_{df=1}$=2.51; n.s.
Highest degree completed High school One or more years of university Bachelor' degree Master's degree	 5 24 4 3	 14% 67% 11% 8%	 6 22 6 1	 17% 63% 17% 3%	 5 20 8 4	 14% 54% 22% 11%	$X^2_{df=3}$=3.51; n.s.
Work intensity with process models (5-point scale)	2.72	0.62	2.83	0.89	2.59	0.60	$T_{df=105}$=0.98; p=0.38
Number of models created or read	4.39	4.51	7.29	10.80	4.24	6.15	$T_{df=105}$=1.82; p=0.17
Familiarity with BPMN process model diagrams	0.33	0.80	0.27	0.66	0.17	0.48	$T_{df=105}$=0.57; p=0.57
Task-related experience (participation in process-improvement initiatives)	0.67	1.29	0.74	1.67	0.73	1.43	$T_{df=105}$=0.03; p=0.97
Domain-related experience (pizzas ordered)	39.31	44.82	17.54	16.32	41.46	51.61	$T_{df=103}$=3.73; p=0.03

Next, we performed manipulation checks, described in Appendix C. Given the results from our manipulation checks, we performed several supplementary analyses to determine the influence of gender, domain experience, and task order. These analyses are summarized in Appendix D.

Finally, we examined our multi-item scales for reliability and internal consistency. The scale used to measure familiarity with process diagrams, adopted from [63], the scale used to measure the tendency toward premature critical evaluation of ideas [4], and the scale used to measure intrinsic task motivation [18] had Cronbach's alpha coefficients of 0.92 (familiarity with process diagrams), 0.76 (tendency toward premature evaluation of ideas), and 0.92 (intrinsic motivation), indicating sufficient reliability and internal consistency. The preference for ideation scale [4] had a Cronbach's alpha of 0.45, indicating a lack of reliability, so we eliminated this factor from all subsequent analyses.

Hypothesis Testing

Data analysis was performed using SPSS Version 20. To identify differences between the main experimental groups ("diagram" and "text"), we performed analysis of covariance (ANCOVA) for repeated measures tests, with the treatment (text or diagram) as the independent variable for each dependent variable (fluency, appropriateness, originality, and impact of a future process; number of control flow-/ information system-/ data-/ technological resources-related ideas) in all three creativity tasks. To determine which measures of creative competence and creative attitude to include in the analysis as covariates, we first checked to see whether any of these control variables had a significant linear correlation (see Appendix C2) with any of the dependent measures (indicating that they needed to be controlled). We retained one measure for individual creativity competence (fluency) as a covariate for three of the eight ANCOVAs with repeated measures.

While intrinsic motivation was not significantly correlated to the dependent variables, it was generally high, averaging 5.46 (SD=1.27) on a 7-point scale. Therefore, the participants considered the tasks to be enjoyable, which was likely to spur creativity.

Hypotheses 1a and 1b

Hypotheses 1a and 1b suggested that solutions proposed by diagram and text users would differ in terms of creativity (viz., fluency for hypothesis 1a and originality, appropriateness, and impact for hypothesis 1b). Results from our ANCOVA for repeated measures tests are summarized in Table 9. Significant main results (at the p=0.05 level) are highlighted grey. Results on the influence of the covariates and interaction effects are only reported if significant. Where the assumption of sphericity was violated, we report Greenhouse-Geisser corrected values. Figure 3 presents the results graphically.

Table 9. Experimental Results: Influence of Representation Format on the Creativity of Process-Innovation Solutions.

Dependent Variable	Factor		F ($df_{Hypothesis}$, df_{Error})	p	η^2
Fluency	Between-Subject Effect	Representation Type (Text vs. Diagram)		>0.10	
	Within-Subject Effect	Creativity Task		>0.10	
	Covariate	Individual Creative Competence (Fluency)	9.70 (1, 68)	**0.003**	0.13
	Interaction	Individual Creative Competence (Originality) X Creativity Task	6.19 (2, 136)	**0.003**	0.08
Appropriateness	Between-Subject Effect	Representation Type (Text vs. Diagram)	6.47 (1,69)	**0.01**	0.09
	Within-Subject Effect	Creativity Task	5.20 (2,118)	**0.01**	0.07
Originality	Between-Subject Effect	Representation Type (Text vs. Diagram)	2.96 (1,69)	0.09	0.04
	Within-Subject Effect	Creativity Task	22.71 (2, 119)	**<0.001**	0.25
Impact	Between-Subject Effect	Representation Type (Text vs. Diagram)	2.92 (1,69)	0.09	0.04
	Within-Subject Effect	Creativity Task	75.30 (2, 138)	**<0.001**	0.52

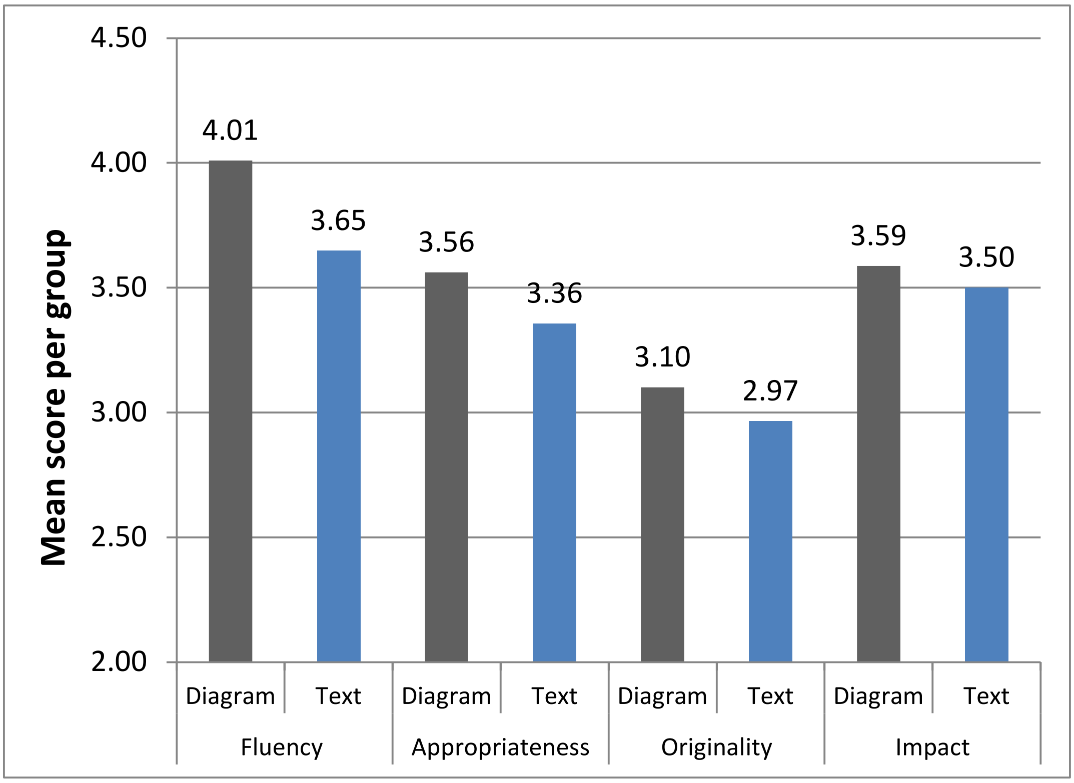


Figure 3. The Influence of the Type of Representation on the Creativity of Solutions.

The results shown in Table 9 and Figure 3 indicate that the "diagram" group generated ideas that were more appropriate than those of the "text" group ($M_{Diagram}$=3.56, $SD_{Diagram}$=0.28; M_{Text}=3.36, SD_{Text}=0.38; p=0.01). They also produced ideas of greater originality ($M_{Diagram}$=3.10, $SD_{Diagram}$=0.33; M_{Text}=2.97, SD_{Text}=0.34; p=0.09) and impact ($M_{Diagram}$=3.59, $SD_{Diagram}$=0.16; M_{Text}=3.50, SD_{Text}=0.25; p=0.09), although these results were not significant at the p=0.05 level. The significance levels stayed similar when the control variables of gender, domain experience, and task order were included in the analyses.

The results also indicate that either the within-subject effect on the creativity task or the interaction effect between the individual creative competence and the creativity task was significant for all dependent variables. Therefore, the innovation objectives influence the creative outcome of the problem-solving task.

Although most of the results were in line with our expectations, the number of ideas produced was similar between the two groups ($M_{Diagram}$=4.01, $SD_{Diagram}$=1.84; M_{Text}=3.65, SD_{Text}=1.37). Only the individual creative competence factor affected the number of ideas produced, confirming the widely held assumption that participants with higher creativity produce more ideas. Therefore, we found no support for hypothesis 1a from the data on fluency of ideas. However, results strongly supported hypothesis 1b regarding appropriateness and partially supported hypothesis 1b regarding originality and impact (in terms of directionality but not significance of the effect). Overall, then, we see enough evidence to accept hypothesis 1b, that the use of diagrammatic process representations leads to higher quality of creative ideas in process-redesign solutions than the use of textual representations, without necessarily impacting the number of outcomes in the idea-generation process (hypothesis 1a).

Hypotheses 2a and 2b

Hypotheses 2a and 2b suggested that uses of process diagrams versus process texts would lead to differing types of process-redesign solutions, and in particular that the use of visual diagrams would lead to more process-redesign solutions featuring control flow (hypothesis 2a) or organizational resources (hypothesis 2b). We again ran ANCOVA for repeated measures tests with the same independent factors and covariates and using the count of ideas per categorization as dependent variable. Table 10 summarizes the significant results from the test, including F-statistics, test result (p value), and effect size (η^2), and Figure 4 visualizes the differences graphically.

Table 10. Experimental Results: Influence of Representation Format on Creative Problem-Solving.

Dependent Variable	Factor		F ($df_{Hypothesis}$, df_{Error})	p	η^2
Control Flow-Related Ideas	Between-Subject Effect	Representation Type (Text vs. Diagram)		p > 0.10	
	Within-Subject Effect	Creativity Task		p > 0.10	
	Covariate	Individual Creative Competence (Fluency)	8.56 (1, 68)	**0.005**	0.11
	Interaction	Individual Creative Competence (Fluency) X Creativity Task	4.03 (2, 98)	**0.02**	0.06
Information System-Related Ideas	Between-Subject Effect	Representation Type (Text vs. Diagram)	6.10 (1, 69)	**0.02**	0.08
	Within-Subject Effect	Creativity Task	47.27 (2, 138)	**< 0.001**	0.41
Data-Related Ideas	Between-Subject Effect	Representation Type (Text vs. Diagram)	4.55 (1, 69)	**0.04**	0.06
	Within-Subject Effect	Creativity Task	7.34 (2, 138)	**0.001**	0.10
Technological Resources-Related Ideas	Between-Subject Effect	Representation Type (Text vs. Diagram)		p > 0.10	
	Within-Subject Effect	Creativity Task		p > 0.10	
	Covariate	Individual Creative Competence (Fluency)	6.09 (1, 68)	**0.02**	0.08
	Interaction	Individual Creative Competence (Originality) X Creativity Task	7.25 (2, 86)	**0.001**	0.10
Organizational Resources	Between-Subject Effect	Representation Type (Text vs. Diagram)		p > 0.10	
	Within-Subject Effect	Creativity Task	10.81 (2,122)	**< 0.001**	0.14

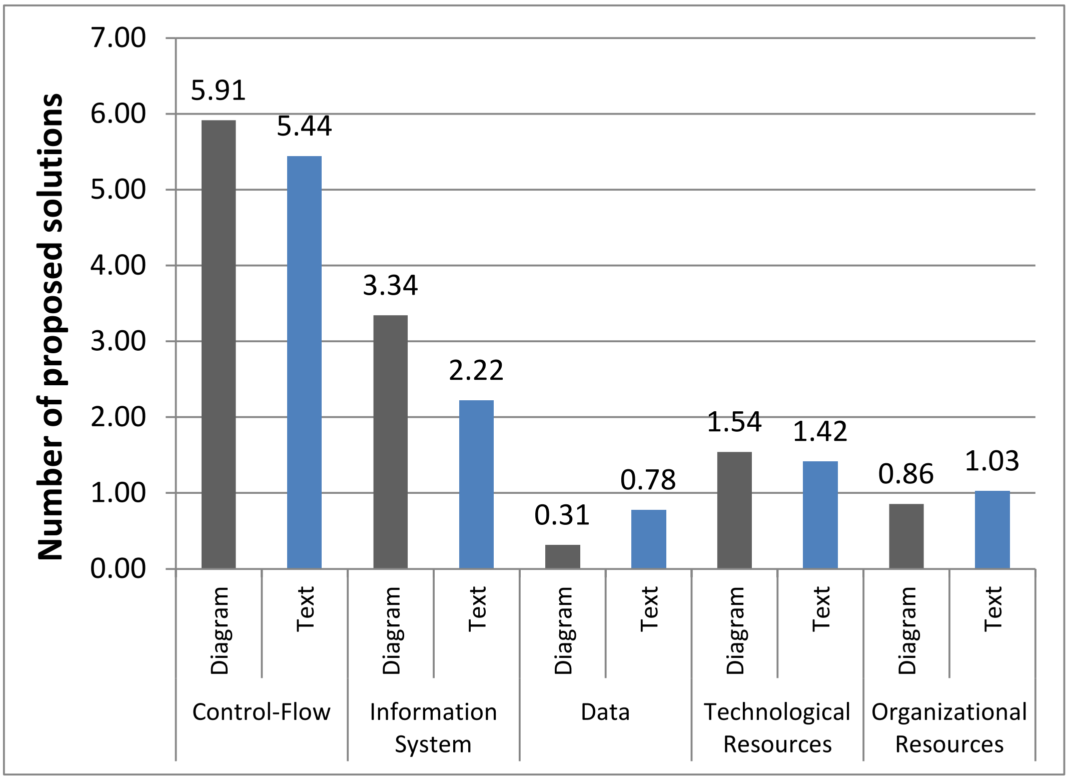


Figure 4. The Influence of Representation on Types of Process-Innovation Solutions.

We noticed that there are significant differences in the categories information systems ($p=0.02$) and data ($p=0.04$) between the diagram and the text group. Participants in the diagram group produced more ideas related to information systems ($M_{Diagram}=3.34$, $SD_{Diagram}=2.09$; $M_{Text}=2.22$, $SD_{Text}=1.73$) and fewer ideas related to data than the text group did ($M_{Diagram}=0.31$, $SD_{Diagram}=0.80$; $M_{Text}=0.78$, $SD_{Text}=1.02$). Individual creative competence is positively associated with the number of ideas related to control flow, data, and technological resources. The data did not provide support for hypotheses 2a and 2b. Diagram users produced more control flow ideas but fewer organizational resource ideas, but neither difference was significant. In sum, the type of process representation influenced some but not all types of process-redesign ideas. Further empirical research and theorizing are required regarding the specific effects hypothesized.

We carried out several supplementary analyses, summarized in Appendix D, for additional evaluation of our hypotheses. These analyses provide further insights into how the tasks, the representation format, and user demographics influence the process-redesign solutions produced in the experiment.

Discussion

We set out to determine the impact of diagrammatic process representations on creativity in redesign tasks for process innovation. Our findings indicate that diagrammatic process representations lead to more creative process changes than textual representations do. The findings confirm a commonly held notion that diagrammatic process models are a useful aid to process analysts in designing future processes. While these results demonstrate that diagrammatic models do not make analysts more creative per se or lead to a higher number of ideas, the redesign solutions offered appear to be beneficial in terms of dimensions like appropriateness and type of idea.

Differences in the originality ratings of ideas generated appear to be sensible to gender and task selection. However, the level of originality did not differ significantly between text and diagram models, so our result differs from that of [31], who found higher originality of ideas with textual stimuli, and [46] who reported more creative ideas for users of pictures. A likely explanation for the differences is that originality depends on the type of visual/pictorial stimulus used, and process models cannot be compared directly to photographs or illustrations.

Our findings do not support the argument that process models evoke fixation and hinder the generation of creative, appropriate ideas, as other researchers have reported for pictorial stimuli in design tasks [8, 37, 79]. On the contrary, our results suggest that users develop a higher number of appropriate ideas when they work with a diagram than with text. This outcome can be interpreted in light of Smith's [78] suggestion to use paraphrasing for a problem setting to overcome fixation. Our study suggests that not only paraphrasing of the problem setting but also further transformation to a diagrammatic representation is helpful. Abstraction, 2D structuring of information, and the additional use of symbolic vocabulary in the diagrammatic representation seem to support creative thinking about process redesign.

These results also align with Ward's [89] observation that abstraction from the solution initially presented can help designers to escape fixation. Making the elements of a business process explicit–e.g., the temporal and logical order of process activities in a diagram–can allow analysts to stick only to the essential elements of the business process.

This interpretation is also supported by the results of our third experimental group, the structured text group. As the results of the structured text representation format fell between the textual and the diagrammatic representation format for all dependent variables, we speculate that both structure and symbolic vocabulary support abstraction, reduce working memory demands, and improve creative performance.

One unanticipated finding was that the number of ideas produced was similar among the experimental groups, which reflects other studies' [8, 46] findings that not the number, but the range of ideas was affected in idea-generation tasks that used textual or pictorial stimulus.

Our results on hypotheses 2a and 2b, concerning the types of ideas generated, indicate that process models may both limit and expand the range of ideas produced. We found a significant effect of representation type for two types of ideas: information systems and data components of a business process. The increase in information system-related ideas in the diagram group could be attributed to the frequent use of process models in requirements engineering for information systems, while the lower number of data-related ideas could stem from the focus on process instead of data in the diagrammatic representations.

Measuring the semantic similarity of concepts [61] may help to explain the result through the associative theory of creativity [50] (Appendix E). Similarity measures based on WordNet [54] demonstrate that English concepts taken from the description of the information-system type of process improvement ideas are somewhat closer to the concept of "diagram," while concepts from the data type of description are closer to the concept of "text." This analysis lends some support to the idea that diagrams are more closely associated with information systems, while data is associated more closely with text. However, the two explanations are similar: they show that an association between the representation's format and the type of process-redesign ideas may stem from practice in information systems development or from a linguistic context.

Implications

Implications for Research

To our knowledge, this study is the first to examine the effects of how information is represented (text versus diagrams) on process redesign as a creative problem-solving task. We identify three central contributions.

First, our study is the first to examine process models in the context of redesigning an organizational process. Thus, our work extends the stream of research on how well individuals understand differing forms of process representations [e.g., 53, 59, 67]. Our research sheds light on how the representation of the problem situation as a process model influences ideas for solutions. This contribution is important both in clarifying how textual or visual process representations influence process redesign and in clarifying the differences in solutions when analysts use either. Our findings also support the development of task-specific theories of process modeling and help to clarify how process models can be designed to be effective in differing types of task settings (such as in analyzing the performance of a current process versus designing future organizational realities, which is this paper's focus).

Second, the paper contributes to the literature on process redesign as a creative problem-solving activity [66, 81]. In particular, we extend the literature on fixation effects in creative problem-solving. In this literature, experiments have predominately provided participants with example solutions and have focused less on how the problem and the context is presented [79]. In addition, our paper adds to these research streams by accounting for the domain-specificity of creativity; we investigated a specific work-related task on *process redesign*, rather than using the architectural or mechanical design tasks on which several studies have focused [9, 11, 28, 29].

Third, we offer a new, nuanced representation of process redesign in terms of the creativity dimensions of originality, appropriateness, and impact and the type of process-redesign ideas (locus of change: control flow, information system, data, and technological and organizational resources). This conceptualization and our newly developed measurement instrument can be used to guide researchers in evaluating business process redesigns.

Implications for Practice

Our findings have implications primarily for process-improvement projects, a key focus of information professionals [24]. We addressed a longstanding debate about the relative merits of process modeling for process redesign tasks and determined the type of process-redesign suggestions that can be expected when users work with diagrammatic or textual process descriptions.

One useful interpretation of our findings is that managers can, at least to some extent, guide the development of future processes by selecting a process representation format that is more or less conducive to producing changes to the control flow, data, resource, or technology components of a business process. Given that some or several components might not be a core focus (or, alternatively, might be taboo) in many projects, our results can aid managers in making decisions about which type of redesign solutions they wish to foster in their teams.

A second implication concerns the application of textual versus diagrammatic process representations for other kinds of tasks. We examined one task, process redesign, and our results suggest that the two kinds of representations influence the outcomes in process redesign. Some might interpret our results to mean that visual models serve this purpose better, but our findings do not suggest that textual diagrams are useless in such tasks or in other tasks. For instance, textual representations offer the advantage of packing in more contextual details than a diagrammatic representation can, which advantage might be helpful in tasks others than process redesign, such as in designing information systems support for the process. Additional contextual information may also be helpful in process redesign itself. Therefore, we suggest that organizations find an optimal trade-off between representation formats by considering the task setting in which process descriptions are used. Based on our results, where the results for the structured text lies between those for diagrams and texts (Figure 3), the common practice of using diagrammatic process models supplemented by structured process descriptions is useful. One implication of this observation is that organizations should maintain representations of processes in a variety of formats (e.g., text and diagram) and offer some or all of these representations to analysts, depending on the objective of a redesign project.

A final implication concerns the dependence of process-redesign solutions based on the type of redesign task to be undertaken. We noted that the type of process redesign varied not only across representation formats but also across the kinds of improvements required in the three tasks. This result suggests that managers should be conscientious about setting appropriate process-redesign objectives and suggesting process-innovation procedures (e.g. using existing improvement patterns) to govern a project. Our results suggest that the choice of task objective acts as a focusing lens for analysts that will vary the solutions they generate.

Limitations

Our study has several limitations. The process representations used in the experiment are simplified versions of models used in practice, although the models themselves are not necessarily simple, and we restricted our investigation to one process scenario so we could examine the problem in a controlled setting. Therefore, external validity in the sense of being able to generalize the findings to other process scenarios (e.g., in terms of process complexity, type of domain, or extent of pre-existing knowledge) is limited. However, because our study is the first experimental study in this domain, internal validity was more important than other forms of validity. Therefore, we used a controlled experimental setting in a daylight computer lab since environmental characteristics like the environment [34], the physical location (e.g., paintings and drawings in a room [9]), or even the simple presence of a light bulb [77] could influence performance in creative problem-solving tasks.

Second, our choice of a student sample limits the external generalizability of our results. Given our research objective, we selected a sample that was representative of future employees who would be concerned with process redesign. This selection strategy misses students groups who perform better in creativity tasks and practitioners with higher levels of domain knowledge, method knowledge, or more experience in creative problem-solving. Concerning domain experience with the pizza-delivery industry, we refrained from including experts to avoid having participants with such elaborate understanding of the pizza-delivery industry that they might answer questions without looking at the stimulus of the process model. We included a variable that measured experience with pizza-delivery services as a customer, but we did not measure experience working in a pizza-delivery business because we assumed that a large population of such workers was unlikely in our sample. Still, we acknowledge that work experience may influence activities and outcomes in our setting. Our main reason for using a student sample was that bias related to knowledge about method would be at most minimal. Senior business users and analysts would be more likely to be “brainwashed” into a particular representation format through years of training and/or practice. The study in [23] confirms such a preferential bias.

Third, the rating method for the ideas may have influenced our results. We pursued a multiple-rater approach to mitigate subjective bias during the coding and to ensure that any influence would be consistent across all three groups.

Fourth, process innovation (and other forms of creative problem-solving) is often conducted in groups to encourage idea composition and evaluation in the group. These interaction effects were not considered in this experiment, which focused primarily on idea generation by individuals. Follow-up work could consider group dynamics in this or subsequent phases.

Fifth, our coding of process-redesign solutions through the team of research assistants, while subjectively reliable, remains subject to interpretation. Our description of materials and processes ensured transparency in our chosen approach, but the possibility of alternative interpretations remains. Replication research will be required to determine whether interpretation bias by our coders influenced the findings.

The generalizability of our findings is constrained by these limitations, especially in terms of external validity. Still, our study provides some insights into the process and outcomes of process redesign that could be useful in real-world settings. Our choice of research design was motivated by a desire to maximize internal validity while maintaining some ecological validity. Internal validity was important because the practice of redesign is relevant and popular in today’s businesses, and research has so far relied largely on descriptive or observational studies. Our reasoning was that, if we can detect differences on outcomes that are due to different representation formats in a controlled and simplified version using student subjects, then these effects will be even more significant in other, perhaps more realistic scenarios involving highly trained and experienced practitioners who use complex representations of key business processes.

Finally, our results are susceptible to the quality of the chosen representation. Our results suggest that visual process representations may be superior to textual formats, but a badly constructed graphical representation may well be worse than a good textual representation. We described in detail how we constructed our materials and believe the quality was high for all three formats used.

Conclusion

The purpose of our study was to determine whether diagrammatic process models differ from textual representations in terms of how well they support analysts in developing creative process-redesign ideas. Our results suggest that diagrammatic models provide better assistance than text in terms of the generation of appropriate ideas. Our findings also suggest that users generate more ideas that are related to information systems and fewer ideas that are related to data when they work with a model than they do when they work with text. In general, participants with more individual creativity produced more ideas, independent of representation type.

References

[1] T.M. Amabile, The social psychology of creativity: A componential conceptualization, Journal of Personality and Social Psychology 45 (2), 1983, pp. 357-376.

[2] A.D. Baddeley, Working memory, Science 255 (5044), 1992, pp. 556-559.

[3] J. Baer and J.C. Kaufman, Gender differences in creativity, The Journal of Creative Behavior 42 (2), 2008, pp. 75-105.

[4] M. Basadur and C.T. Finkbeiner, Measuring preference for ideation in creative problem-solving training, Journal of Applied Behavioral Science 21 (1), 1985, pp. 37-49.

[5] P. Bera, Does cognitive overload matter in understanding BPMN Models? Journal of Computer Information Systems 52 (4), 2012, pp. 59-69.

[6] Z. Bilda and J.S. Gero, The impact of working memory limitations on the design process during conceptualization, Design Studies 28 (4), 2007, pp. 343-367.

[7] M. Broadbent and P. Weill, The implications of information technology infrastructure for business process redesign, MIS Quarterly 23 (2), 1999, pp. 159-182.

[8] C. Cardoso and P. Badke-Schaub, Idea fixation in design: The influence of pictures and words, *Proceedings of the ICORD 09: Proceedings of the 2nd International Conference on Research into Design, Bangalore, India*, 2009.

[9] H.P. Casakin and G. Goldschmidt, Reasoning by visual analogy in design problem-solving: The role of guidance, environment and planning, Planning and Design 27 (1), 2000, pp. 105-119.

[10] P.-K. Cheung, P.Y.K. Chau and A.K.K. Au, Does knowledge reuse make a creative person more creative? Decision Support Systems 45 (2), 2008, pp. 219-227.

[11] B.T. Christensen and C.D. Schunn, The relationship of analogical distance to analogical function and preinventive structure: The case of engineering design, Memory & Cognition (pre-2011) 35 (1), 2007, pp. 29-38.

[12] M.M. Clapham, The convergent validity of the torrance tests of creative thinking and creativity interest inventories, Educational and Psychological Measurement 64 (5), 2004, pp. 828-841.

[13] A. Collins and M. Quillian, Retrieval time from semantic memory, Journal of Verbal Learning and Verbal Behavior 8 (2), 1969, pp. 240-247.

[14] A.M. Collins and E.F. Loftus, A spreading activation theory of semantic processing, Psychological Review 82 (6), 1975, pp. 407-428.

[15] D.R. Compeau, B.L. Marcolin, H. Kelley and C.A. Higgins, Generalizability of information systems research using student subjects — A reflection on our practices and recommendations for future research, Information Systems Research 23 (4), 2012, pp. 1093-1109.

[16] B. Cramond, J. Matthews-Morgan, D. Bandalos and L. Zuo, A report on the 40-year follow-up of the Torrance tests of creative thinking: Alive and well in the new millennium, Gifted Child Quarterly 49 (4), 2005, pp. 283-291.

[17] T.H. Davenport and J. Short, The new industrial engineering: Information technology and business process redesign, Sloan Management Review, 1990, pp. 11-27.

[18] F.D. Davis, R.P. Bagozzi and P.R. Warshaw, Extrinsic and intrinsic notivation to use computers in the workplace, Journal of Applied Social Psychology 22 (14), 1992, pp. 1111-1132.

[19] D.L. Dean, J.M. Hender, T.L. Rodgers and E.L. Santanen, Identifying quality, novelty, and creative ideas: Constructs and scales for idea evaluation, Journal of the Association for Information Systems 7 (10), 2006, pp. 646-699.

[20] A.R. Dennis, G. Hayes and R.M. Daniels, Business process modeling with group support systems, Journal of Management Information Systems 15 (4), 1999, pp. 115-142.

[21] M. Dumas, M. La Rosa, J. Mendling and H.A. Reijers, Fundamentals of Business Process Management, Springer: Berlin, Germany, 2013.

[22] R. Eisenman, Creativity and academic major: Business versus English majors, Journal of Applied Psychology 53 (5), 1969, pp. 392-395.

[23] K. Figl and J. Recker, Exploring cognitive style and task-specific preferences for process representations, Requirements Engineering 19 (3), 2014, pp. 1-23.

[24] Gartner Group, Leading in times of transition: The 2010 CIO agenda, EXP Premier Report, January 2010.

[25] A. Gemino and D. Parker, Use case diagrams in support of use case modeling: Deriving understanding from the picture, Database 20 (1), 2009, pp. 1-24.

[26] A.M. Glenberg and W.E. Langston, Comprehension of illustrated text: Pictures help to build mental models, Journal of Memory and Language 31 (2), 1992, pp. 129-151.

[27] K. Goff and E.P. Torrance, Abbreviated Torrance Test for Adults (ATTA). Scholastic Testing Service: Bensenville, Illinois, 2002.

[28] G. Goldschmidt and A.L. Sever, Inspiring design ideas with texts, Design Studies 32 (2), 2011, pp. 139-155.

[29] G. Goldschmidt and M. Smolkov, Variances in the impact of visual stimuli on design problem solving performance, Design Studies 27 (5), 2006, pp. 549-569.

[30] M. Gonçalves, C. Cardoso and P. Badke-Schaub, Find your inspiration: Exploring different levels of abstraction in textual stimuli, *Proceedings of the 2nd International Conference on Design Creativity (ICDC2012)*, Glasgow UK, 2012.

[31] M. Gonçalves, C. Cardoso and P. Badke-Schaub, How far is too far? Using different abstraction levels in textual and visual stimuli, *Proceedings of the Design 2012: 12th International Design Conference*, Dubrovnik, Croatia, 2012.

[32] J.P. Guilford, Three faces of intellect, American Psychologist 14 (8), 1959, pp. 469-479.

[33] P. Harmon, Business Process Change: A Guide for Business Managers and BPM and Six Sigma Professionals, Morgan Kaufmann: San Francisco, California, 2007.

[34] S. Hemlin, C.M. Allwood and B.R. Martin, Creative knowledge environments, Creativity Research Journal 20 (2), 2008, pp. 196 - 210.

[35] M. Indulska, P. Green, J. Recker and M. Rosemann, Business process modeling: Perceived benefits, In Conceptual Modeling - ER 2009, S. Castano, U. Dayal and A. H. F. Laender (Eds.), Springer: Gramado, Brazil, 2009, pp. 458-471.

[36] P.W. Jackson and S. Messick, The person, the product, and the response: Conceptual problems in the assessment of creativity, Journal of Personality 33 (3), 1965, pp. 309-329.

[37] D.G. Jansson and S.M. Smith, Design fixation, Design Studies 12 (1), 1991, pp. 3-11.

[38] A. Jeyaraj and V.L. Sauter, Validation of business process models using swimlane diagrams, Journal of Information Technology Management 25 (4), 2014, pp. 27.

[39] T. John and D. Kundisch, Why Fit Leads to Surprise: An Extension of Cognitive Fit Theory to Creative Problems, Proceedings of the International Conference on Information Systems (ICIS), Forth Worth, 2015.

[40] W. Kettinger, J. Teng and S. Guha, Business process change: A study of methodologies, techniques, and tools, MIS Quarterly 21 (1), 1997, pp. 55-80.

[41] N. Kock, J. Verville, A. Danesh-pajou and D. Deluca, Communication flow orientation in business process modeling and its effect on redesign success: Results from a field study, Decision Support Systems 46 (2), 2009, pp. 562-575.

[42] M. Kunze, A. Luebbe, M. Weidlich and M. Weske, Towards understanding process modeling–the case of the BPM academic initiative, *Proceedings of Business Process Model and Notation*, Lecture Notes in Business Information Processing 95, Lucerne, Switzerland, 2011.

[43] J.H. Larkin and H.A. Simon, Why a diagram is (sometimes) worth ten thousand words, Cognitive Science 11 (1), 1987, pp. 65-100.

[44] H. Leopold, J. Mendling and A. Polyvyanyy, Generating natural language texts from business process models, *Proceedings of Advanced Information Systems Engineering*, Lecture Notes in Computer Science, Springer, Berlin, Heidelberg, 2012.

[45] J. Liu, S. Zhang and J. Hu, A case study of an inter-enterprise workflow-supported supply chain management system, Information & Management 42 (3), 2005, pp. 441-454.

[46] R.A. Malaga, The effect of stimulus modes and associative distance in individual creativity support systems, Decision Support Systems 29 (2), 2000, pp. 125-141.

[47] D. Mani, A. Barua and A.B. Whinston, An empirical analysis of the impact of information capabilities design on business process outsourcing performance, MIS Quarterly 34 (1), 2010, pp. 39-62.

[48] R.E. Mayer, Multimedia Learning, Cambridge University Press: Cambridge, Massachusetts, 2009.

[49] J.M. McCoy and G.W. Evans, The potential role of the physical environment in fostering creativity, Creativity Research Journal 14 (3), 2002, pp. 409-426.

[50] S.A. Mednick, The associative basis of the creative process, Psychological Review 69 (3), 1952, pp. 220-232.

[51] J. Mendling, Metrics for Process Models: Empirical Foundations of Verification, Error Prediction and Guidelines for Correctness, Springer: Berlin, Germany, 2008.

[52] J. Mendling, H.A. Reijers and J. Recker, Activity labeling in process modeling : Empirical insights and recommendations, Information Systems 35 (4), 2010, pp. 467-482.

[53] J. Mendling, M. Strembeck and J. Recker, Factors of process model comprehension — Findings from a series of experiments, Decision Support Systems 53 (1), 2012, pp. 195-206.

[54] G.A. Miller, WordNet - A lexical database for English, Communications of the ACM 38 (11), 1995, pp. 39-41.

[55] M.D. Mumford, K. Hester and I. Robledo, Chapter 3 - Methods in creativity research: Multiple approaches, multiple levels, In Handbook of Organizational Creativity, D. M. Michael (Ed.), Academic Press: San Diego, 2012, pp. 39-65.

[56] L.A. O'Hara and R.J. Sternberg, It doesn't hurt to ask: Effects of instructions to be creative, practical, or analytical on essay-writing performance and their interaction with students' thinking styles, Creativity Research Journal 13 (2), 2001, pp. 197-210.

[57] Object Management Group, BPMN 2.0 by Example, http://www.omg.org/spec/BPMN/2.0/examples/PDF/10-06-02.pdf, 2010 (accessed 22.02.16).

[58] Object Management Group, Business Process Model and Notation (BPMN) (Version 2.0.2), http://www.omg.org/spec/BPMN/2.0.2, 2013 (accessed 22.02.16).

[59] A. Ottensooser, A. Fekete, H.A. Reijers, J. Mendling and C. Menictas, Making sense of business process descriptions: An experimental comparison of graphical and textual notations, Journal of Systems and Software 85 (3), 2012, pp. 596-606.

[60] S. Patig and V. Casanova-Brito, Requirements of process modeling languages-Results from an empirical investigation, *Proceedings of the Wirtschaftsinformatik*, 2011.

[61] T. Pedersen, S. Patwardhan and J. Michelizzi, WordNet::Similarity: Measuring the Relatedness of Concepts, Demonstration papers at *HLT-NAACL 2004*, Association for Computational Linguistics, Boston, Massachusetts, 2004, pp. 38-41.

[62] D. Piffer, Can creativity be measured? An attempt to clarify the notion of creativity and general directions for future research, Thinking Skills and Creativity 7 (3), 2012, pp. 258-264.

[63] J. Recker, Continued use of process modeling grammars: The impact of individual difference factors, European Journal of Information Systems 19 (1), 2010, pp. 76-92.

[64] J. Recker, Empirical investigation of the usefulness of Gateway constructs in process models, European Journal of Information Systems 22 (6), 2013, pp. 673-689.

[65] J. Recker, M. Rosemann, E. Roohi Goohar, A. Hjalmarsson and M. Lind, Modeling and analyzing the carbon footprint of business processes, In Green Business Process Management - Towards the Sustainable Enterprise, J. vom Brocke, S. Seidel and J. Recker (Eds.), Springer: Heidelberg, Germany, 2012, pp. 93-110.

[66] H.A. Reijers and S.L. Mansar, Best practices in business process redesign: An overview and qualitative evaluation of successful redesign heuristics., Omega 33 (4), 2005, pp. 283-306.

[67] H.A. Reijers and J. Mendling, A study into the factors that influence the understandability of business process models, IEEE Transactions on Systems, Man, and Cybernetics - Part A 41, 2011, pp. 449-462.

[68] T.R. Rohleder and E.A. Silver, A tutorial on business process improvement, Journal of Operations Management 15 (2), 1997, pp. 139-154.

[69] M. Rosemann, Potential pitfalls of process modeling: part B, Business Process Management Journal 12 (3), 2006, pp. 377-384.

[70] M. Rosemann, J. Recker and C. Flender, Contextualization of business processes, International Journal of Business Process Integration and Management 3 (1), 2008, pp. 47-60.

[71] M.A. Runco, Operant theories of insight, originality, and creativity, The American Behavioral Scientist 37 (1), 1993, pp. 54-54.

[72] E.L. Santanen, R.O. Briggs and G.-J.D. Vreede, Causal relationships in creative problem solving: Comparing facilitation interventions for ideation, Journal of Management Information Systems 20 (4), 2004, pp. 167-198.

[73] J. Sarkkinen and H. Karsten, Verbal and visual representations in task redesign: how different viewpoints enter into information systems design discussions, Information Systems Journal 15 (3), 2005, pp. 181-211.

[74] M. Scaife and Y. Rogers, External cognition: How do graphical representations work?, Int. J. Hum.-Comput. Stud. 45 (2), 1996, pp. 185-213.

[75] A. Sharp and P. McDermott, Workflow Modeling: Tools for Process Improvement and Application Development, Artech House, 2001.

[76] A. Shtub and R. Karni, Business process improvement, In ERP, Springer: US, 2010, pp. 217-254.

[77] M.L. Slepian, M. Weisbuch, A.M. Rutchick, L.S. Newman and N. Ambady, Shedding light on insight: Priming bright ideas, Journal of Experimental Social Psychology 46 (4), 2010, pp. 696-700.

[78] S.M. Smith, Fixation, incubation, and insight in memory and creative thinking, In The Creative Cognition Approach, S. M. Smith, T. B. Ward and R. A. Finke (Eds.), The MIT Press: Cambridge, MA, 1995, pp. 135-156.

[79] S.M. Smith, T. Ward and J. Schumacher, Constraining effects of examples in a creative generation task, Memory & Cognition 21 (6), 1993, pp. 837-845.

[80] R.J. Sternberg, Cognitive Psychology, Wadsworth, Cengage Learning: Belmont, 2009.

[81] D.B. Stoddard and S.L. Jarvenpaa, Business process redesign: Tactics for managing radical change, Journal of Management Information Systems 12 (1), 1995, pp. 81-107.

[82] L. Sun, W. Xiang, C. Chai, C. Wang and Z. Liu, Impact of text on idea generation: An electroencephalography study, International Journal of Technology and Design Education 23 (4), 2013, pp. 1047-1062.

[83] S.X. Sun, J.L. Zhao, J.F. Nunamaker Jr and O.R. Liu Sheng, Formulating the data-flow perspective for business process management, Information Systems Research 17 (4), 2006, pp. 374-391.

[84] S.M. Turner, S.T. DeMers, H.R. Fox and G. Reed, APA's guidelines for test user qualifications: An executive summary, American Psychologist 56 (12), 2001, pp. 1099-1113.

[85] G. Valiris and M. Glykas, Critical review of existing BPR methodologies, Business Process Management Journal 5 (1), 1999, pp. 65-86.

[86] W.M.P. van der Aalst, M. Rosemann and M. Dumas, Deadline-based escalation in process-aware information systems, Decision Support Systems 43 (2), 2007, pp. 492-511.

[87] W.M.P. van der Aalst, A.H.M. ter Hofstede, B. Kiepuszewski and A.P. Barros, Workflow patterns, Distributed and Parallel Databases 14 (1), 2003, pp. 5-51.

[88] I. Vessey and R. Weber, Structured tools and conditional logic: An empirical investigation, Commun. ACM 29 (1), 1986, pp. 48-57.

[89] T.B. Ward, What's old about new ideas? In S. M. Smith, T. B. Ward, R. A. Finke (Eds.), The Creative Cognition Approach, MIT Press, Cambridge, MA, 1995, pp. 157-178.

[90] M.A. West and J.L. Farr, Innovation and Creativity at Work: Psychological and Organizational Strategies, John Wiley: Chichester, 1990.

[91] K. Whitley, Visual programming languages and the empirical evidence for and against, Journal of Visual Languages and Computing 8 (1), 1997, pp. 109-142.

[92] W.D. Winn, An Account of how readers search for information in diagrams, Contemporary Educational Psychology 18 (2), 1993, pp. 162-185.

[93] L. Zeng, R.W. Proctor and G. Salvendy, Can traditional divergent thinking tests be trusted in measuring and predicting real-world creativity? Creativity Research Journal 23 (1), 2011, pp. 24-37.

[94] M. zur Muehlen, Organizational management in workflow applications - Issues and perspectives, Information Technology and Management 5 (3), 2004, pp. 271-291.

Appendix A: Experimental Material Used (Selection)

Instructions

Imagine you are a business consultant, and a pizza-delivery service contacts you to help them improve their business processes. They provide you with a short description of their main business process, which is shown below. Please study this description carefully before proceeding.

Structured Text Description of Process

pizza costumer			
BEGIN			
select a pizza from leaflet			
order pizza by phone	**clerk**	**pizza chef**	**delivery person**
	write note with order		
	stick note to kitchen		
		check oven temperature	
		prepare dough	
		add tomato base	
		add selected toppings	
		grate cheese	
		bake pizza	
		IF pizza = done	
		notify delivery person	
IF waiting time >60 minutes			
ask for the pizza			
	calm costumer **IF** costumer not calmed cancel order		
	TERMINATE		
	ENDIF		
ENDIF			
			deliver the pizza by car
receive the pizza			
pay the pizza			
			give change
			write receipt
			END

Figure 5. Control Group Treatment: Structured Text.

Your task as a consultant is to generate ideas on *how to improve the process of the pizza-delivery service from several points of view*. (These viewpoints could be—but do not have to be—cost, quality, turnaround time, customer satisfaction, increased market share, and so forth). Please note that you don't have the complete information about the pizza-ordering service's processes and that it is important to use your imagination. For each of the following questions, briefly describe as many improvement ideas as you can in the space provided. You do not need to make complete sentences when writing the ideas—just use simple phrases, and don't worry about grammar. You can use English and/or German. You have **5 minutes** to complete each of the following three tasks, for a total of 15 minutes.

Process Innovation Tasks (Creative Redesign Task)

Task 1: The pizza-delivery service wants to improve its processes so customers know at all times when their pizzas will arrive. How can the process be changed to implement this improvement? Write down as many options as you can think of.

Task 2: The pizza-delivery service is willing to hire a new employee. How could the employee be used to improve the process? Provide as many options as you can think of.

Task 3: The pizza-delivery service wants to cut costs. How could the process be changed to reduce costs? Provide as many options as you can think of.

Demographics

1. What is your age? __ years

2. What is your gender?

- o Female
- o Male

3. What is the highest degree or level of school you have completed?

- o No high school diploma High school graduate
- o One or more years of college/university; major subject: __
- o Bachelor's degree; major subject: __
- o Master's degree; major subject: __
- o Doctoral degree; major subject: __

4. Are you currently working and/or studying? (multiple responses possible)

- o No, I don't work and am not in an education program.
- o Yes, I work, and my job title is __.
- o Yes, I study, and my major subject is ___.

5. Have you ever done any process modeling (e.g., with EPCs, BPMN, Flowcharts, Petri Nets)?

- o Yes
- o No

6. How often do you work with process models?

○	○	○	○	○
never	rarely	sometimes	often	always

7. Number of models created
Approximately how many process models have you created to date? ___ ○ None

8. Number of models read
Approximately how many process models have you read to date? ___ ○ None

9. Process improvement initiatives
During your working life, have you ever contributed to a process-improvement initiative (e.g., an initiative to redesign a process or to develop new software for a process)?

_____times overall ○ Never

10. BPMN familiarity
Are you familiar with BPMN? ○yes ○no

In case you are familiar with BPMN, please rate your degree of familiarity with BPMN.

	strongly disagree						**strongly agree**
Overall, I am very familiar with BPMN diagrams.	○	○	○	○	○	○	○
I feel very confident in understanding process models created with BPMN diagrams.	○	○	○	○	○	○	○
I feel very competent in using BPMN diagrams for process modeling.	○	○	○	○	○	○	○

11. The following questions are related to your first task on improving the pizza-delivery service process.

To what extent do you agree or disagree with the following statements?

	strongly disagree						**strongly agree**
I found the task of providing improvement ideas on the	○	○	○	○	○	○	○

pizza order service to be enjoyable.							
The actual process of performing the task of providing improvement ideas on the pizza order service was pleasant.	○	○	○	○	○	○	○
I had fun performing the task of providing improvement ideas on the pizza order service.	○	○	○	○	○	○	○

12. Pizza

Approximately how many times have you ordered a pizza?
_____times overall ○ Never

Appendix B: Coding Schema (*self-developed criteria, specific for the domain of process innovation)

Criteria	Sub-dimension (where applicable)	Definition	Explanation and Examples	Coding Instructions
Creativity of process improvement idea	*Fluency*	The **quantity of relevant ideas** provided.	This attribute measures the ability to produce quantities of ideas that are relevant to the task instructions.	Count the number of answers provided.
	Originality	Something that is **original, unexpected,** and **novel**.	If the task is to list as many creative uses for a tissue as possible, the answer "using a tissue as a napkin" is less original than the response "using tissues to make a costume for the next Halloween party (e.g., ghost or fairy)."	Evaluate each answer on a 5-point scale (1 = not at all original, 3 = medium originality, and 5= very original).
	Appropriate-ness	Something that is **useful,** meets task constraints, and is **purposeful**.	Something can be original but not appropriate. For instance, a participant describes how to improve the quality of pocket tissues instead of listing as many creative uses for tissues as possible. These answers may be original, but they are not in line with the task requirements. Another example, knotting tissues together to make a rope to escape from a fire on the thirtieth floor, might be original but not appropriate, as the rope would tear and could catch fire easily.	Evaluate each answer on a 5-point scale (1 = not at all appropriate, 3 = medium appropriateness, and 5= very appropriate).
	Impact	Measure of the **positive tangible and intangible effects** (consequences) of one thing's or entity's action or influence upon another. We refer to "impact" as the benefits that can be derived from implementing a proposed solution, that is, the profit or gain in monetary and/or non-monetary terms (e.g., cost or time savings, increased customer or staff satisfaction, or other criteria).	Raising the price of cigarettes has a greater and more immediate impact on the reduction of tobacco consumed than large anti-smoking campaigns do. Being physically active in old age has a significant positive impact on both the individual's well-being (intangible benefit) and health status (both intangible and tangible benefits, e.g., fewer expenses for doctor visits and increased quality of life). Short-term solutions have a greater impact than long-term solutions because the benefits (tangible and/or intangible) can be harvested immediately.	Evaluate each answer on a 5-point scale (1 = no positive impact at all, 3 = medium positive impact and 5= very positive impact).
Type of process-improvement idea	*Locus of change*	Measure of the **key focus of the improvement idea**. We refer to the area that the improvement idea primarily addresses. The relevant areas in relation to the pizza-delivery process are: - *control flow*: the nature, sequence and order of the tasks that need to be executed in pizza delivery (e.g., prepare dough, bake pizza, select toppings). - *organizational resources*: staff involved in the pizza-delivery process (e.g., delivery person, pizza chef). - *technological resources*: tools and infrastructure involved in the pizza-delivery process (e.g., oven, refrigeration, car). - *information system*: any computerized system that might be involved in the pizza-delivery process (e.g., online ordering system, short messaging services, pizza status dashboard, electronic payment system). - *data*: any input or output information required or created in the pizza-delivery process (e.g., recipe, pizza orders).	Hiring more experienced staff to execute tasks is a change associated with the *organizational resources* in a process. Using a web-based system for online pizza ordering is an *information-system*-related change. Eliminating a quality assurance task is a change in the *control flow* of a process. Buying a new oven is a *technological resource* idea.	For each answer, identify whether the focus of the change idea falls into any of the five change areas: *control flow*, *data*, *information system*, *technological resource*, or *organizational resource*. Denote the locus of change only if one area **is clearly the most prevalent** one (e.g., not if a change simultaneously addresses data and organizational resources).

Appendix C: Manipulation Checks

First, we examined correlation statistics (Appendices C1 and C2) and the descriptive statistics for our key measures (Appendix C3). Correlations with significance levels $p < 0.05$ (two-sided) are marked with an asterisk and shaded grey. Correlations are based on the subsamples of the diagram and the text group (n=71). In particular, we examined the influence of domain-related experience to determine whether the group difference introduced bias. To do so, we calculated Pearson correlations of the measure *domain-related experience* with the means of all dependent variables over the three tasks. *Domain-related experience* correlated with *originality* (r=-0.18, p=0.03), as the more pizzas participants had ordered, the less creative were their ideas.

Appendix C1: Correlations of Control Variables with Dependent Measures (Pearson Coefficient).

	Types of ideas					Creativity of redesign			
Control Variables	Control Flow	Information System	Data	Technological Resources	Organizational Resources	Fluency	Appropriate-ness	Originality	Impact
Creative competence: fluency	0.34*	0.12	0.13	0.29*	0.07	0.36*	0.19	0.05	0.07
Creative competence: originality	-0.03	0.02	0.20	0.14	0.11	0.10	0.00	0.05	-0.11
Creative competence: elaboration	0.09	-0.03	0.07	0.18	0.04	0.11	0.10	-0.07	0.17
Creative attitude: intrinsic motivation	0.23	-0.05	0.05	0.09	0.05	0.16	0.12	0.14	0.08
Creative attitude: tendency toward premature evaluation of ideas	0.13	-0.06	-0.03	-0.06	-0.10	0.01	0.00	-0.14	0.06
Task-related experience: experience with process-improvement initiatives	-0.12	-0.07	-0.02	0.02	0.23	-0.05	0.00	0.14	-0.05
Domain-related experience: number of times ordered a pizza	-0.09	-0.20	0.03	-0.04	0.23	-0.09	-0.15	-0.20	-0.03
Age	-0.13	-0.11	-0.15	-0.27*	-0.13	-0.25*	0.12	0.13	-0.04

Appendix C2: Inter-correlations of Dependent Measures (Pearson Coefficient).

		Types of ideas					Creativity of redesign			
		Control Flow	Information System	Data	Technological Resources	Organizational Resources	Fluency	Appropriate-ness	Originality	Impact
Types of ideas	Control Flow	-	0.14	0.12	0.29*	-0.01	0.75*	-0.09	-0.25*	-0.15
	Information System		-	0.07	0.32*	-0.11	0.56*	0.22	0.27*	0.13
	Data			-	0.27*	0.08	0.39*	-0.35*	-0.22	-0.29*
	Technological Resources				-	0.27*	0.68*	-0.16	-0.13	-0.15

	Organizational Resources					-	0.28*	-0.29*	-0.10	-0.30*
Creativity of redesign	Fluency						-	-0.14	-0.14	-0.20
	Appropriateness							-	0.60*	0.75*
	Originality								-	0.45*
	Impact									-

Second, some studies reported gender-based influences on creative achievement [3], so we examined gender differences in our results. Independent sample t-tests showed that gender influenced the number of control flow related ideas (t=2.20, p=0.03) and the originality of ideas (t=2.65, p=0.01). Female participants developed more ideas concerning control flow ($M_{Females}$=6.22, $SD_{Females}$=3.00; M_{Males}=4.98, SD_{Males}=2.77), but their answers were rated less original ($M_{Females}$=2.97, $SD_{Females}$=0.30; M_{Males}=3.13, SD_{Males}=0.32).

Third, we examined potential effects of experiment fatigue. To avoid task-order effects, we used two orders of tasks. Subsequent t-tests showed that task order did not have a significant effect on the dependent variables, with one exception: the number of ideas related to organizational resources was related to task order (t=2.79, p=0.01). Overall, however, we argue that our experimental task setting was largely robust.

Appendix C3: Descriptive Statistics for Dependent Measures.

		Mean	SD
Fluency	Diagram	4.01	1.84
	Structured Text	3.92	1.52
	Text	3.65	1.37
Appropriateness	Diagram	3.56	0.28
	Structured Text	3.50	0.29
	Text	3.36	0.38
Originality	Diagram	3.10	0.33
	Structured Text	3.07	0.28
	Text	2.97	0.34
Impact	Diagram	3.59	0.16
	Structured Text	3.54	0.18
	Text	3.50	0.25
Control Flow	Diagram	5.91	3.52
	Structured Text	5.65	3.00
	Text	5.44	2.29
Information System	Diagram	3.34	2.09
	Structured Text	3.05	1.53
	Text	2.22	1.73
Data	Diagram	0.31	0.80
	Structured Text	0.41	0.72
	Text	0.78	1.02

Technological Resources	Diagram	1.54	1.07
	Structured Text	1.51	1.28
	Text	1.42	1.34
Organizational Resources	Diagram	0.86	0.91
	Structured Text	0.97	1.07
	Text	1.03	1.32

Appendix D: Supplementary Analyses

Post-hoc Analysis: Task

The correlations between dependent variables (Appendix C2) show that the number of ideas related to data, information systems, and the organization differed among the three innovation tasks. For both sets of hypotheses and for all dependent variables, we find that either the within-subject effect of the creativity task or the interaction effect between individual creative competence and the creativity task was significant. Thus, our results confirm that the specified objectives for the task setting determine the number and types of ideas generated.

Post-hoc Analysis: Gender

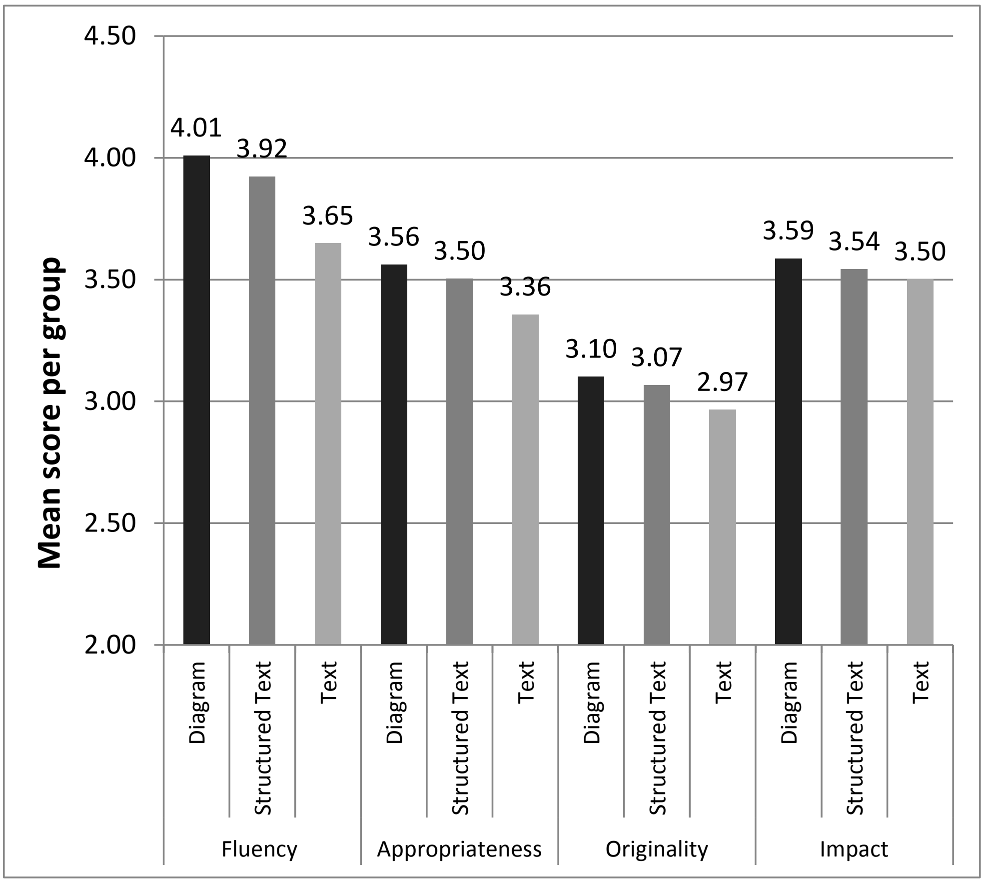
Our manipulation checks revealed that gender differences accounted for differences in the number of control flow ideas and originality. To determine differences between diagrams and text on the development of process-innovation solutions, we performed sub-sample tests that kept the gender factor constant while varying the other factor (i.e., diagram or text). We performed this analysis for all of the affected dependent measures. Appendix D1 summarizes the results. The number of control flow ideas is not influenced by the representation type in neither the male nor the female sub-group. In both sub-groups, the difference between the originality scores in the text and the diagram groups is not significant ($M_{Diagram}$=3.00; $SD_{Diagram}$=0.27; M_{Text}=2.88; SD_{Text}=0.33 for females and $M_{Diagram}$=3.30; $SD_{Diagram}$=0.36; M_{Text}=3.04; SD_{Text}=0.34 for males). This result might also be affected by the task objectives. A detailed look at the results at the task level revealed that, in tasks 1 and 3, gender and the type of representation are significant influence factors for originality, but not in task 2. One reason for this result might be that tasks 1 and 3 have more room for being original than task 2 does, as task 2 specifically asked how to use an employee instead of how to change the process in general.

Appendix D1. Sub-Sample Analysis for Gender Effects.

Sub-sample	Comparison	Significant difference on dependent variable?	
		DV: Originality	DV: Count of control flow ideas
Males	Representation Type (text vs. diagram)	Yes/No [$F_{df=1;38}$ = 3.97, p = 0.06]	Yes/No [$F_{df=1;37}$ = 0.01, p = 0.94]
Females	Representation Type (text vs. diagram)	Yes/No [$F_{df=1;29}$ = 1.59, p = 0.22]	Yes/No [$F_{df=1;28}$ = 0.00, p = 1.00]

Post-hoc Analysis: Structured Text

Next, we examined our main results in light of the data collected on the intermediary representation format, “structured text,” which was included to ease interpretation. The main results of this post-hoc analysis are summarized in Appendix D2, which demonstrates that, for all dependent variables for which we identified significant differences between the “text” and the “diagram” group, the results of the “structured text” group fall between the textual and the diagrammatic representation format. Values for structured text are based on a sample of thirty-seven participants drawn from the same basic population as the two main experimental groups; see Appendix C3 for descriptive statistics for all dependent measures.



Appendix D2. The Influence of Representation (Diagram, Structured Text, Text) on the Creativity of Process Innovation Solutions.

Appendix E: Associations of "Diagram" and "Text" with Types of Process Improvement Ideas

Appendix E1. Similarity according to WordNet. The path-length measure gives the inverse of the shortest path length between two concepts [61]. The maximum value is 1.			
Types of Process Improvement Ideas	Word Input	Path Length "Diagram"	Path Length "Text"
Control flow	"Sequence" "Order" "Task" "Control" "Process"	0.13 0.13 0.11 0.14 0.11	0.09 0.17 0.08 0.08 0.13
Organizational resources	"Organization" "Staff" "Employee"	0.08 0.14 0.09	0.11 0.13 0.08
Technological resources	"Technology" "Tools" "Infrastructure"	0.06 0.13 0.07	0.08 0.10 0.09
Information system	"Information system" "Computer" "System"	0.13 0.11 0.14	0.10 0.09 0.13
Data	"Data" "Input" "Output" "Information"	0.08 0.10 0.17 0.08	0.11 0.14 0.17 0.14