How Collaborative Technology Supports Cognitive Processes in Collaborative Process Modeling: A Capabilities-Gains-Outcome Model

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Abstract

We examine which capabilities technologies provide to support collaborative process modeling. We develop a model that explains how technology capabilities impact cognitive group processes, and how they lead to improved modeling outcomes and positive technology beliefs. We test this model through a free simulation experiment of collaborative process modelers structured around a set of modeling tasks. With our study, we provide an understanding of the process of collaborative process modeling, and detail implications for research and guidelines for the practical design of collaborative process modeling.

Keywords

Process modeling; collaboration; distributed modeling; collaborative technology

Introduction

Collaborative technology is an important means to facilitate group work in settings where people from various backgrounds across heterogeneous locations need to collaborate on specific projects [44]. One collaborative work setting that we are interested in is collaborative process modeling [14], that is, the design of graphical blueprints of inter- or intra-organizational business processes for purposes of global process standardization, organizational re-structuring or process performance measurement.

A variety of tools are available to create and analyze models of business processes [e.g., 65]; yet still studies and anecdotal evidence alike report challenges in the process of process modeling, most notably in the phases of eliciting business process information from relevant stakeholders, and formalizing them in a process model [26, 40]. These challenges are exacerbated in globalized set-ups of organizations and projects in which cross-organizational processes have to be designed. This is because in such a setting, required stakeholders (e.g., analysts, project managers and domain experts) are often geographically dispersed and need to engage in the process modeling effort from different, often remote locations.

While distributed collaborative process modeling could theoretically benefit from collaborative technology, to date, our understanding of the support of collaboration technology for process modeling is still limited. Our interest in this paper is thus to examine theoretically and empirically how collaborative technology can support process modeling in distributed settings. We draw on existing theories of group work to examine cognitive group processes involved in distributed process modeling. We theorize how technology can support essential steps in the process modeling process, resulting in enablement of collaborative modeling. We examine our model by studying groups of students that perform process modeling using a collaborative technology. Our results confirm a first conceptualization of the key cognitive group processes in process modeling, how they can be supported by technology and how they affect the outcomes of the process modeling process.

The sections that follow first discuss relevant research on process modeling, collaboration and collaborative technology. We then describe the development of our research model. Next, we discuss the set-up of our empirical study. In the following section we discuss the findings from our empirical study. We discuss the emerging implications for research and technology design. Finally, we conclude the paper with a review of contributions and limitations.

Background

Process Modeling in Collaboration

Process modeling describes the task of designing semi-formal, graphical descriptions of organizational or IT-based business processes [37]. Process models are designed using so-called process modeling grammars, i.e., sets of graphical constructs and rules, which define how to combine these constructs [67]. Most available grammars are essentially graph-based flowcharting notations that make use of basic shapes such as rectangles or circles, and arcs. Figure 1 gives an example of a process model that depicts start and end conditions, tasks, and relevant conditions specifying the order of execution, decision points, and paths of concurrent execution.

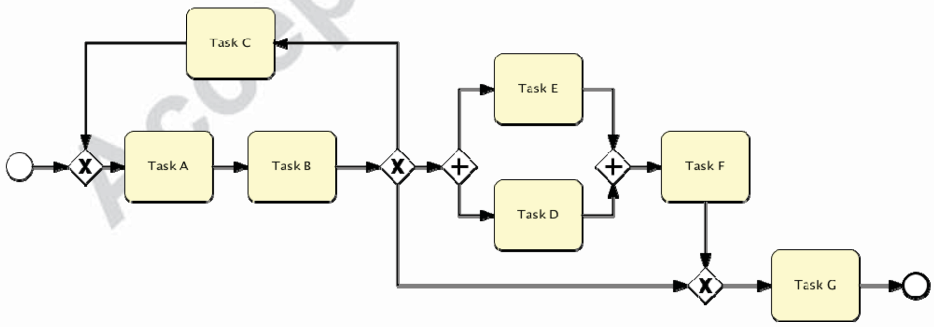


Figure 1: Example process model.

Process modeling grammars are implemented and used as a part of process modeling tools [62]. These tools typically provide a graphical model editor and complementary functionality enabling simulation, reporting, analysis, or even execution of the stored process models.

Perusing grammar and tools, the act of constructing a process model is commonly referred to as the *process of process modeling* [10, 36]. This process typically involves the three stages elicitation, modeling and validation [26].

During *elicitation*, a natural language (e.g., textual or verbal) description of the problem domain is developed by collecting relevant information objects (e.g., documents, data or informal explanations from process stakeholders), which are then verbalized using a common language. During *modeling*, these information objects are transformed into a formal specification (i.e., a process model) by mapping the components of the informal specification onto modeling concepts and relationships provided by the chosen modeling grammar and tool. Last, during *validation*, the model is typically paraphrased again in natural language in order to be able to validate the resulting text against the natural language description created during the elicitation stage [25].

In the literature, the process of process modeling has commonly been conceptualized as a single-person activity, i.e., one person being responsible for eliciting domain knowledge, creating a conceptual model, and validating the model. In academic settings, this single-person perspective is often used to train students in the competencies of both domain expertise and method expertise.

In corporate reality, however, method and domain expertise are typically distributed amongst different staff members in an organization, requiring the integration of the different viewpoints [17, 21]. Therefore it is necessary to include several domain experts in the process of modeling, whose knowledge needs to be elicited and consolidated. The integration of multiple stakeholders is also important for the validation stage, as a single person would be a potential source for modeling errors and subjective bias. In turn, the process of process modeling, by nature, is a collaboration task setting across all three stages rather than an individual task.

More recently, perspectives have emerged that describe process modeling as a goal-driven multi-stakeholder negotiation process [58]. This view acknowledges that different parties are involved in process modeling, most notably, the domain experts who generate and validate statements about the domain, and the business/process analysts who create and validate formal models.

This view of process modeling as a collaborative activity that includes dialogue and negotiation across multiple group members as part of the information elicitation, modeling, and validation stages, is appropriate especially in multi-national, multi-organizational or otherwise distributed process settings, where relevant domain and method experts work in a separated manner from geographically dispersed locations. In such settings, acts of dialogue or negotiation are difficult to perform due to the geographical and temporal dispersion of relevant stakeholders. This is similar to challenges in group work in general, and organizations therefore look for technology to provide support for collaboration in the process of modeling [8].

Early research on collaboration in process modeling has developed methodologies for business process reengineering on the basis of participatory design principles [5]. This stream of research has also yielded cooperative visual editors to support the elicitation stage of process modeling [61]. Recently, technologies have emerged to support some elements of group work across the three modeling stages elicitation, modeling and validation, by proposing process modeling or management suites with dedicated collaboration or 'social' features [28], such as commenting, social networking or user polling. A review of the implementation of such features in existing process modeling tools based on the level of social interaction is provided in [45].

Practitioner-oriented elaborations have focused on integrating the concept of social BPM into a wider organizational context for, e.g., enterprise transformation, process governance or change management [24]. Finally, some progress has been made in proposing novel technologies for collaborative modeling, for example on the basis of virtual reality platforms [8] or through the development of decisively collaborative modeling methods [60].

There is also some empirical research around collaborative process modeling [18, 59]. This work has in common that a specific collaboration technology was provided in an experimental setting to examine how a particular technology feature impacted on the process of collaboration in modeling.

A cross-sectional examination of technology support across all stages of the process modeling process, however, remains absent in the literature.

Collaborative Work

Collaborative process modeling can be described as a type of group work in which people frequently join forces to accomplish their task objectives through collaboration. By collaboration we mean a joint effort toward a common goal [13], such as jointly developing a model of an inter-organizational process. While such team efforts can be productive and successful [47], group work is also fraught with challenges that can lead to unproductive processes and failed efforts [48, 49].

Research on group work and technology support has addressed the advantages and disadvantages of technology-supported collaboration for many years. Importantly, this work has established that group work can be characterized on the one hand by a potential for *cognitive process losses* [49], such as airtime fragmentation, free riding, information overload, evaluation apprehension and incomplete use of information, which describe potential risks of reduced outcome levels in group work when compared to individual work efforts. On the other hand, group work can lead to improved outcomes in terms of *cognitive process gains* such as more information [42], more objective evaluation [63], knowledge sharing [2] and more learning opportunities [34].

Our interest is specifically in *cognitive process losses and gains* that occur when process modeling is conducted in collaboration from remote locations, and how technology can be used to offset the losses and improve the gains. One may imagine, for example, that collaborative technology could lead to process gains by providing *more information* about the process during elicitation, enabling pair wise *learning* by the participants and thereby improve joint knowledge about the modeled process as well as process modeling per se, and improving the ability for joint, consensual *evaluation* during the validation stage. We review relevant attributes of collaboration technology in the following, to examine whether such gains may potentially manifest during collaborative process modeling.

Collaboration Technology for Process Modeling

Collaborative technologies describe classes of IT systems employed to support the complex processes in distributed group work [4]. The provided capabilities of these technologies can be described using the groupware grid based on the Team Theory of Group Productivity [6]. The model posits that in group work, team members must divide their limited attention resources among three cognitive processes:

1. *Communication* refers to the cognitive processes involved in choosing words, behaviors, images, and other forms of communication to invoke collaboration with others. Typically, they require some sort of medium (e.g., audio/video, email or other) to collaborate effectively.
2. *Deliberation* refers to the cognitive processes involved in problem-solving activities related to the group task objective. These typically include problem sense-making, solution development and evaluation.
3. *Information access* refers to the cognitive processes involved in finding, storing, processing, and retrieving the information the group members need to accomplish their tasks.

Based on these three processes, team theory posits that technology has the potential to reduce the cognitive costs of joint efforts, in turn avoiding process losses and enabling process gains. This is because groups may become less productive if the cognitive demands for communication, deliberation, or information access become too high in collaborative settings. Technologies that provide support for some or all of these processes can reduce the cognitive costs (and thus reduce process losses) and improve productivity (and thus enhance process gains) [7].

To examine typical technology features for collaboration as they may be of relevance to process modeling, we examine each stage of the process of process modeling in turn:

1. During *elicitation*, collaborative modeling technologies can provide features to support information access and exchange between the involved stakeholders. The support typically manifests in features for synchronous and asynchronous communication (such as features for chats, multi user dialogues, and audio or video conferences).

2. During *modeling*, most modeling tools rely on single-user editing functionality, in which one user is allowed to make additions or other changes to a process model, which may be viewed (but typically not edited) by others after a commit (e.g., a saved version). Recently, collaborative modeling editors have been developed that allow for the simultaneous editing of process model content (such as addition, change or deletion of modeling constructs) congruent to an ongoing discussion of stakeholders logged in to the collaboration session.
3. During *validation*, technological support can exist in the form of features that provide easy access to current and historical data as well as logs of model change operations and information exchanges.

Research Model

We are interested in examining how collaborative technology features provided to participants involved in collaborative process modeling influences usage behaviors, and perceptions about the collaboration process and outcomes.

We conceptualize our view of technology support for collaborative process modeling in the model shown in Figure 2. Our view proposes that technologies, which provide features to support three stages of the process modeling process, viz., elicitation, modeling and validation, will enable cognitive process gains for the collaboration group in terms of empowerment and knowledge development. In turn, these process gains will result in elevated outcomes from the collaborative process in terms of the perceived quality of the model produced as the output of the collaboration process, as well as behavioral beliefs about the technology in use as perceptions about the collaboration process itself. We discuss the elements of our conceptual model and the key hypotheses contained in the model in turn.

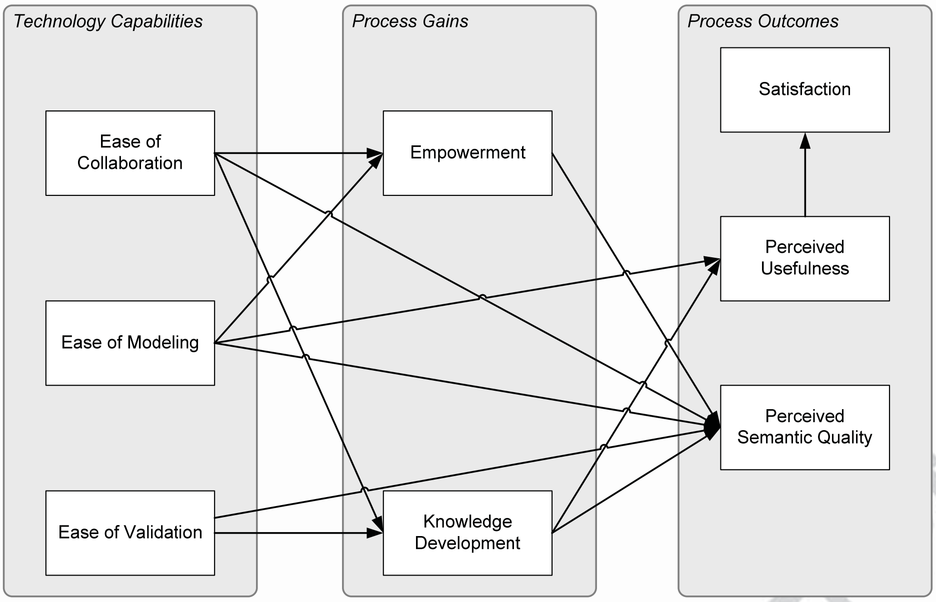


Figure 2: Research Model.

Effects of Technology Capabilities

Our model posits that collaborative process modeling technology that can support each of the three stages elicitation, modeling and validation will produce distinct effects manifesting as process gains as well as elevated beliefs about the outcomes of the collaboration process. We discuss these two types of effects below. Foreshadowing our empirical analysis that follows, we will refer to the example of the ProcessWave system to illustrate our arguments.

Ease of Collaboration

We argue that the technologies such as the ProcessWave platform can provide collaboration support in terms of enhanced communication features that are important especially during the elicitation phase of process modeling. Specifically, we posit that such communication features reduce the collaboration effort required to elicit relevant process information in terms of e.g. overcoming domination, lack of information and airtime fragmentation [49]. Accordingly, we expect that communication features increase the *ease of collaboration*, which we define as the effort of communication that occurs synchronously or asynchronously at the same space or concurrently at different spaces [19].

Ease of collaboration will lead to two gains in the collaborative work process: First, it will lead to *empowerment* of individual team members as they are enabled to provide and request information without being exerted to conformance pressure (reluctance to participate because of politeness or social fear), airtime fragmentation, or attenuation blocking [49]. Instead, ease of collaboration can lead to stimulation in that individuals are empowered to contribute and perform better [42, 63].

Second, ease of collaboration will contribute to process gains in terms of *knowledge development* opportunities. Easier access to, and provision of, information through communication features will allow the group to obtain more information than an individual alone [42] and individuals are provided an opportunity to learn from others [34].

Further, we also expect that ease of collaboration will directly contribute to building a better process model as the primary task outcome. A good process model is defined here as a model that achieves high levels of semantic quality as perceived by the stakeholders [43], which expresses how valid and complete a model is with respect to the users' perception of the problem domain. Efficiency gains that are enabled through improved collaboration support will enable individuals to peruse freed resources to increase performance in the modeling task and will lead to better information access for involved stakeholders, in turn increasing the likelihood of producing a high-quality model.

Ease of Modeling

Collaborative modeling technology may also provide features that directly contribute to the modeling stage of the process modeling process. For instance, tools such as ProcessWave allow for the simultaneous editing of process models by all involved stakeholders. Such features increase the *ease of modeling*, which captures the effort that is required to apply a modeling grammar in developing a diagrammatic representation of a business process [53].

We suggest that three effects stem from increased ease of modeling. First, it will lead to increased *empowerment* as a cognitive gain within the collaborative process of modeling. Individuals are enabled to contribute directly and without time or resource constraints in the actual act of modeling (viz., creating, editing or deleting), allowing them to contribute their ideas, abilities and skills directly and more easily to this task.

Second, the increased ease of modeling also results in the production of a better model in terms of the *perceived semantic quality* of the model, as the modeling act can benefit from the expertise brought to the task not by one individual but by the collection as a whole, and freed efforts in modeling allow users to deploy their resources more effectively in the task itself.

Finally, due to the criticality of the modeling stage as the key element of the process modeling process [26], we believe that technology that eases the effort of modeling will elevate perceptions about the *usefulness* of that technology. Perceived usefulness captures performance beliefs about the use of collaborative modeling technology in terms of whether the use of the technology improves the quality of the model produced or the overall success of the process modeling initiative, and reflects experienced effectiveness and efficiency gains [53].

Ease of Validation

In the last stage of the modeling process, we believe that technology features that provide access to all information exchanged during the act of modeling as well as access to historical data about how the model creation process unfolded lead to increased *ease of validation*, which we define as the effort applied for evaluating the accuracy and validity of the model as a representation of the process domain.

Our model posits that ease of validation will have two effects. On the one hand, it will contribute to process gains in terms of increased *knowledge development* for the team members. This is because information and historical data access will allow participants to learn more about the domain modeled as well as the process of modeling itself, in turn increasing the amount of available information but also overcoming information overload problems [49], as well as providing increased opportunities to observe and learn from skills and abilities brought to the modeling task by other members of the team [34].

On the other hand, ease of validation will also directly contribute to the *perceived semantic quality* of the model produced, as the effort required for identifying, evaluating and amending modeling errors during and after the modeling stage will be reduced through the technology, in turn leading to increased ability to identify and rectify modeling errors, thereby elevating beliefs about the quality of the model.

Effects of Process Gains

The team theory of group productivity argues that collaborative technology can provide features that assist cognitive group processes, overcoming process losses and leading to process gains. These gains will likely lead to better productivity in the group [48].

In the specific case of collaborative process modeling, two outcomes are of particular interest. First, the key outcome of such work is the model that is produced as the shared, agreed representation of a process domain. Our model posits that the process gains in terms of both knowledge development and empowerment that stem from the use of collaborative modeling technology will lead to a better process model produced through the collaborative work and will thus result in elevated beliefs about the *perceived semantic quality* of the process model produced in the collaborative modeling session.

Second, the process gains achieved through the collaborative modeling technology will also result in elevated positive beliefs about the use of the technology itself. Past research on the use and success of technology [16, 66] has suggested two key variables to be of primary relevance. *Perceived usefulness* describes the beliefs of users how much the technology allowed them to perform their work tasks (here: process modeling) effectively, i.e., how it enabled them to meet their task objectives [12]. Increased perceptions of usefulness will depend on the modeling capacities supplied by the technology (as captured in the ease of modeling construct and as hypothesizes above), but also through the levels of knowledge development enabled through the use of the technology. This is because process modeling is essentially a cognitive information processing task in which individuals apply, and increase, two types of knowledge: knowledge about the act of modeling (method knowledge) as well as knowledge about the process domain being modeled (domain knowledge) [31, 39]. Technology that allows group members to increase knowledge development, therefore, contributes directly to performance gains in process modeling, which will manifest in elevated usefulness perceptions.

Finally, perceived usefulness will lead to *satisfaction* with technology use as a reflection on the outcome of the technology-enabled task. Usefulness perceptions describe the beliefs about the instrumentality of the collaborative modeling technology for the task, and positive beliefs thus imply realization of expected benefits from technology use (such as assistance in meeting process modeling objectives, provision of all modeling constructs required to depict desired real-world phenomena and easing the effort of elicitation, modeling and validation) [3].

Research Method

Data Collection Strategy

To collect empirical data to examine our research model, we conducted a free simulation experiment [27] with student subjects. Free simulation experiments are different from traditional factorial experiment designs in that subjects are placed in a complex environment resembling a real-world situation as closely as possible where they are free to behave (within the required boundaries of the study, e.g., the rules of the task setting at hand) and are asked to make decisions and choices as they see fit. Free simulations do not involve preprogrammed treatments, and thus allow the values of the independent variables to range over the natural range of the subject's experience. In effect, the experimental tasks induce subject responses, which are then measured via the research instrument. Figure 3 visualizes the design of our free simulation experiment.

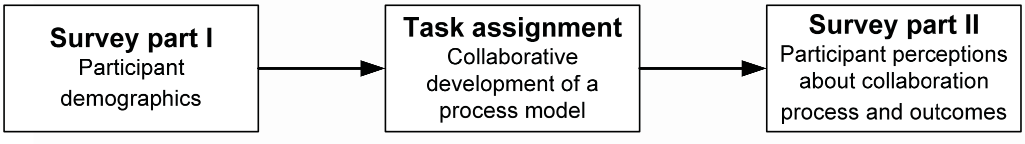


Figure 3: Design of the Free Simulation Experiment.

Specifically, in our data collection, we set up lab sessions in which invited participants were asked to model a process using a collaborative process modeling tool (http://www.processwave.org/), which runs on basis of the Google Wave technology. Appendix A provides relevant details about the tool used in our study. Prior to commencing the modeling task, subjects were asked to fill out a survey capturing basic demographics and experience information.

In designing the modeling task assignment, we perused the framework for evaluating conceptual modeling approaches proposed in [30]. This framework is based on two main dimensions (see Figure 4). The first dimension comprises factors that affect the conceptual modeling approach whereas the second consists of affected factors (i.e., outcomes).

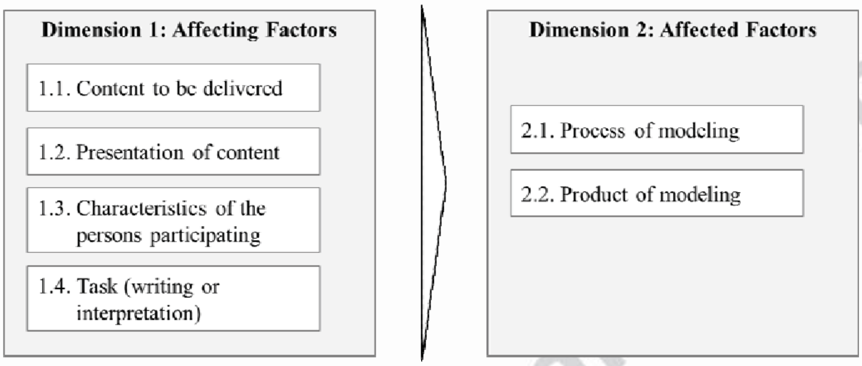


Figure 4: Framework for comparing modelling approaches (adapted from [30]).

Factor 1.1 (*content to be delivered)* refers to the type of information contained within the modeling cases. We deemed one modeling case to be sufficient to allow participants to explore, appropriate and use the collaborative modeling tool and, in turn, develop beliefs about the technology capabilities and their impact on the modeling process and outcome. We chose the process of purchasing a book on Amazon.com as an appropriate domain, because we could safely assume that all participants had some but varying levels of domain knowledge about this process, thereby resembling a realistic distribution of domain knowledge across all participants. Importantly, participants did not receive a case description but instead had to rely on their own knowledge of the domain to realistically simulate the elicitation and validation stages.

The second affecting factor (1.2 - *presentation of content)*, includes the following dimensions relevant to the study design. We selected BPMN as it is the most widely adopted standard for process modeling in industry [54], and included it with all its design rules [68]. Each participant was acting individually, relying on the collaborative support provided by ProcessWave, which includes textual representation (Google Wave) as well as graphical features (the ProcessWave modeling environment within a Wave). In this way, our study can be denoted as an intra-grammar comparison [30].

The third affecting dimension (1.3) describes the *characteristics of the persons participating* in the study. We collected data about method and domain knowledge during survey part I. We also collected data about prior experiences with process modeling, the domain, and the use of collaborative technology (such as Skype).

The last dimension (1.4) is the *task* itself, which usually is either model creation (‘writing’) or model viewing (‘interpretation’). In our research we focus on the act of model creation, thereby complementing the active stream of research investigating process model interpretation [e.g., 51, 56].

The *affected factors* describe the observable outcomes of the tasks that can be used as the source of dependent measures in empirical comparisons. Focus of observation points to what has been measured, either the process or the product of using a conceptual modeling approach. As per our research model, our interest is, first, the process of collaborative process modeling in terms of the developed beliefs about the perceived usefulness [12] of the supporting collaborative modeling technology and the perceived satisfaction [52] with the collaborative modeling technology; and second, the resulting product in terms of the semantic quality [43] of the process model created in the collaboration process.

We conducted a pilot study with four post-graduate research students to validate the study set-up and infrastructure. The findings from the pilot are reported in [33] and led to minor modifications to the procedure and instrumentation.

Procedures

We set up several sessions in which we invited students in groups of three to five modelers to use the ProcessWave platform for modeling the Amazon process in a collaborative, distributed manner. Overall, we conducted seventeen sessions. Our set-up allowed us to geographically disperse the participants whilst allowing them to work at the same time. All modeling sessions were supervised by the research team, by being (non-active) participants in the waves. Experiment instructions are available in Appendix B.

Task completion times were monitored but participants were given unlimited time to complete the modeling task. Each session started with a research assistant handing out the part I survey and then providing some basic instructions on using the ProcessWave platform (signing in to Google Wave, navigating the wave, using menu features). No modeling instructions were provided. Next, participants were informed about the task assignment (modeling the process of purchasing a book from Amazon.com), with the objective of creating an accurate, complete and clear BPMN model of the process. After completing this task, each participant was asked to fill out an online questionnaire (survey part II in Figure 3), in which we captured their experiences with the process and the technology in accordance with our research model and as detailed below.

Participants

The majority of existing experimental research in the space of process modeling [e.g., 46, 56] and other forms of conceptual modeling [e.g., 9, 31] relies on well-trained students. Also the stream of research on collaboration technology often relies on post-graduate students as experimental participants [e.g., 22]. We thus decided to invite post-graduate Information Systems students as participants to our study, to allow for the comparability of our results to other studies. This decision was also based on the argument that the use of experts can significantly bias experimental results [50], e.g., about the use of technology or method, not because of features of the artifact but because participants may be more familiar with the complexity or characteristics of the domain in which the experimental task operates.

Participants were drawn from post-graduate Information Systems courses in Australia and Germany. Each student had previously undertaken at least one coursework unit on process modeling with BPMN. This ensured that all participants had some but varying levels of expertise in process modeling with BPMN. Participants were randomly assigned to sessions and teams. Participation was voluntary and as incentives the students were offered the chance to receive one of several course books. Each modeling session was monitored to assure individuals completed the assigned tasks independently, relying only on the collaboration features provided through the ProcessWave platform.

In total, 65 students participated in overall 17 collaboration sessions. 70% of respondents were male. 30.6 % of participants were native English speakers, and the average age was 26 years (with a minimum age of 22 and a maximum of 51). Almost a third of the participants (32%) had professional experience with using BPMN for process modeling, and 34% had some experience with the ProcessWave platform prior to the study. The respondents, on average, had created 18 BPMN process models prior to the study, ranging from zero to 100 models.

Measurement

Eight constructs were measured in this study. All constructs were measured using multiple-item scales, using seven-point Likert scales anchored between “strongly disagree” (coded as 1) and “strongly agree” (coded as 7), with the midpoint “neither disagree nor agree (coded as 4).

Specifically, perceived usefulness of the ProcessWave platform was measured using the three-item scale for perceived usefulness of process modeling grammars developed by Recker and Rosemann [57] and used extensively in prior work [e.g., 53, 55]. The scale measures usefulness in terms of a general judgment of usefulness, and usefulness with regards to the participant's process modeling purpose and objective.

Satisfaction with the use of the ProcessWave platform was measured using the four-item scale by [64] as previously used in studies of process modeling grammar use [53]. The adopted scale captures respondents’ satisfaction levels (both in intensity and direction) along four semantic dimensions, these being contention, satisfaction, pleasure and delightedness.

Perceived ease of modeling was measured using the three-item scale adopted by Recker and Rosemann [57] from Davis’ [12] original scale. This scale has also been used extensively previously [e.g., 53, 55]. The scale differentiates the effort of using an approach for modeling from the effort of learning how to use the modeling approach.

The perceived semantic quality of the model produced was measured using the five-item scale developed and applied in [43], which has been used in a variety of modeling studies [32, 46]. The scale measures the perceived process model quality in terms of correctness, realistic representation, extent of contradictions, relevance and completeness.

Ease of collaboration was a newly developed scale, which we created by adopting the perceived ease of modeling scale – developed using the procedure in [57] – to focus on the process of collaboration on basis of the ProcessWave technology platform. Thus, the items of the scale were congruent to the perceived ease of modeling scale.

Similarly, we measured ease of validation by again appropriating the three-item perceived ease of modeling scale to the process of validating a process modeling on basis of the ProcessWave technology.

The scale for assessing perceived empowerment (PE) was self-developed as well, drawing on the theoretical dimensions identified in [11]. The five-item scale measures the perceived encouragement to contribute, the ability to exhibit ideas, the availability of equal rights in decision-making, the perceived process influence and the impact on the modeling process.

Finally, regarding the knowledge development aspect, we developed a six-item scale, differentiating between knowledge gains in the domain of process modeling (i.e. how to model processes) and the application domain (i.e. about the process modeled) on basis of the ProcessWave technology. The question phrasing for each of the two dimensions was based on the PU scale. Appendix C displays all scale items used.

Results

To ensure validity and reliability of our data, we first performed a confirmatory factor analysis. Appendix D provides the results, confirming appropriateness of our data.

Then, our data analysis concerned the estimation of a structural model through LISREL Version 8.80 [38]. The SEM approach is particularly appropriate for testing theoretically justified models

[29], as was the case in this study. Using LISREL, we created a structural model that linked the theoretical constructs as hypothesized in our research model. Each indicator was modeled in a reflective manner.

Figure 5 shows the structural model results. Goodness of fit statistics for the structural model (GFI = 0.82, NFI = 0.91, NNFI = 0.98, CFI = 0.98, SRMR = 0.06, RMSEA = 0.00, χ^2 = 419.03, df = 389, p = 0.14, χ^2/df = 1.08) suggest good approximate fit of the model to the data set [35]. We note a relatively low GFI value, however, some authors report values above 0.80 as representing reasonable fit [20]. Importantly, the model failed the χ^2 test (p = 0.14), lending strong support for model fit [23].

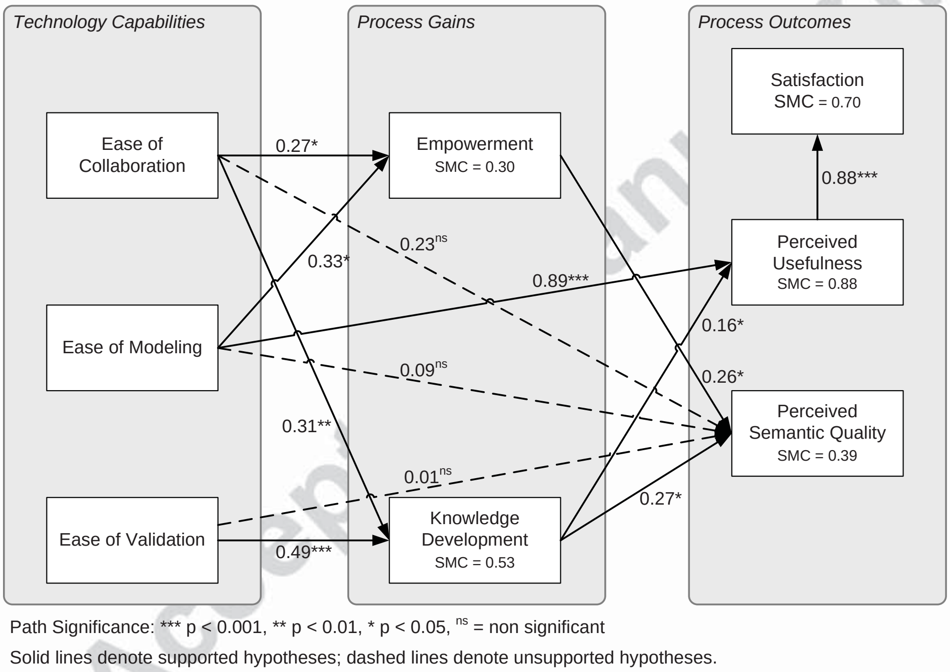


Figure 5: Structural model results.

We now examine the structural model for the significance and effect sizes (β) of each hypothesized path as well as the average squared multiple correlation explained (SMC) for each dependent construct.

First, the squared multiple correlation (SMC) values show that the model accounts for 70.0 percent of the variance in satisfaction with the use of the collaborative modeling tool, 88.0 percent of the variance in perceived usefulness and 39.0 percent of the variance in perceived semantic quality.

Empowerment and knowledge development achieved squared multiple correlation values of 30.0 percent and 53.0 percent, respectively.

Examining the hypothesized paths in the model, Figure 5 shows that all but three theorized paths were significant (at least at $p < 0.05$). Notably, the hypothesized direct effects of collaborative modeling technology capabilities and perceived semantic quality as an outcome were all insignificant, with β values ranging between 0.10 and 0.23. All other paths were statistically significant and in the correct directionality, overall lending good support for our research model.

Discussion

In general the data supports our proposed conceptual model. Nine out of twelve hypothesized paths in the model received significant support from the data, and the explanatory power of the three main dependent variables exceed 38 percent. Still, our empirical analysis identified one important deviation from the proposed conceptual model: contrary to our expectations, the effect of technology capabilities on the quality of models produced is not direct as expected but instead fully mediated by process gains in terms of enablement and knowledge development. There are several important conclusions that can be drawn from these results.

First, our findings emphasize the **importance of technology to create cognitive process gains for the collaborators** that, in turn, contribute to the semantic quality of the resulting models. Consequently, these findings also **de-emphasize any potential direct consequences of modeling technology support**. This finding stresses the importance of viewing technology as an enabler of collaborative work processes as opposed to technology as an aid for the act of process modeling itself.

Our findings also suggest that **ease of modeling as a technology capability is of central importance for making a collaborative modeling tool useful** (relative path significance of 0.89 versus 0.16 stemming from knowledge development). This is consistent with informal feedback we received from participants during our preliminary investigation. For instance, some participants encountered technical problems with the used tool, e.g. in terms of delays or errors in the synchronous editing of process models [33]. Such negative technology experiences were often attributed to the complex act of modeling. In the present study, the high coefficient of ease of modeling suggests this construct to be a hygiene factor of collaborative process modeling tools, i.e., a key requirement that users expect a modeling technology to provide.

Next, we found **empowerment and knowledge development are equally important to creating high-quality models**. This finding is consistent with a conceptualization of modeling quality as a relation between, among others, the model, its purpose, and its real-world counterpart [41]. We found that modeling **empowerment during modeling depends on collaboration support** offered by a tool, as much as **knowledge development requires suitable modeling and validation features** to be provided.

Finally, we found that **tool satisfaction and usefulness perceptions are independent from the quality of the produced models.** While elevated beliefs about the ease of modeling with the tool lead people to perceive the tool to be useful, this tool support does not guarantee that the models that are produced using these tools are good. **Users can be satisfied with a modeling technology even though the models they produce are not necessarily of high quality.** This finding is in line with the work on process modeling success factors [1], which also includes model quality and user satisfaction as two independent success measures. This finding draws attention to conceptual differences between behavioral beliefs about a technology as an outcome of a technology-enabled process versus the object beliefs about the outcome produced. Our model further clarifies that outcome generation (producing a good process model) is positively influenced by gains such as empowerment, which, however, are not influencing technology evaluations.

In summary, based on our findings we identify four main conclusions:

1. Process model quality is independent from the perceived usefulness of, and satisfaction with, a modeling tool. Tool satisfaction and usefulness are mainly driven by how easy or complex modeling can be performed with the tool.

2. Collaboration technology can lead to process gains in a group of modelers, which in turn will improve perceived process model quality.
3. Collaboration and validation technology features help gathering and extending knowledge in terms of the process domain and the modeling method.
4. Easy collaboration and modeling technology support are required to empower involved stakeholders to contribute.

Implications

For Research

For the stream of research on understanding the use of process modeling methods and tools in practice and the required enablers and inhibitors [e.g., 1, 55], our research adds a first conceptualization of the process of collaborative process modeling as enabled through dedicated collaborative process modeling technology. Notably, our findings remain consistent with models of process model quality [41] and process modeling success factors [1] whilst exploring in more detail the direct and mediating effects of advanced collaborative technology features onto the process of process modeling in a group.

To the body of knowledge on collaborative process modeling [e.g., 18, 59], we have added a first substantive cross-sectional empirical study of a novel conceptualization of the IT-enabled collaborative process modeling process. Our findings provide theoretical arguments that can aid design science on the development of advanced collaboration support [e.g., 8].

Further research can extend our study in several ways. Collaboration support can be implemented in different ways . For instance, technology features such as wikis, content provisions, recommendation agents or advanced visualization or communication features may also impact on the process of collaborative modeling. What is thus still required is a more extensive inventory of collaboration features of potential use to process modeling. Based on this feature list, we will be able to theorize in more detail about the detailed impact of each feature on empowerment and knowledge development. Experimental studies and think-aloud sessions could help to investigate which features provide the strongest process gains.

Also, decades of collaborative work research [48] has identified other process gains (such as stimulation or synergies) that could manifest in group work through appropriate technology support. Further studies could examine their impact on the process and outcomes of collaborative process modeling as a specific instance of group work.

Group support systems research has also shown how IT-enabled collaboration can also lead to process losses such as failure to remember, information overload, concentration blocking or socializing [49]. One important stream of research should thus examine decisively *negative* effects of technology support for process modeling. This could be done, for instance, through comparative experiments with traditional workshop settings for process modeling.

For Practice

We identify three primary ways in which our study informs the process modeling ecosystem. We discuss each area, in turn.

Collaborative Process Modeling Tool Design

Our results show that empowerment and knowledge development are potential benefits of collaborative modeling technology over and above any direct effects that technology has on the process modeling task. The value of corresponding tool features, however, strongly depends upon the ease of modeling offered by a modeling tool. Taken together, these results send a clear signal to tool vendors to draw attention to the collaboration support their solutions are offerings, whilst at the same time ensure a tight integration between the features, such that the core functionality of modeling business processes is not impaired. Instead, it will be important to support the act of collaboration independent from, but in addition to, supporting the act of modeling.

Tool Selection for Process Modeling Initiatives

Both empowerment and knowledge development have a considerable impact on perceived semantic quality of the produced models. These insights give directions for managers of modeling initiatives to consider tools that have dedicated collaboration features. To complement such tools, our results also suggest that managers may consider other technology-agnostic mechanisms to provide even more empowerment and learning opportunities for all involved stakeholders. Simple tools may include reflective journals, memos or feedback sessions, which participants can use to reflect on the collaboration and the learning experience. Our findings suggest that this might help to leverage empowerment and knowledge development, which will eventually translate to modeling success. This finding stresses the importance of selecting a modeling tool with appropriate collaboration support in order to increase the likelihood of success of an organization´s modeling project, and also stresses the importance to consider additional collaboration and learning tool support outside of the modeling tool market.

Employee Training and Team Composition

Regarding the stakeholders involved in the actual process (i.e. the domain experts), our findings draw attention to the importance of cognitive gains in the collaboration process, and the usefulness of technology to enable such gains. In turn, these findings suggest the importance of a faithful technology appropriation process by all involved parties. Warranting the appropriate use of the technology will enable benefits for the collaboration of stakeholders and will also create positive beliefs about the work and the technology itself. Faithful appropriation depends on clear messages about the design-intended use of a technology together with relevant tool training to enable faithful use. Key mechanisms to employ are conventions for the act of modeling as well as appropriate governance schemes that guide faithful tool use.

Further, in terms of knowledge development we suggest that collaborative modeling in itself can be a form of employee training where stakeholders collaboratively exchange domain information and modeling expertise, provided that collaboration support is appropriate. From an employer's perspective, the empowerment of employees is beneficial as it is associated with modeling results of higher quality. The consideration of different types of employee personalities (e.g., in terms of confidence or introversion) concerning team composition can be relaxed given the modeling tool empowers the stakeholders with respect to ease of modeling and collaboration.

Limitations

Our research bears some limitations. Our sample size can be considered small (n = 65). However, our measurement and structural model analysis yielded significant results with appropriate goodness of fit values, suggesting the adequacy of our sample size for our analysis. Our sample was drawn from post-graduate student cohorts, which have been argued to be adequate proxies for novice analysts [9]. A field study of practitioners was not feasible in our case due to the unavailability of a large population of collaborative modeling technology users. Over time, these technologies may enjoy wider adoption, which will then facilitate further cross-sectional field studies.

Aspects that threaten the generalizability of our findings to industry scenarios may be the homogeneity in the level of experience in process modeling (standard deviation: SD_{ME1}= 1.19, SD_{ME2}= 0.93, SD_{ME3}= 1.07) and collaboration technology usage experience (standard deviation: SD_{CE1}= 1.00, SD_{CE2}= 1.10, SD_{CE3}= 1.06) of our students, which might not be the case in industry. We did not examine statistically how varying levels of experience with process modeling, with collaborative technology or with the domain may lead to changes in the model produced. Such study is conducive to experimental research in which the effects and causal paths can be examined in more controlled scenarios than in our study design.

Another concern could be that the used tool may not be representative for other collaboration tools in process modeling, thus inducing a potential bias due to interaction of setting and treatment. This means that a similar task setting with a different tool in a replication may lead to a difference in results. For example, the restriction to communicate solely through chat functionality could be seen as an artificial constraint, as participants could also peruse audio communication features (e.g.

Skype or telephone conferencing) available elsewhere. This decision was made in favor of internal validity, to maximize the insights about the technology support and its consequences.

Conclusions

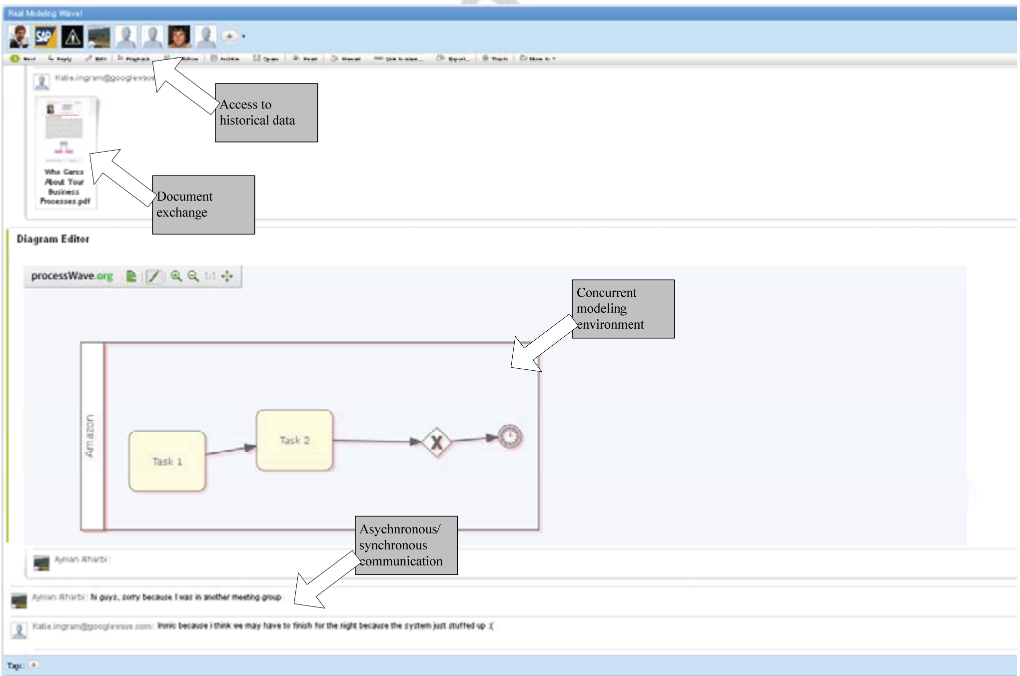
In this paper we reported on an empirical study of collaborative process modeling on basis of collaborative modeling technology. We advanced and tested a Capabilities-Gains-Outcomes model, which suggests a set of key technology capabilities that support three stages of the collaborative modeling process, the cognitive process gains this support enables, and its impact on outcomes of the collaboration in terms of quality of the model produced and evaluations of the technology.

We found that the effect of technology capabilities on the quality of models produced is fully mediated by process gains (i.e., enablement and knowledge development), thus stressing the importance of viewing technology as an enabler of collaborative work processes. Further, the ease of modeling construct as a technology capability appears to be of central importance for the perceived usefulness of a collaborative modeling tool. Next, we found empowerment and knowledge development to be equally important in predicting the perceived quality of process models. Additionally, empowerment builds on the collaboration support offered by a tool, as much as knowledge development requires suitable modeling and validation features to be provided. Finally, in terms of outcomes, tool satisfaction and usefulness are independent from the quality of the produced models. Overall, our research draws a picture of collaborative technology as an enabler of process modeling in distributed settings, with effects that are mediated through gains in the collaboration process itself.

Appendix

Appendix A: Details about ProcessWave

In the collaborative modeling task, subjects were assigned to use the ProcessWave modeling editor. ProcessWave is an outcome of the academic open source project ORYX [15] and runs on the Google Wave technology (http://wave.google.com). Even though the Google Wave technology was discontinued in April 2012, ProcessWave remains accessible via Google+ (http://www.processwave.org/2011/10/diagram-editor-for-google-hangouts.html). The tool provides standard process modeling functionality (supporting BPMN 2.0 and other notations) combined with real-time communication functionality in chat format from the Google Wave platform. Appendix A1 shows a screenshot of the ProcessWave tool, in which the concurrent, synchronous model editing and communication are visible in the form of waves of text, artifacts and model editing environment. The screenshot also shows other relevant functionality, such as the playback feature that allows for access to the historical log of communications as well as model change operations thereby enabling repetitive data analysis.



Appendix A1: ProcessWave Screenshot

Appendix B: Task Instructions in the Free Simulation Experiment

Please model the process of *'purchasing a book on Amazon.com'*.

Use the modeling notation BPMN. Assume that you are asked to create a model that can be used for communicating details about the process with relevant process stakeholders. This means the model should be accurate and complete! You should produce a model that is agreed upon by the whole team.

Hint: You are the ones to decide where the process starts, where it ends, what assumptions can be made about it and which level of abstraction is appropriate (and all other details).

At the beginning you should organize the modeling session, i.e. set the agenda/proceeding of the modeling session before you start the modeling. Use the modeling editor 'processWave Editor' (on Google Wave) to model the process.

When modeling, use only the provided tool features to communicate (e.g. chat), i.e. do not talk to your collaborators through other means (e.g., mobile phone) during this session. In doing so, please inform others of the decisions you are about to make. Example: You identified the step "buyer enters credit card details" to be an important part of the process. To model this you might think that "enter credit card details" is an activity performed by the buyer/ client which should be modeled as an rectangle in the pool of the buyer. Conveying these types of ideas and decisions to the others will be important for the collaboration to be effective.

Please use only the workstation that is assigned to you (see top of the login sheet). You should be logged in already (otherwise use the login code on your sheet). Use the wave 'Purchase on Amazon.com'.

Once you have completed your model in the group, please give a signal to the instructor.

Appendix C: Measurement Instrument

Construct	No	Item Definition	Reference
Perceived usefulness	PU1	Overall, I find ProcessWave useful for modeling processes.	[57]
	PU2	I find ProcessWave useful for achieving the purpose of my process modeling.	
	PU3	I find ProcessWave helps me in meeting my process modeling objectives.	
Ease of modeling	EOM1	I find it easy to model processes in the way I intended using ProcessWave.	[57]
	EOM2	I find learning to use ProcessWave for process modeling was easy.	
	EOM3	I find creating process models using ProcessWave is easy.	
Perceived semantic quality	PSQ1	The process model created using ProcessWave represents the business process correctly.	[43]
	PSQ2	The process model created using ProcessWave is a realistic representation of the business process.	
	PSQ3 (not retained in analysis)	The process model created using ProcessWave contains contradicting elements.	
	PSQ4	All the elements in the process model created using ProcessWave are relevant for the representation of the business process.	
	PSQ5	The process model created using ProcessWave gives a complete representation of the business process.	
Ease of collaboration	EOC1	I find it was easy to collaborate with other participants on process modeling using ProcessWave.	Self-developed
	EOC2	I find collaboration using ProcessWave for process modeling was easy.	
	EOC3	I find collaborating in order to create process models using ProcessWave was easy.	

Perceived empowerment	PE1	During this session I felt encouraged to contribute to achieving the process modeling results.	Self-developed, drawing on [11]
	PE2	I find that ProcessWave enabled an equitable decision making process during the process modeling.	
	PE3 (not retained in analysis)	Overall, I felt that I was able to bring in ideas and thoughts to the process modeling.	
	PE4	With ProcessWave, I have significant influence over what happens in modeling process.	
	PE5	With ProcessWave, my impact on what happens in the modeling process is large.	
Knowledge development	KD1	Overall, I find ProcessWave helped me gain knowledge on the modeled process.	Self-developed
	KD2	I find ProcessWave useful for learning about the process modeled.	
	KD3	I find ProcessWave helps me in acquiring knowledge about the modeled process.	
	KD4	Overall, I find ProcessWave helped me gain knowledge about process modeling.	
	KD5	I find ProcessWave useful for learning how to model processes.	
	KD6	I find ProcessWave helps me in acquiring knowledge about the modeling of processes.	
Ease of validation	EOV1	I find it easy to validate the process model in the way I intended using ProcessWave.	Self-developed
	EOV2	I find using ProcessWave for process model validation was easy.	
	EOV3	I find validating process models using ProcessWave is easy.	
Satisfaction with Processwave	SAT1	I am [extremely displeased – extremely pleased] with the use of ProcessWave for process modeling.	[52]
	SAT2	I am [extremely frustrated – extremely frustrated] with the use of ProcessWave for process modeling.	
	SAT3	I am [extremely disappointed – extremely delighted] with the use of ProcessWave for process modeling.	
	SAT4	I am [extremely dissatisfied – extremely satisfied] with the use of ProcessWave for process modeling.	

Appendix D: Scale Validation

To assess the reliability and validity of our scales, several iterations of confirmatory factor analysis were conducted using SPSS to identify and eliminate problematic measurement items. During this process, it became apparent that one item (contradiction, PSQ3) of the PSQ scale did not load appropriately – similar to the original study [43]. Therefore, we retained a four-item PSQ scale for all subsequent analyses (as shown in Appendix C). Also, for perceived empowerment (PE) we found that item PE3, the ability to exhibit ideas, did not load appropriately. We assume this is because the ideation process, which is the focus of this time, is not of relevance in a work setting where the task setting is to develop an accurate and realistic model of a current process – as opposed to contributing ideas to the development of a potential future (to-be) process. We excluded this item from all further analyses.

We discuss the measurement model analysis in the following. Item factor loadings are shown in Appendix D1. Appendix D2 and D3 summarize scale properties and construct correlations.

For all items, scale reliabilities were assessed using Cronbach's Alpha and found to be above 0.8 in all cases. The standard deviations of all scales were above 1, suggesting adequate variance in the scales.

All constructs were correlated with each other, with the highest correlations being between ease of modeling and perceived usefulness (see Appendix D3).

Internal consistency, discriminant and convergent validity were tested by extracting the factor and cross loadings of all indicator items to their respective latent constructs. The results shown in Appendix D1 and D2 indicate that all items loaded on their respective construct from a lower bound of 0.74 to an upper bound of 0.97, and more highly on their respective construct than on any other. Furthermore, each item's factor loading on its respective construct was significant at $p < 0.001$.Convergent validity was further supported by all composite reliabilities being 0.89 or higher and AVE of each construct being 0.73 or higher. Discriminant validity was supported by showing that the AVE of each construct was higher than the squared correlation between any two factors (the highest squared correlation was 0.66 between EOM and PSQ, see Appendix D3).

Appendix D1: Factor Loadings.

Item	EOC	EOV	KD	PE	EOM	PSQ	PU	SAT
EOC1	**0.92**	0.46	0.42	0.53	0.50	0.55	0.55	0.62
EOC2	**0.95**	0.56	0.54	0.54	0.53	0.53	0.57	0.70
EOC3	**0.96**	0.59	0.57	0.57	0.57	0.57	0.64	0.71
EOV1	0.57	**0.95**	0.63	0.48	0.48	0.51	0.60	0.57
EOV2	0.54	**0.97**	0.60	0.49	0.51	0.44	0.59	0.53
EOV3	0.56	**0.97**	0.62	0.49	0.51	0.51	0.57	0.57
KD1	0.45	0.39	**0.80**	0.41	0.39	0.36	0.50	0.50
KD2	0.48	0.58	**0.90**	0.49	0.51	0.43	0.60	0.52
KD3	0.44	0.63	**0.88**	0.44	0.41	0.41	0.51	0.48
KD4	0.57	0.55	**0.90**	0.44	0.36	0.50	0.52	0.57
KD5	0.42	0.57	**0.82**	0.36	0.31	0.42	0.42	0.42
KD6	0.46	0.56	**0.87**	0.35	0.30	0.44	0.46	0.50
PE1	0.35	0.34	0.39	**0.74**	0.32	0.37	0.31	0.33
PE2	0.34	0.45	0.32	**0.77**	0.45	0.44	0.44	0.38
PE4	0.49	0.31	0.29	**0.80**	0.47	0.48	0.42	0.43
PE5	0.49	0.32	0.30	**0.85**	0.57	0.45	0.49	0.52
EOM1	0.58	0.54	0.45	0.54	**0.90**	0.49	0.82	0.74
EOM2	0.37	0.27	0.24	0.40	**0.77**	0.37	0.51	0.44
EOM3	0.47	0.47	0.41	0.53	**0.89**	0.41	0.70	0.57
PSQ1	0.57	0.48	0.45	0.52	0.53	**0.92**	0.49	0.45
PSQ2	0.56	0.46	0.45	0.57	0.43	**0.95**	0.50	0.46
PSQ4	0.37	0.43	0.36	0.42	0.32	**0.75**	0.37	0.42
PSQ5	0.51	0.39	0.46	0.43	0.43	**0.85**	0.51	0.46
PU1	0.56	0.51	0.55	0.54	0.77	0.59	**0.94**	0.75
PU2	0.61	0.55	0.52	0.55	0.81	0.50	**0.96**	0.77
PU3	0.60	0.68	0.59	0.51	0.73	0.46	**0.95**	0.75
SAT1	0.74	0.61	0.62	0.57	0.72	0.58	0.86	**0.94**
SAT2	0.60	0.48	0.44	0.40	0.54	0.38	0.63	**0.91**
SAT3	0.53	0.47	0.43	0.53	0.66	0.37	0.63	**0.86**
SAT4	0.73	0.53	0.58	0.45	0.63	0.51	0.75	**0.94**

Legend:
EOC – Ease of Collaboration, EOV – Ease of Validation, KD – Knowledge Development, PE – Perceived Empowerment, EOM – Ease of Modeling, PSQ – Perceived Semantic Quality, PU – Perceived Usefulness, SAT - Satisfaction

Appendix D2: Scale Porperties.

Construct	Average factor score	St. Dev.	CRONBACH's α	ρ_c	AVE
EOC	3.21	1.64	0.94	0.96	0.89
EOV	3.52	1.56	0.96	0.98	0.93
EOM	3.78	1.69	0.82	0.89	0.73
KD	3.97	1.53	0.93	0.95	0.74
PE	4.49	1.55	0.85	0.89	0.73
PSQ	3.92	1.69	0.89	0.92	0.76
PU	3.73	1.78	0.95	0.96	0.90
SAT	3.57	1.47	0.93	0.95	0.83

Legend:
EOC – Ease of Collaboration, EOV – Ease of Validation, KD – Knowledge Development, PE – Perceived Empowerment, EOM – Ease of Modeling, PSQ – Perceived Semantic Quality, PU – Perceived Usefulness, SAT - Satisfaction

Appendix D3: Construct Correlations.

Construct	EOC	EOV	KD	PE	EOM	PSQ	PU	SAT
EOC	1.00							
EOV	0.57	1.00						
KD	0.55	0.64	1.00					
PE	0.58	0.50	0.48	1.00				
EOM	0.57	0.52	0.44	0.58	1.00			
PSQ	0.58	0.50	0.50	0.56	0.50	1.00		
PU	0.62	0.61	0.58	0.56	0.81	0.54	1.00	
SAT	0.72	0.58	0.58	0.54	0.70	0.51	0.80	1.00

Legend:
EOC – Ease of Collaboration, EOV – Ease of Validation, KD – Knowledge Development, PE – Perceived Empowerment, EOM – Ease of Modeling, PSQ – Perceived Semantic Quality, PU – Perceived Usefulness, SAT - Satisfaction

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