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A User Study on Modeling IoT-Aware Processes with BPMN 2.0

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Abstract: Integrating the Internet of Things (IoT) into business process management (BPM) aims to increase the automation level, efficiency, transparency, and comprehensibility of the business processes taking place in the physical world. The IoT enables the seamless networking of physical devices, allowing for the enrichment of processes with real-time data about the physical world and, thus, for optimized process automation and monitoring. To realize these benefits, the modeling of IoT-aware processes needs to be appropriately supported. Despite the great attention paid to this topic, more clarity is needed about the current state of the art of corresponding modeling solutions. Capturing IoT characteristics in business process models visually or based on labels is essential to ensure effective design and communication of IoT-aware business processes. A clear discernibility of IoT characteristics can enable the precise modeling and analysis of IoT-aware processes and facilitate collaboration among different stakeholders. With an increasing number of process model elements, it becomes crucial that process model readers can understand the IoT aspects of business processes in order to make informed decisions and to optimize the processes with respect to IoT integration. This paper presents the results of a large user study (N = 249) that explored the perception of IoT aspects in BPMN 2.0 process models to gain insights into the IoT's involvement in business processes that drive the successful implementation and communication of IoT-aware processes.

Keywords: IoT; BPM; BPMN; IoT-aware processes; user study

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1. Introduction

In a world rapidly moving towards unprecedented connectivity, the Internet of Things (IoT) has emerged as a disruptive technology paradigm that promises to revolutionize the way of interacting with the physical world [1]. As the electronic components of IoT devices are becoming cheaper, smaller, and more powerful, the IoT trend is progressing [2,3]. IoT devices are used in different domains such as cyber-physical systems, smart cities, and smart healthcare [4–6]. As IoT devices are typically equipped with actuators, sensors, network interfaces, and software, data can be collected from the physical environment and exchanged over the network. Sensors can be used, for example, to provide real-time information about the execution of activities, state of devices, interactions, and the current state of the environment, whereas actuators transform electrical signals into mechanical motion (e.g., rotate or translate) [7].

Business process management (BPM), in turn, aims to continuously improve processes to increase their performance, quality, and efficiency [8–10]. BPM involves a series of steps that make up the BPM lifecycle, including the analysis, design, modeling, automation, monitoring, and evolution of business processes [10]. Extending BPM with IoT capabilities offers a multitude of benefits when automating repetitive activities, monitoring the progress of a process and its activities, enhancing decision making, and tracking physical resources [9,11,12]. To realize these benefits, business processes need to accurately represent IoT involvement as well as IoT behavior.

1.1. Problem Statement

An IoT-aware process model utilizes IoT devices and maps IoT behavior to process activities and events, respectively [8]. For example, an IoT-aware order process involves IoT devices, describes the behavior of these IoT devices, and contains all activities to process the order. More specifically, an IoT-aware process model captures the activities, decisions, IoT devices, stakeholders, and resources involved in the corresponding process [13]. To benefit from an IoT-aware process model, it needs to be intuitively understandable to promote process model comprehension.

In order to comprehend process models correctly, an understanding of the semantics of the various modeling elements (e.g., activities or events) is crucial. In addition, a model reader should be able to determine where a process starts and where it ends and to determine the order in which the elements are traversed, the resources that are involved, and the specific behavior of the involved IoT devices. Without this information, the process model might be misinterpreted. In addition to these semantical and syntactical aspects of the modeling elements, the interpretation of the textual information, e.g., activity labels, is crucial as well. Proper labeling enhances the clarity of models by accurately describing the behavior of the respective modeling elements. This clarity is essential for understanding the purpose of each modeling element in a process model [13].

Misunderstanding a process model might affect its implementation and, thus, its execution at runtime [14]. An insufficient comprehension of the information derived from process models can lead to business processes not achieving the intended outcomes or even failing. In the realm of process modeling, the identification of relevant information relies on the recognition of related pictographs and their precise association with corresponding semantics. Pictographs, e.g., circles denoting events, serve as visual representations in process models, each carrying a distinct meaning. In BPMN 2.0, for example, pictographs include circles representing events, rectangles representing activities, and diamonds representing decision points. Activities may be enhanced with icons; e.g., a service task is depicted using a gear icon, whereas a script task contains a script icon [10]. For model readers, the challenge is to correctly associate the pictographs with the intended semantics, which requires a profound understanding of the nuanced distinctions of the various icons [13,14].

When interpreting rectangles as activities or diamonds as decision points, a clear understanding of their semantics is essential. This complicated procedure goes beyond mere visual recognition, necessitating a comprehensive understanding of semantics. Mastering these skills enables professionals to not only identify the components of a process model, but to interpret and analyze the flow of the model in a nuanced way [14,15].

There are several modeling notations for business processes, such as Petri nets, event-driven process chains (EPCs), Unified Modeling Language (UML), and business process modeling and notation (BPMN). The latter is the de facto standard for modeling business processes in the BPM domain, and is broadly used in both industry and academia [8]. Researchers [3,6,16–26] have contended that BPMN 2.0 possesses capabilities that allow for the modeling of IoT-aware business processes as well. They further argue that BPMN 2.0 is a standardized notation for business process modeling, providing a framework that effectively captures various aspects of complex processes, including IoT-aware processes. Contrary to the viewpoint that BPMN 2.0 can seamlessly model IoT processes without extensions, other researchers emphasize the need of explicitly distinguishing between non-IoT-related tasks and IoT-related tasks during the design phase [16,25–34].

Modeling IoT-aware processes in the context of BPM has been extensively studied in the literature [25,26,35]. Researchers have dedicated substantial attention to investigating the challenges associated with integrating the IoT into the modeling phase of the BPM lifecycle. This research primarily examines the technical aspects from an expert perspective, often neglecting the viewpoints of end users, developers, analysts, and stakeholders. Investigating the user perspective, however, is important as it makes a crucial contribution to the practical applicability and acceptance of modeling approaches. While the expert perspective provides valuable insights into theoretical concepts and technical aspects, the domain expert perspective reflects the reality of those who will actually apply these models [8,10,25]. Consequently, user studies are needed to evaluate the various approaches proposed to integrate IoT aspects and BPMN 2.0. Corresponding studies should provide insights into the perspective of end users, developers and analysts and the perception of stakeholders. To the best of our knowledge, no other user studies investigating IoT involvement in BPMN 2.0 process models from a domain expert perspective exist so far.

1.2. Contribution

In this paper, we explore the discernibility of IoT aspects in BPMN 2.0 process models with respect to the user perspective in an empirical study (i.e., questionnaire) with 249 users. We want to know whether IoT involvement, i.e., the use of sensors and actuators in a BPMN 2.0 process model, becomes visually or label-based discernible when modeling IoT-aware business processes with BPMN 2.0. In particular, we are interested in whether certain BPMN 2.0 modeling elements visually indicate the IoT's involvement in the process clearer than others. Furthermore, we want to investigate the difficulty of reading IoT-aware processes modeled with BPMN 2.0. We present multiple variants of an IoT-aware process to study participants using different modeling elements (e.g., service task, script task, business rule task, and pool) in each variant that shall represent IoT involvement. The results of this study will enable detailed insights into the modeling of IoT-aware business processes with BPMN 2.0 as well as potential limitations emerging in this context. Our findings reveal significant insights into the effectiveness of current BPMN modeling practices in conveying IoT aspects, highlighting the challenges users face in discerning IoT involvement solely based on visual cues or task labels. By providing a detailed analysis of these challenges, our study not only contributes to the academic discourse on BPMN and IoT integration but also offers practical recommendations for improving BPMN modeling conventions to better accommodate IoT modeling elements.

The remainder of this paper is structured as follows: Section 2 presents the related work. Section 3 introduces the background needed to understand the fundamentals of IoT-aware business processes. Section 4 presents the study goal, materials, and method of the study. In Section 5, study results, including the inferential statistics, are presented. Section 6 discusses the implications as well as limitations of these results. Finally, Section 7 summarizes the paper and gives an outlook on future work.

2. Related Work

In recent years, many approaches, extensions, and notations for handling IoT-aware business processes have been developed. The evaluation of related work is based on a literature study regarding the topics of the *Internet of Things*, *business process management*, *business processes*, *IoT-aware business processes*, *cyber-physical systems*, and *wireless sensor networks*. Moreover, this study is complemented by various literature surveys on these topics [16,25,26,35–41].

Ref. [16] explores the integration of the IoT in business process management through BPMN 2.0. It further provides an overview of the IoT paradigm, differentiating between sensors and actuators, and discusses the integration of the IoT with business processes. Moreover, this paper reviews the current BPMN 2.0 modeling elements that could support IoT modeling and execution such as scripts, services, and business rule tasks, events, resources, and data handling approaches. However, the authors acknowledge the need for further development of the BPMN 2.0 notation to fully support IoT process modeling, configuration, and execution.

Ref. [18] introduces a methodology for managing IoT devices within controlled environments and agriculture using a BPMN-based approach. This method employs the BPMN script task to facilitate both push and pull interactions with IoT devices, proposing an intricate architecture. Additionally, the approach suggests a system for monitoring IoT-aware business processes through a web framework built on Python with the Django framework.

Refs. [30–32] advocate for applying the BPMN standard in documenting aspects of wireless sensor network (WSN) applications, where Java and C# codes are produced and executed on the Mote Runner WSN platform. This involves converting BPMN 2.0 process models into executable code using specific patterns.

The **uBPMN** [28] extension enhances BPMN 2.0 with additional task types for comprehensive IoT device interaction, including tasks for sensing, reading, image processing, audio processing, and general data collection from ubiquitous technology (e.g., NFC, tags, magnetic stripes, and RFID). uBPMN also introduces IoT-driven data and context objects for a more nuanced representation of IoT data and contexts.

Ref. [19] focuses on utilizing BPMN 2.0 for modeling business processes and converting these models into Guard-Stage-Milestone (GSM) artifacts for deployment on smart objects, necessitating a distinct infrastructure setup. Ref. [20] recommends employing the BPMN resource class for integrating IoT devices as data objects and the BPMN performer class for specifying the IoT devices in the process. The BPMN 2.0 process models are then converted into executable code for the Callas platform, enabling IoT device operation.

Ref. [21] discusses the surveillance of multi-party IoT-aware business processes, starting with modeling these processes using BPMN 2.0, followed by deriving an extended GSM model from each BPMN artifact, and finally, employing smart objects to convert BPMN artifacts into active entities. A specific architecture for monitoring is also proposed.

Ref. [22] suggests defining IoT-aware business processes with BPMN 2.0 and managing the interaction between IoT devices and business processes through the Bosch IoT Things Service. Refs. [3,23] explore using BPMN 2.0 for modeling IoT-aware business processes and propose architectures for executing these models, including decentralized execution over mobile nodes and a microservice architecture, respectively. Ref. [42] proposes using BPMN 2.0 service and script tasks for IoT-related activities and a layered architecture for their execution and monitoring.

The **SPU** [43] extension to BPMN 2.0 focuses on managing data streams within IoT-aware business processes through two specific tasks for event stream specification and processing, alongside introducing the concept of data streams for smart device communication. The *event stream specification* task reflects the input and output data in the form of event streams, whereas *event stream processing* manages the event stream.

BPMNE4WSN [33] extends BPMN 2.0 to specifically address wireless sensor networks by introducing WSN tasks, pools, and performance annotations, enriching the modeling capabilities for WSN applications. Furthermore, the specific tasks include different attributes such as (1) *actionType* for defining the operation (e.g., sensing or actuating), (2) *tWSNOperation* for binding a WSN operation, and (3) *isEventDriven* to mark the specific task as event-driven.

BPMNE4CPS [29] extends BPMN 2.0 for cyber-physical systems by introducing additional task types and a symbolic pool to represent physical entities, facilitating the modeling of complex CPS processes. BPMNE4CPS extends the BPMN 2.0 metamodel with a sensor, an actuator, a web service, an embedded service, and cloud service tasks.

FloBP [6] is a model-driven method for integrating IoT capabilities into business processes. This approach aims to overcome the challenges of merging the IoT with business processes by providing a structured methodology that separates concerns between the IoT and business process management, fostering interdisciplinary collaboration. In general, FloBP uses modeling tools and a microservice architecture to deploy BPMN models and facilitate the integration with the physical world, thus supporting multiple IoT device technologies.

Refs. [44,45] extend BPMN 2.0 with elements for sensing and actuation tasks and representing physical entities (e.g., a bottle of milk), enhancing the process model with the ability to depict interactions with smart devices and physical entities. Ref. [46] extends BPMN 2.0 for smart services and sensor device management, respectively, providing more granular control and interaction capabilities with IoT devices within business processes. The presented approach suggests extending the BPMN 2.0 metamodel with a sensor task.

The extension presented by [47] introduces location-based event types to BPMN 2.0 for representing sensitive information, improving the process model for geographically oriented applications. For this purpose, three location-based events are presented: (1) place achieved, (2) position update, and (3) conditional positional event.

Discussion of Related Work

Research on the topic of integrating IoT capabilities into business processes falls into two categories: extending the BPMN 2.0 metamodel with IoT-specific modeling elements, and using standard BPMN 2.0 modeling elements like tasks (i.e., service, script, and business rule tasks), events, and pools. Many researcher argue that BPMN 2.0 in its current version may not be specific enough to effectively represent the complexity of IoT-aware business processes and propose a BPMN 2.0 extension to better adapt BPMN 2.0 to the specific IoT behavior. Opponents of this strategy note that these expansions may increase the complexity of modeling business processes, confuse the process modeler, and make it more difficult for stakeholders to comprehend the business process without more training. On the other hand, researchers utilizing BPMN 2.0 as-is contend that BPMN 2.0 is sufficient and adaptable for expressing IoT-aware business processes utilizing its current modeling elements.

The debate on using BPMN 2.0 to model IoT-aware business processes is mostly from a technical perspective, with experts who delve into the theoretical and practical nuances of business process modeling. This expert-driven discussion highlights a notable gap in the literature: the absence of user studies specifically investigating the suitability of BPMN 2.0 for IoT-aware business processes. This gap highlights a critical oversight, as the discussion relies on expert views and theoretical arguments without directly addressing how these models translate into practice, especially for those who design, implement, and interact with these processes on a daily basis. This gap highlights the need for empirical research that evaluates the effectiveness and clarity of using BPMN 2.0 in the context of the IoT and bridges the gap between theoretical assumptions and practical applicability.

3. Background

This section provides the basics of the process models, Internet of Things, and IoT-aware process models.

3.1. Process Model

In the area of modeling, the essence of a business process model takes center stage, representing a tool that depicts the process flow as well as the interactions within a given technique or system (e.g., databases and data warehouses) [48]. A process model is described as ”a set of activities performed in coordination in an organizational and technical environment” [49]. More precisely, a process model represents an effective tool for analyzing and documenting the intricacies of complex processes. Usually, a process model includes elements such as sequence flows, decisions, inputs and outputs, and resources (e.g., IoT devices) that enable a comprehensive visualization of the dynamic nature of a given system [10].

A standard notation for visually modeling processes, both in research and practice, is BPMN 2.0 [50]. The key modeling elements of BPMN 2.0 are grouped into four basic categories: (1) Flow objects (i.e., activities, events, and gateways), which define the behavior of the process. The flow objects and (2) additional artifacts (i.e., data object and data storage) are connected to each other by means of (3) connection objects (i.e., sequence flow, message flow, and associations). To assign the activities to a certain role or participant, (4) swimlanes (i.e., pools and lanes) can be used [51].

The use of these modeling concepts enables the visual representation of process models [51,52]. These process models not only cover process behavior visually, but also contain detailed process information. The latter includes, for example, information on the resources performing a task (i.e., who is responsible for which task) or information on whether or not a task is automated. Furthermore, visual process models foster collaborative modeling and enable a common understanding of the process flow. To illustrate the different BPMN 2.0 modeling concepts, Figure 1 shows an example of a BPMN 2.0 process model of a supplier purchasing process.

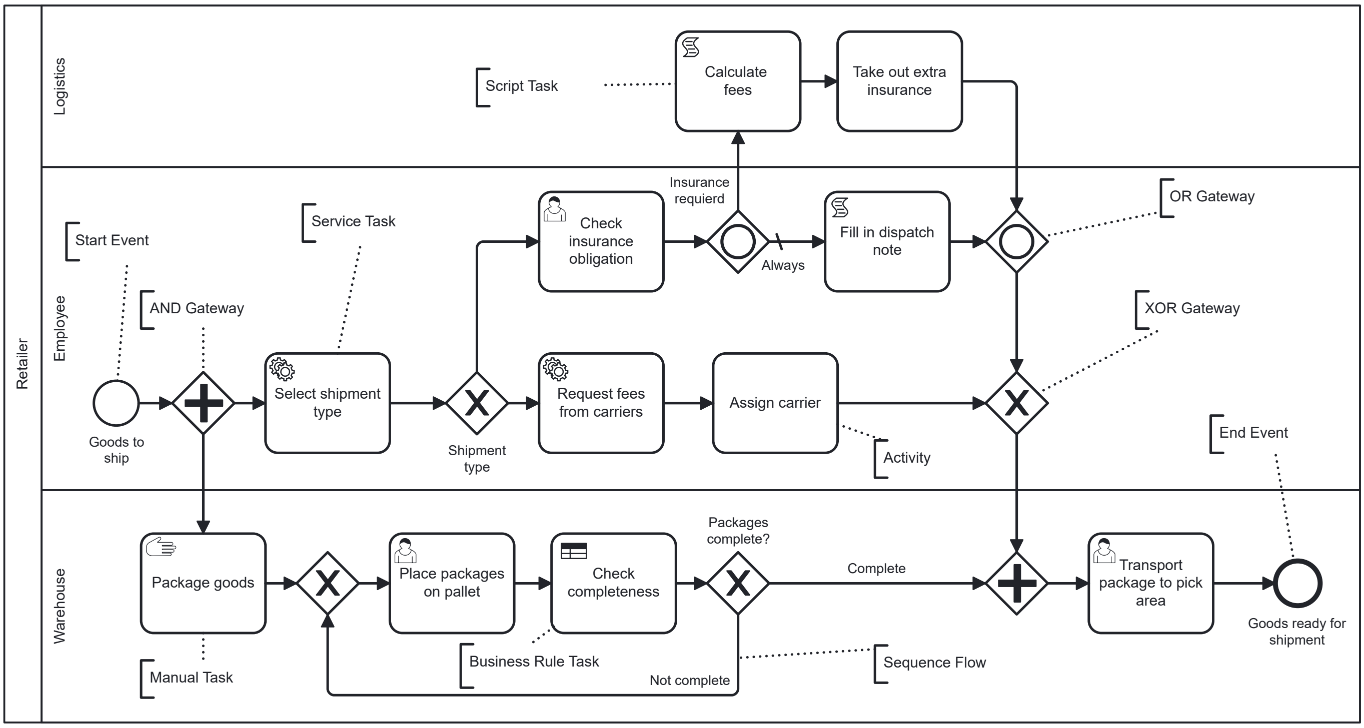

Figure 1. BPMN 2.0 process model.

3.2. Internet of Things

The Internet of Things (IoT) is characterized by a network of interconnected physical objects equipped with actuators, sensors, software, hardware, and network connections [3,8,9,42,53]. These interconnected IoT devices facilitate the collection, processing, and utilization of data from the physical world, enabling an impact on the physical environment as well as communication with other smart entities. The IoT reference model [54] consider sensors and actuators as key components within IoT devices and environments. An IoT device may comprise multiple sensors and actuators. From the IoT perspective, the following fundamental types of devices are relevant:

- Sensors play a central role in detecting and measuring a variety of physical and chemical properties, such as brightness, temperature, and humidity. Thereby, a sensor detects the desired physical parameter and converts it into an electrical output signal using various transducers such as inductive, capacitive, magnetic, or piezoelectric mechanisms [3,17,55]. These sensors may be placed near physical objects and be seamlessly integrated into the environment or even embedded directly into a smart device. Typically, the resulting sensor data are accessed by clients via web-based protocols such as MQTT or RESTful API via a publish/subscribe framework [11,54]. This seamless integration of sensors and communication protocols not only enriches our understanding of the physical world, but also provides a framework for various applications in the broader IoT field.
- Actuators serve as dynamic components and act as driving elements that convert electrical signals into tangible mechanical actions, including translation and rotation [54,56]. In addition, they are able to change physical quantities such as the light intensity, pressure, or temperature in their operating environment. Essentially, actuators have the inherent ability to change the state of a physical entity and thus play

a transformative role in the field of technological interfaces [8,9]. The orchestration and control of actuators are often facilitated by web services that follow the REST paradigm and work with the HTTP protocol. This connectivity and control mechanism highlights the versatility of actuators and their central role in orchestrating the responsive and adaptive behavior in various technological applications [56,57].

Another crucial dimension in the realm of interconnected IoT devices is the exchange of information and their interaction with external systems (e.g., a BPM system). In this context, IoT devices have intrinsic features such as parallelism, asynchronicity, and event-driven communication [3,17,27,57]. Note that these aspects are defined in the information view layer of the IoT reference model [54], offering a comprehensive framework for understanding how data are structured and exchanged within the interconnected IoT devices.

The following intrinsic characteristics are crucial for the application of connected IoT devices: parallelism, asynchronicity, and event-driven communication [3,17,54,57,58]. Parallelism refers to the simultaneous execution of several tasks or processes, which increases the efficiency of the device when processing different operations at the same time [55]. Asynchronicity, in turn, describes the concept where the non-blocking nature of IoT devices allows them to complete independent tasks without waiting for other tasks to finish [57]. Finally, the push and pull interactions describe the bidirectional communication capabilities, with the devices either actively transmitting data (push) or requesting certain information (pull) depending on their operational requirements [58–60]. Note that the use of IoT devices requires systems that support the described intrinsic characteristics of the IoT devices.

3.3. IoT-Aware Process Models

A process model is considered as IoT-aware when it describes and depicts the influence of the Internet of Things on the process model [4,29,35,45]. IoT-aware process models consider the integration of individual IoT devices such as sensors, actuators, and objects. Furthermore, the process models can be used to identify how data from IoT devices are recorded, processed, and integrated [27,35]. Additionally, IoT-aware process models are able to (1) automate processes with the help of IoT devices (e.g., actuators), (2) transfer the physical world into the digital world, (3) support decision making by taking into account the current state of the real world, (4) enable more accurate monitoring of the currently running process (e.g., through the use of sensors), and (5) support the logging of the process, as processes can be observed more precisely using IoT devices [9,18,25,35]. In general, there are two types of interactions between a business process and IoT devices [9,54,61]:

1. **BP-to-IoT interaction:** the business process initiates communication, explicitly requesting data or triggering actions within an IoT device (e.g., move x-axis).
2. **IoT-to-BP interaction:** this represents a more autonomous data flow, where IoT devices proactively contribute information to the business process.

4. Materials and Methods

This section describes the user study we conducted. In general, we combined the methodologies from [62,63] to obtain profound insights into IoT involvement in BPMN 2.0 process models from a user perspective (i.e., process model reader).

4.1. Study Goal

The primary objective of the study is to evaluate the current capabilities and limitations of BPMN 2.0 in modeling IoT-aware business processes. In this context, it is crucial to understand how effectively BPMN 2.0 supports the representation and understanding of IoT devices and their interactions within a process model. This study aims to bridge the gap in the literature, identified as the absence of user perspective analyses in expert-driven discussions on the adequacy of BPMN 2.0 for modeling IoT-aware processes, by conducting an empirical investigation on how users perceive the IoT's involvement in BPMN 2.0 process models, both IoT-to-BP and BP-to-IoT (cf. Section 3.3). By focusing on the user perspective, this study aims to gain insights into the visual (i.e., task types) and label-based (i.e., task labels) discernibility of IoT devices in process models and the way these aspects influence the comprehension of IoT-aware business processes. Furthermore, this study shall explore the cognitive load and user experience associated with the modeling and interpretation of IoT-aware processes using BPMN 2.0. Overall, the following research questions are considered:

RQ1 Is the involvement of the IoT in BPMN 2.0 process models visually discernible?
RQ2 Is the involvement of the IoT in BPMN 2.0 process models discernible based on task labeling (i.e., label-based)?
RQ3 Is the involvement of the IoT in BPMN 2.0 process models discernible with a combination of both visual and label-based representation?
RQ4 Are there modeling elements in BPMN 2.0 that make the involvement of the IoT clearer than others?
RQ5 Are there modeling elements in BPMN 2.0 that reduce the effort and frustration of humans when reading IoT-aware business processes?

RQ1 focuses on the visual discernibly of IoT involvement in a process model. It aims to ascertain the clarity of this involvement concerning the visual representation of business processes. When addressing RQ2, the focus is shifted to the textual dimension, exploring whether the presence of proper BPMN 2.0 task labels enhances the study participants' ability to properly identify IoT involvement. RQ3 focuses on a combination of visual and label-based discernibly of IoT aspects in BPMN 2.0 process models. For RQ4, we use diverse BPMN 2.0 modeling elements to represent IoT involvement, aiming to figure out whether certain BPMN 2.0 modeling elements make IoT involvement clearer for study participants than other elements. Finally, RQ5 delves into the potential impact of IoT involvement on the efforts and frustration of model readers by exploring whether the cognitive demand increases when trying to comprehend IoT-aware process.

4.2. Participants

This study involved 303 participants in total who could access to the questionnaire over a period of thirteen months. A total of 260 participants completed the online questionnaire, resulting in a completion rate of 85.81%; 11 participants were identified as outliers and hence were excluded from the analysis due to invalid responses or incompletely filled questionnaires, leaving a total of 249 complete responses. The average completion time of the questionnaire was 17 min and 10 s.

There were no prerequisites for participating in the online study. All participants were recruited at Ulm University and included research assistants, professionals in the academic network, and students from various disciplines such as software engineering, computer science, business informatics, business analytics, and business economics. A total of 158 (63.45%) participants were male and 91 (36.55%) were female; their mean age was 23.30 years (SD = 3.40). The majority (58.63%) of respondents held a bachelor's degree.

To distinguish between experts and novices, the participants were examined using BPMN 2.0 process models. Here, the participants had to specify the task types used in the process model. This distinction identified in 66 experts (26.50%) and 183 (73.49%) novices. In addition, participants were asked about the number of processes they had modeled before participating in our study. While the experts had modeled on average 17 (SD = 20.29) process models, the novices had modeled 4 (SD = 8.99) processes. By using a 5-point Likert scale, participants were asked for their prior experience in BPMN 2.0 (i.e., ranging from not experienced (1) to highly experienced (5)). Table 1 summarizes the sample description.

Table 1. Description of demographic statistics.

		All Participants	Experts	Novices
Age	Mean (SD)	23.30 (3.40)	24.35 (3.10)	22.93 (3.45)
Gender	male	158 (63.45%)	44 (33.33%)	114 (62.30%)
	female	91 (36.55%)	22 (66.66%)	69 (37.70%)
Education	Bachelor's degree	146 (58.63%)	99 (54.10%)	47 (71.21%)
	High school diploma	68 (27.30%)	62 (33.88%)	6 (9.10%)
	Master's degree	19 (7.63%)	8 (4.37%)	11 (16.67%)
	Studies without degree	15 (6.02%)	13 (7.10%)	2 (3.03%)
	PhD	1 (0.41%)	1(0.55%)	0 (0.00%)
Processes modeled	Mean (SD)	7.71 (14.10)	17.03 (20.29)	4.33 (8.99)
Experience	1 (Not at all)	16 (6.43%)	16 (8.74%)	0 (0.00%)
	2 (Novice)	29 (11.65%)	29 (15.85%)	0 (0.00%)
	3 (Beginner)	42 (16.88%)	42 (22.95%)	0 (0.00%)
	4 (Intermediate)	44 (17.67%)	44 (24.04%)	0 (0.00%)
	5 (Competent)	37 (14.86%)	24 (13.11%)	13 (19.70%)
	6 (Experienced)	31 (12.50%)	11 (6.01%)	20 (30.30%)
	7 (Proficient)	26 (10.44%)	10 (5.46%)	16 (24.24%)
	8 (Advanced)	17 (6.83%)	4 (2.19%)	13 (19.70%)
	9 (Highly skilled)	6 (2.41%)	2 (1.10%)	4 (6.10%)
	10 (Expert)	1 (0.40%)	1 (0.55%)	0 (0.00%)
Total	N	249	183	66

4.3. Materials

To evaluate whether IoT involvement in BPMN 2.0 process models is discernible visually and/or based on labels, we considered 13 process models from different scenarios. The selected process models were derived from the literature [8,42] as well as from real-world BPM projects we have been involved in. The process models vary in size and complexity, which shall allow for a generalization of the results.

Following the demographic questions, the participants were given a brief textual introduction to the IoT. The term IoT was first defined and then the basics of sensors and actuators were briefly explained. Following this, thirteen BPMN 2.0 process models with different modeling element combinations were presented. Note that in process models analyzing visual IoT involvement, the labels of the modeling elements use single letters to avoid label-based influences on the results. The first seven process models analyze whether IoT involvement, sensors, and actuators can be visually identified by the study participants. The next four process models examine whether IoT involvement can be identified based on BPMN 2.0 task labels. Finally, the last two process models evaluate the effort and frustration when reading IoT-aware BPMN 2.0 process models. Note that all modeling elements in the process models were numbered to allow participants to clearly refer to individual modeling elements by their identifier when answering questions. The used questionnaire and process models are publicly available (https://drive.google.com/file/d/15gN5wOOZydRYqPCvYjcBMiKWfyqRZTas/view?usp=sharing, accessed on 17 March 2024). In the following, the thirteen process models (PM) are described in detail and the various combinations of modeling elements are described.

4.3.1. Visual IoT Aspects

Many works [11,16,18,19,21,23,25,30,31] argue that BPMN 2.0 modeling elements, such as different task types and pools, are sufficient for visually representing IoT aspects. In [16], the integration of the IoT in business process management is examined. In addition, the current BPMN 2.0 modeling elements that could support IoT modeling are reviewed. The results of this research revealed that IoT involvement can be effectively represented through the use of service tasks, script tasks, and business rule tasks. These tasks enable the integration of IoT devices and services into business processes by allowing for the automation of tasks that interact with the physical environment, invoke external applications or services, and apply decision logic based on IoT data.

Building on the insights from the study by [16] on integrating the IoT into business process management, PM1–PM5 delve deeper into the practical aspects of IoT involvement from a user's perspective. While the current research at the time (cf. [16]) provided a solid technical foundation for integrating IoT capabilities into BPMN 2.0 through service tasks, script tasks, and business rule tasks, it approached the subject through the lens of technical experts. As analyzed in [64], symbols and icons in tasks should provide cues to their meaning. Furthermore, [64] advocates for an evidence-based approach to visual notation design. To complement this, PM1–PM5 aim to assess the intuitiveness and clarity of IoT integration into business processes, with a focus on visual IoT involvement without relying on textual labels. More precisely, PM1–PM5 prioritized the use of task icons, examining whether users could understand and interpret the role and functionality of IoT devices within business processes based solely on visual cues. The objective is to evaluate the effectiveness of iconography (i.e., visual IoT involvement) in conveying complex IoT aspects. Note that the focus is set on the service, script, and business rule tasks because these elements are pivotal in representing the interaction between business processes and IoT devices within BPMN 2.0 models. These tasks encapsulate the core functionalities necessary for IoT integration (i.e., automating interactions, invoking services, and applying decision logic based on IoT data) [8,16].

The following process models are utilized to analyze visual IoT involvement from a user (i.e., process model reader) perspective. Note that participants may answer "yes" or "no" to the question whether IoT involvement can be visually identified. When selecting the answer option "yes", an additional text field was displayed and participants were asked to enter the activity identifier.

PM1 A BPMN 2.0 process model with one manual task, one business rule task, one abstract task, three service tasks, and two script tasks. PM1 is used to examine whether the involvement is visually discernible. Furthermore, it is used to identify which task type makes IoT involvement more discernible for study participants than other elements.

PM2 A BPMN 2.0 process model with two business rule tasks and four service tasks. PM2 is used to examine whether the involvement of sensors is visually discernible. Furthermore, it is used to identify which task type makes the involvement of sensors more discernible for study participants than other task types.

PM3 A BPMN 2.0 process model with two business rule tasks and four service tasks. PM3 is used to examine whether the involvement of actuators is visually discernible. Furthermore, it is used to identify which task type makes the involvement of actuators more discernible for study participants than other task types.

PM4 A BPMN 2.0 process model with two business rule tasks and four script tasks. PM4 is used to examine whether the involvement of sensors is visually discernible. Furthermore, it is used to identify which task type makes the involvement of sensors more discernible for study participants than other task types.

PM5 A BPMN 2.0 process model with two business rule tasks and four script tasks. PM5 is used to examine whether the involvement of actuators is visually discernible. Furthermore, it is used to identify which task type makes the involvement of actuators more discernible for study participants than other task types.

PM6 A BPMN 2.0 process model with four pools, one message send task, one message receive task, two message start events, two service tasks, and four abstract tasks. Note that this process model originates from [42]. All BPMN 2.0 modeling elements are labeled in this process model. PM6 is used to examine whether IoT involvement can be identified from a user perspective when combining different modeling elements and labels.

PM7 A BPMN 2.0 process model with one pool, one boundary timer event, and six abstract tasks. All BPMN 2.0 modeling elements are labeled in this process model.

PM7 is used to examine whether the IoT involvement in a combination of different modeling elements and labels can be identified from a user perspective.

4.3.2. Label-Based IoT Aspects

Four process models are used to examine whether IoT involvement can be identified based on the labels of process model elements (e.g., query temperature, move x-axis, or switch motor off). In order to set the focus on the labels of the process model elements, these process models solely comprise abstract modeling elements (i.e., tasks without icons).

PM8 A BPMN 2.0 process model with a total of six activities, each with typical IoT terms (e.g., query humidity sensor or move x-axis). PM8 describes a process relying on two sensors and four actuators.

PM9 A BPMN 2.0 process model with a total of seven activities. PM9 describes a process relying on one actuator.

PM10 A BPMN 2.0 process model with a total of seven activities, each with typical IoT terms (e.g., start conveyor belt or detect color). PM10 describes a process relying on contains two sensors and four actuators.

PM11 A BPMN 2.0 process model with a total of twelve modeling elements, eight activities, two message start events, and four pools each with typical IoT terms (e.g., switch on lamp, light sensor, lamp controller, or activate switch). PM11 describes a process relying on one sensor, four actuators, and four IoT objects.

4.3.3. Effort and Frustration

Finally, we use two additional process models to examine effort and frustration. These process models originate from ref. [8].

PM12 PM12 is a process model comprising fifteen activities. The IoT-related activities of this model are labeled with characteristic IoT terms (e.g., get workpiece color, start Robot 1, or put workpiece in high-bay warehouse). PM12 covers three sensors and eight actuators.

PM13 PM13 is a process model comprising eight activities and four pools. The IoT-related activities of this model are labeled with characteristic IoT terms (e.g., start temperature recording or activate switch). PM13 covers one sensor and eight actuators.

To determine the degree of effort and frustration, six questions were posed. Participants answered these questions on a 5-point scale, ranging from (0) *does not apply* to (5) *fully applies*.

Q1: IoT involvement in the process model is visually clear.
Q2: I can distinguish IoT-related tasks from other tasks.
Q3: It is difficult to identify IoT involvement in the process model.
Q4: The larger the process model becomes, the more difficult it is to identify IoT involvement.
Q5: It is exhausting to determine the involvement of IoT aspects in the process model.
Q6: It is not possible to visually distinguish between IoT-related modeling elements from other modeling elements.

5. Results

5.1. Descriptive Statistics

This section presents the descriptive statistics of the complete sample as well as separately for experts and novices. The task numbers provided by the study participants (i.e., the task they consider as being IoT-related) were evaluated. For this purpose, a sample reading was created as a reference point for process models PM6–PM11. Note that there is no predefined solution for PM1–PM5, as these process models were designed to identify BPMN 2.0 task types, making IoT involvement more discernible for study participants. Two key metrics were used to assess the participants' performance in the context of PM6–PM11. The first metrics assessed the accuracy of the overall interpretation, i.e., the extent to which the modeling elements were correctly identified as IoT elements or traditional

BPMN 2.0 elements. The second metrics specifically examined the correct identification of IoT-related modeling elements in the BPMN 2.0 process model. These two metrics provide insights into the participants' understanding of IoT involvement in BPMN 2.0 process models. The values of these metrics can contribute to a nuanced understanding of the participants' comprehension of the IoT involvement in BPMN 2.0 process models and provide valuable implications for both research and practical applications.

5.1.1. All Participants

According to the descriptive results (cf. Table 2), neither experts or novices were able to fully detect IoT involvement (PM1), sensors (PM2 and PM4), and actuators (PM3 and PM5) based on visual BPMN elements. Participants who visually identified IoT involvement, sensors, and actuators reported this identification specifically in the context of service and script tasks (cf. Figure 2).

Table 2. Descriptive results concerning visual IoT aspects for all participants (N = 249).

Question	Yes	No	Task Type		
			Service Task	Script Task	Business Rule Task
PM1: Can you visually identify Internet of Things (IoT) involvement?	60 ǀ 24.10%	189 ǀ 75.90%	x	x	x
PM2: Can you visually identify the involvement of sensors?	44 ǀ 17.67%	205 ǀ 82.33%	78.26%	x	21.74%
PM3: Can you visually identify the involvement of actuators?	73 ǀ 29.32%	176 ǀ 70.68%	79.57%	x	20.43%
PM4: Can you visually identify the involvement of sensors?	51 ǀ 20.48%	198 ǀ 79.52%	x	74.63%	25.37%
PM5: Can you visually identify the involvement of actuators?	62 ǀ 24.90%	187 ǀ 75.10%	x	75.33%	24.67%

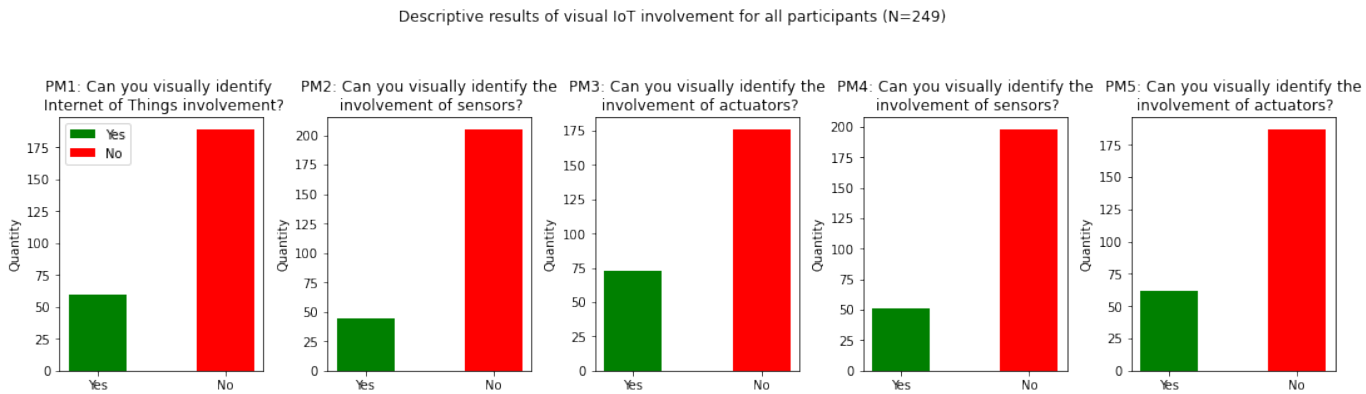

Figure 2. Descriptive results concerning visual IoT/sensor/actuator aspects for all participants (N = 249).

The descriptive results concerning IoT involvement in PM6 and PM7, which consider both visual (task types) and label-based (task label) indicators of IoT involvement (cf. Table 3), reveal that the combination of task types and labels enhances the identification of IoT involvement by the study participants. As another important finding, IoT involvement in PM7 became clearer for the study participants than in the context of PM6. Nonetheless, the results of PM6 and PM7 (cf. Table 3) show that the accuracy of the overall interpretation is only two out of seven on average (i.e., the extent to which the modeling elements were correctly identified as IoT-related or as non-IoT-related BPMN 2.0 elements). The same applies to the accuracy of IoT identification. Regarding PM6, on average, participants identified only two out of seven IoT aspects. Similarly, for PM7, the participants identified on average only three out of nine IoT aspects. Table 4 shows the descriptive statistics of label-based aspects. The table lists the task labels used in PM6 and PM7 and indicates whether the respective task is an IoT-related or non-IoT-related modeling element. Furthermore, the table shows how many of the participants specified the modeling element in combination with the label as IoT-related or non-IoT-related. The analysis of the label-based aspects shows that several typical IoT labels, such as in PM6 (*start conveyor belt*), were not clearly identified as IoT-related. Other IoT-related modeling elements, such as *Switch on Lamp 1* in PM7, were clearly identified as IoT-related.

The descriptive statistics for label-based IoT involvement (cf. Table 5) reveal that the majority of study participants were able to identify IoT involvement. The analysis has further shown that the label-based IoT involvement in PM11 was clearer than in PM8–PM10. Nonetheless, the results of PM8–PM11 (cf. Table 5) reveal that the overall identification is mediocre at best. The same applies to the accuracy of IoT identification. Table 6 presents the detailed descriptive statistics of the text labels for PM8–PM11.

When considering more complex process models (PM12 and PM13), the study participants reported that identifying IoT aspects was difficult and exhausting (cf. Table 7). Furthermore, they stated that they were unable to distinguish between IoT-related modeling elements and non-IoT-related ones.

Table 3. Descriptive results concerning visual and label-based IoT aspects for all participants (N = 249).

Question	Yes	No	Overall Identification		IoT Identification	
			Mean	SD	Mean	SD
PM6: Can you visually identify Internet of Things (IoT) involvement?	110 | 44.18%	139 | 55.82%	2/7	1/7	2/7	1/7
PM7: Can you visually identify the involvement of sensors?	190 | 76.30%	59 | 23.70%	5/12	2/12	3/9	2/9

Table 4. Descriptive results concerning visual and label-based IoT aspects for all participants based on the label for PM6 (N = 249).

Label	IoT	BPM	Modeling Element	Specified as IoT	Specified as BPM
Process Model PM6					
Factory	✓	✗	Abstract Task	8 | 7.27%	102 | 92.73%
Start conveyor belt	✓	✗	Abstract Task	25 | 22.72%	85 | 77.27%
Detect color	✓	✗	Abstract Task	47 | 42.72%	63 | 57.27%
Workpiece arrived at warehouse	✓	✗	Abstract Task	38 | 34.55%	72 | 65.45%
Stop conveyor belt	✓	✗	Abstract Task	46 | 41.82%	64 | 58.18%
Transport workpiece to warehouse 1	✓	✗	Abstract Task	40 | 36.40%	70 | 63.60%
Transport workpiece to warehouse 2	✓	✗	Abstract Task	38 | 34.55%	72 | 65.45%
Process Model PM7					
Light Sensor	✓	✗	Pool	73 | 38.42%	117 | 61.58%
Send Light events	✗	✓	Send Task	88 | 46.32%	102 | 53.68%
Lamp 1 Controller	✓	✗	Pool	64 | 33.68%	126 | 66.32%
Activate Switch	✓	✗	Abstract Task	54 | 28.42%	136 | 71.58%
Lamp 2 Controller	✓	✗	Pool	60 | 31.58%	130 | 68.42%
Activate Switch	✓	✗	Abstract Task	55 | 28.95%	135 | 71.05%
Smart Home Control System	✓	✗	Pool	39 | 20.53%	151 | 79.47%
Receive Light Sensor Event	✗	✓	Receive Task	95 | 50.00%	95 | 50.00%
Switch on Lamp 1	✓	✗	Service Task	107 | 56.32%	83 | 43.68%
Switch on Lamp 2	✓	✗	Service Task	90 | 47.37%	100 | 52.63%
Update Database	✗	✓	Abstract Task	46 | 24.21%	144 | 75.79%
Start temperature recording	✓	✗	Abstract Task	54 | 28.42%	136 | 71.58%

Table 5. Descriptive results concerning label-based IoT aspects for all participants (N = 249).

Question	Yes	No	Overall Identification		IoT Identification	
			Mean	SD	Mean	SD
PM8: Can you textually identify Internet of Things (IoT) involvement?	197 | 79.12%	52 | 20.88%	3/6	2/6	3/6	2/6
PM9: Can you textually identify Internet of Things (IoT) involvement?	174 | 69.88%	75 | 30.12%	4/7	1/7	1/2	1/2
PM10: Can you textually identify Internet of Things (IoT) involvement?	160 | 64.26%	89 | 35.74%	1/7	1/7	2/7	2/7
PM11: Can you textually identify Internet of Things (IoT) involvement?	218 | 87.55%	31 | 12.45%	5/12	2/12	3/9	2/9

Table 6. Descriptive results concerning label-based IoT aspects for all participants based on the label for PM8–PM11 (N = 249).

Label	IoT	BPM	Modeling Element	Specified as IoT	Specified as BPM
Process Model PM8					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Query temperature sensor	✓	✗	Abstract Task	137 | 69.54%	60 | 30.46%
Query humidity sensor	✓	✗	Abstract Task	135 | 68.53%	62 | 31.47%
Move x-axis	✓	✗	Abstract Task	74 | 37.56%	123 | 62.44%
Move y-axis	✓	✗	Abstract Task	73 | 37.10%	124 | 62.90%
Move z-axis	✓	✗	Abstract Task	73 | 37.10%	124 | 62.90%
Switch motor off	✓	✗	Abstract Task	93 | 47.21%	104 | 52.79%
Process Model PM9					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Check heart rhythm	✗	✓	Pool	90 | 51.72%	84 | 48.28%
Sound emergency alarm	✓	✗	Send Task	91 | 52.29%	83 | 47.71%
Check COPD severeness	✗	✓	Pool	86 | 49.42%	88 | 50.58%
Administer oxygen mask	✗	✓	Abstract Task	23 | 13.21%	151 | 86.78%
Administer inhaler	✗	✓	Pool	20 | 11.49%	154 | 88.51%
Analyze result of treatment	✗	✓	Abstract Task	81 | 46.55%	93 | 53.45%
Update patient record	✗	✓	Pool	92 | 52.87%	82 | 47.12%
Process Model PM10					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Factory	✓	✗	Abstract Task	20 | 12.50%	140 | 87.50%
Start conveyor belt	✓	✗	Abstract Task	54 | 33.75%	106 | 66.25%
Detect color	✓	✗	Abstract Task	91 | 56.87%	69 | 43.13%
Workpiece arrived at warehouse	✓	✗	Abstract Task	51 | 31.87%	109 | 68.13%
Stop conveyor belt	✓	✗	Abstract Task	69 | 43.12%	91 | 56.88%
Transport workpiece to warehouse 1	✓	✗	Abstract Task	56 | 35.00%	104 | 65.00%
Transport workpiece to warehouse 2	✓	✗	Abstract Task	55 | 34.37%	105 | 66.63%
Process Model PM11					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Light Sensor	✓	✗	Pool	77 | 35.32%	141 | 64.68%
Send Light events	✗	✓	Send Task	104 | 47.70%	114 | 52.30%
Lamp 1 Controller	✓	✗	Pool	63 | 28.90%	155 | 71.10%
Activate Switch	✓	✗	Abstract Task	85 | 39.00%	133 | 61.00%
Lamp 2 Controller	✓	✗	Pool	63 | 28.90%	156 | 71.10%
Activate Switch	✓	✗	Abstract Task	77 | 35.32%	141 | 64.68%
Smart Home Control System	✓	✗	Pool	47 | 21.56%	171 | 78.44%

Table 6. *Cont.*

Process Model PM11					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Receive Light Sensor Event	✗	✓	Receive Task	111 ǀ 50.90%	107 ǀ 49.10%
Switch on Lamp 1	✓	✗	Service Task	125 ǀ 57.34%	93 ǀ 42.66%
Switch on Lamp 2	✓	✗	Service Task	115 ǀ 52.75%	103 ǀ 47.25%
Update Database	✗	✓	Abstract Task	63 ǀ 28.90%	155 ǀ 71.10%
Start temperature recording	✓	✗	Abstract Task	64 ǀ 29.36%	154 ǀ 70.64%

Table 7. Effort and frustration for all participants (N = 249).

Process Model PM12	**Median**	**SD**
The visual involvement of the IoT in the process model is clear	2.81 ǀ partially applies	1.17
I can distinguish IoT-aware tasks from other BPMN tasks.	2.40 ǀ tends not to apply	1.04
It is difficult to clearly determine the involvement of the IoT in the process model.	3.78 ǀ strongly applies	1.03
The larger the process model, the more difficult it is to identify the IoT.	3.63 ǀ strongly applies	1.23
It is exhausting to clearly determine the involvement of the IoT in the process model.	3.78 ǀ strongly applies	1.16
It is not possible to visually distinguish between IoT tasks and BPMN tasks.	3.10 ǀ partially applies	1.15
Process Model PM12	**Median**	**SD**
The visual involvement of the IoT in the process model is clear	3.37 ǀ partially applies	1.16
I can distinguish IoT-aware tasks from other BPMN tasks.	3.00 ǀ partially applies	1.10
It is difficult to clearly determine the involvement of the IoT in the process model.	3.33 ǀ partially applies	1.10
The larger the process model, the more difficult it is to identify the IoT.	3.50 ǀ strongly applies	1.23
It is exhausting to clearly determine the involvement of the IoT in the process model.	3.36 ǀ partially applies	1.04
It is not possible to visually distinguish between IoT tasks and BPMN tasks.	2.73 ǀ partially applies	1.10

5.1.2. Experts

According to the descriptive results based on visual BPMN 2.0 elements solely, experts cannot identify IoT involvement (PM1), sensors (PM2 and PM4), and actuators (PM3 and PM5) with certainty (cf. Table 8). Experts who were able to visually identify IoT involvement, sensors, and actuators in BPMN 2.0 reported this identification specifically in the context of the service and script task (cf. Figure 3).

The descriptive results concerning IoT involvement in PM6 and PM7, which consider both visual (task types) and label-based indicators of IoT involvement (cf. Table 9), reveal that the combination of IoT-related task types and task labels enhances the identification of IoT involvement by experts. As another important finding, IoT involvement in PM7 became clearer to the experts than in PM6. Nonetheless, the results of PM6 and PM7 (cf. Table 9) show that the accuracy of the overall interpretation is only two out of seven on average (i.e., the extent to which the modeling elements were correctly identified as IoT-related elements or non-IoT-related elements). The same applies to the accuracy of IoT identification. In PM7, on average, experts identified only two out of seven IoT-related process aspects. Similarly, in PM7, experts identified on average of two out of nine IoT-related process aspects. Table 10 represents the descriptive results of label-based IoT aspects. The table lists the task labels used in PM6 and PM7 and indicates whether the labels are IoT-related or non-IoT-related modeling elements and how many of the experts specified the modeling element in combination with the label as IoT-related or non-IoT-related. The analysis of label-based IoT aspects has shown that various IoT-related labels, such as in PM6

(*Factory*), were not clearly identified as IoT-related. Other IoT-related modeling elements, such as *Switch on Lamp 1* in PM7, were clearly identified as IoT-related by the experts.

The descriptive results for label-based IoT involvement (cf. Table 11) reveal that most experts were able to identify IoT involvement. The analysis has further shown that the label-based IoT aspects in PM11 became clearer than in PM8 to PM10. Nonetheless, the results obtained in the context of PM8 to PM11 (cf. Table 11) reveal that the overall identification is mediocre at best. The same applies to the accuracy of IoT identification. Table 12 presents the detailed descriptive analysis of the text labels for PM8–PM11.

When considering more complex processes (PM12 and PM13), the experts reported that identifying IoT aspects was difficult and exhausting (cf. Table 13). Furthermore, the experts stated that they were unable to distinguish between IoT-related modeling elements and non-IoT-related ones.

Table 8. Descriptive results concerning visual IoT aspects for experts (N = 66).

Question	Yes	No	Task Type		
			Service Task	Script Task	Business Rule Task
PM1: Can you visually identify Internet of Things (IoT) involvement?	11 | 16.66%	55 | 83.33%	x	x	x
PM2: Can you visually identify the involvement of sensors?	8 | 12.12%	58 | 87.87%	91.67%	x	8.33%
PM3: Can you visually identify the involvement of actuators?	13 | 19.70%	53 | 80.30%	83.33%	x	16.70%
PM4: Can you visually identify the involvement of sensors?	8 | 12.12%	58 | 87.87%	x	62.50%	37.50%
PM5: Can you visually identify the involvement of actuators?	11 | 16.66%	55 | 83.33%	x	82.14%	17.86%

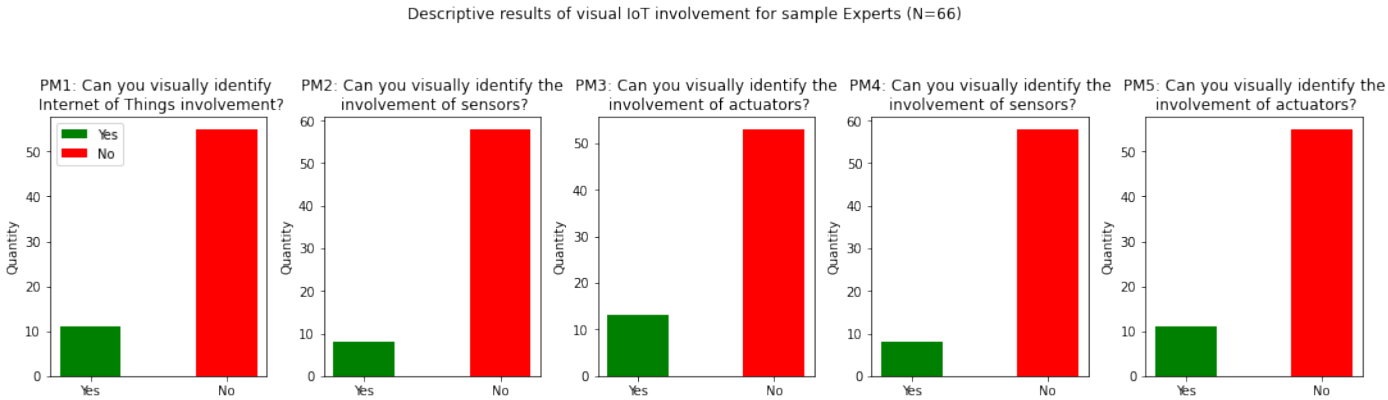

Figure 3. Descriptive results concerning visual IoT aspects for experts (N = 66).

Table 9. Descriptive results concerning visual and label-based IoT aspects for experts (N = 66).

Question	Yes	No	Overall Identification		IoT Identification	
			Mean	SD	Mean	SD
PM6: Can you visually identify Internet of Things (IoT) involvement?	26 | 39.39%	40 | 60.60%	2/7	1/7	2/7	1/7
PM7: Can you visually identify the involvement of sensors?	51 | 77.27%	15 | 22.72%	5/12	2/12	3/9	2/9

Table 10. Descriptive results concerning visual and label-based IoT aspects for experts (N = 66).

Label	IoT	BPM	Modeling Element	Specified as IoT	Specified as BPM
Process Model 6					
Factory	✓	✗	Abstract Task	2 | 7.69%	24 | 92.31%
Start conveyor belt	✓	✗	Abstract Task	5 | 19.23%	21 | 80.77%
Detect color	✓	✗	Abstract Task	16 | 61.54%	10 | 38.46%
Workpiece arrived at warehouse	✓	✗	Abstract Task	12 | 46.15%	14 | 53.85%
Stop conveyor belt	✓	✗	Abstract Task	11 | 42.30%	15 | 57.70%
Transport workpiece to warehouse 1	✓	✗	Abstract Task	9 | 34.62%	17 | 65.38%
Transport workpiece to warehouse 2	✓	✗	Abstract Task	9 | 34.62%	17 | 65.38%
Process Model 7					
Light Sensor	✓	✗	Pool	23 | 45.10%	28 | 54.90%
Send Light events	✗	✓	Send Task	23 | 45.10%	28 | 54.90%
Lamp 1 Controller	✓	✗	Pool	19 | 37.25%	32 | 62.75%
Activate Switch	✓	✗	Abstract Task	18 | 35.29%	33 | 64.71%
Lamp 2 Controller	✓	✗	Pool	18 | 35.29%	33 | 64.71%
Activate Switch	✓	✗	Abstract Task	17 | 33.33%	34 | 66.66%
Smart Home Control System	✓	✗	Pool	8 | 15.70%	43 | 84.30%
Receive Light Sensor Event	✗	✓	Receive Task	28 | 54.90%	23 | 45.10%
Switch on Lamp 1	✓	✗	Service Task	32 | 62.75%	19 | 37.25%
Switch on Lamp 2	✓	✗	Service Task	27 | 52.94%	24 | 47.05%
Update Database	✗	✓	Abstract Task	10 | 19.60%	41 | 80.40%
Start temperature recording	✓	✗	Abstract Task	15 | 29.41%	36 | 70.59%

Table 11. Descriptive results concerning label-based IoT aspects for experts (N = 66).

Question	Yes	No	Overall Identification		IoT Identification	
			Mean	SD	Mean	SD
PM8: Can you textually identify Internet of Things (IoT) involvement?	58 | 87.87%	8 | 12.12%	3/6	2/6	3/6	2/6
PM9: Can you textually identify Internet of Things (IoT) involvement?	43 | 65.15%	23 | 34.85%	4/7	1/7	1/2	1/2
PM10: Can you textually identify Internet of Things (IoT) involvement?	42 | 63.63%	24 | 36.36%	2/7	1/7	3/7	2/7
PM11: Can you textually identify Internet of Things (IoT) involvement?	63 | 95.45%	3 | 4.55%	5/12	2/12	4/9	2/9

Table 12. Descriptive results concerning label-based IoT aspects for experts (N = 66).

Label	IoT	BPM	Modeling Element	Specified as IoT	Specified as BPM
Process Model 8					
Query temperature sensor	✓	✗	Abstract Task	45 | 77.59%	13 | 22.41%
Query humidity sensor	✓	✗	Abstract Task	45 | 77.59%	13 | 22.41%
Move x-axis	✓	✗	Abstract Task	27 | 46.55%	31 | 53.45%
Move y-axis	✓	✗	Abstract Task	26 | 44.83%	32 | 55.17%
Move z-axis	✓	✗	Abstract Task	26 | 44.83%	32 | 55.17%
Switch motor off	✓	✗	Abstract Task	33 | 56.90%	25 | 43.10%

Table 12. *Cont.*

Process Model 9					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Check heart rhythm	✗	✓	Pool	27 | 62.79%	16 | 37.21%
Sound emergency alarm	✓	✗	Send Task	25 | 58.14%	18 | 41.86%
Check COPD severeness	✗	✓	Pool	27 | 62.80%	16 | 37.20%
Administer oxygen mask	✗	✓	Abstract Task	2 | 4.65%	41 | 95.35%
Administer inhaler	✗	✓	Pool	2 | 4.65%	41 | 95.35%
Analyze result of treatment	✗	✓	Abstract Task	24 | 55.81%	19 | 44.19%
Update patient record	✗	✓	Pool	22 | 51.16%	21 | 48.84%
Process Model 10					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Factory	✓	✗	Abstract Task	5 | 11.90%	37 | 88.10%
Start conveyor belt	✓	✗	Abstract Task	22 | 52.38%	20 | 47.62%
Detect color	✓	✗	Abstract Task	29 | 69.05%	13 | 30.95%
Workpiece arrived at warehouse	✓	✗	Abstract Task	10 | 23.80%	32 | 76.20%
Stop conveyor belt	✓	✗	Abstract Task	24 | 57.14%	18 | 42.86%
Transport workpiece to warehouse 1	✓	✗	Abstract Task	15 | 35.71%	27 | 64.29%
Transport workpiece to warehouse 2	✓	✗	Abstract Task	14 | 33.33%	28 | 66.66%
Process Model 11					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Light Sensor	✓	✗	Pool	21 | 33.33%	42 | 66.66%
Send Light events	✗	✓	Send Task	30 | 47.61%	33 | 52.39%
Lamp 1 Controller	✓	✗	Pool	15 | 23.80%	48 | 76.20%
Activate Switch	✓	✗	Abstract Task	31 | 49.20%	32 | 50.80%
Lamp 2 Controller	✓	✗	Pool	15 | 23.80%	48 | 76.20%
Activate Switch	✓	✗	Abstract Task	25 | 39.68%	38 | 60.32%
Smart Home Control System	✓	✗	Pool	11 | 17.46%	52 | 82.54%
Receive Light Sensor Event	✗	✓	Receive Task	34 | 53.97%	29 | 46.03%
Switch on Lamp 1	✓	✗	Service Task	44 | 69.84%	19 | 30.16%
Switch on Lamp 2	✓	✗	Service Task	40 | 63.49%	23 | 36.51%
Update Database	✗	✓	Abstract Task	14 | 22.22%	49 | 77.77%
Start temperature recording	✓	✗	Abstract Task	20 | 31.75%	43 | 68.25%

Table 13. Effort and frustration for experts (N = 66).

Process Model 12 (PM12)—Question	Median	SD
The visual involvement of the IoT in the process model is clear.	2.72 | partially applies	1.19
I can distinguish IoT-aware tasks from other BPMN tasks.	2.49 | tends not to apply	1.02
It is difficult to clearly determine the involvement of the IoT in the process model.	3.75 | mostly applies	0.86
The larger the process model, the more difficult it is to identify the IoT.	3.63 | mostly applies	1.24
It is exhausting to clearly determine the involvement of the IoT in the process model.	3.87 | mostly applies	1.08
It is not possible to visually distinguish between the IoT tasks and BPMN tasks.	3.16 | partially applies	1.19

Table 13. *Cont.*

Process Model 13 (PM13)—Question	Median	SD
The visual involvement of the IoT in the process model is clear.	3.39 ǀ partially applies	1.23
I can distinguish IoT-aware tasks from other BPMN tasks.	3.15 ǀ partially applies	1.15
It is difficult to clearly determine the involvement of the IoT in the process model.	3.27 ǀ partially applies	1.08
The larger the process model, the more difficult it is to identify the IoT.	3.46 ǀ mostly applies	1.26
It is exhausting to clearly determine the involvement of the IoT in the process model.	3.39 ǀ partially applies	1.35
It is not possible to visually distinguish between the IoT tasks and BPMN tasks.	2.68 ǀ partially applies	1.16

5.1.3. Novices

According to the descriptive results based solely on visual BPMN 2.0 elements, novices cannot identify IoT involvement (PM1), sensors (PM2 and PM4), and actuators (PM3 and PM5) with certainty (cf. Table 14). Novices who were able to visually identify IoT involvement, sensors, and actuators in BPMN 2.0 reported this identification specifically in the context of the service and script task (cf. Figure 4).

Table 14. Descriptive results concerning visual IoT aspects for sample Novices (N = 183).

Question	Yes	No	Task Type		
			Service Task	Script Task	Business Rule Task
PM1: Can you visually identify Internet of Things (IoT) involvement?	49 ǀ 26.78%	134 ǀ 73.22%	x	x	x
PM2: Can you visually identify the involvement of sensors?	36 ǀ 19.67%	147 ǀ 80.33%	74.45%	x	25.55%
PM3: Can you visually identify the involvement of actuators?	60 ǀ 32.80%	123 ǀ 67.20%	77.63%	x	22.37%
PM4: Can you visually identify the involvement of sensors?	43 ǀ 23.50%	140 ǀ 76.50%	x	81.00%	19.00%
PM5: Can you visually identify the involvement of actuators?	50 ǀ 27.33%	133 ǀ 72.67%	x	73.33%	26.67%

The descriptive statistics for PM6 and PM7, which consider both visual (task types) and label-based (task label) IoT indicators of IoT involvement (cf. Table 15), reveal that the combination of IoT-related task types and task labels enhances the identification of IoT involvement by novices. As another important finding, IoT involvement in PM7 became clearer to the novices than in PM6. Nonetheless, the results of PM6 and PM7 (cf. Table 15) show that the accuracy of the overall interpretation is only two out of seven on average (i.e., the extent to which the modeling elements were correctly identified as IoT-related elements or non-IoT-related elements). The same applies to the accuracy of IoT identification. In PM7, on average, novices identified only two out of seven IoT-related process aspects. Similarly, in PM7, novices identified on average of two out of nine IoT-related process aspects. Table 16 represents the descriptive results of label-based (i.e., task label) aspects. The table lists the task labels used for PM6 and PM7 and indicates whether the labels are IoT-related or non-IoT-related modeling elements. The analysis of the label-based aspects has shown that various IoT-specific labels, such as in PM6 (e.g., *Factory*), were not clearly identified as IoT-related. Other IoT-related modeling elements, however, such as *Switch on Lamp 1* in PM7, were clearly identified as IoT-related by the novices.

The results of the descriptive statistics for label-based IoT aspects (cf. Table 17) reveal that the majority of novices were able to identify label-based IoT aspects. The analysis has further shown that IoT involvement became clearer in PM11 than in PM8–PM10. Nonetheless, the results of PM8–PM11 (cf. Table 17) reveal that the overall identification (i.e., the extent to which the modeling elements were correctly identified as IoT-related and non-IoT-related) is mediocre at best. The same applies to the accuracy of identifying IoT involvement (i.e., the correct identification of IoT-related modeling elements in the process model). Table 18 presents the detailed descriptive statistics for the task labels for PM8–PM11.

When considering more complex processes (PM12 and PM13), novices reported that identifying IoT aspects was difficult and exhausting (cf. Table 19). Furthermore, they were unable to distinguish between IoT-related modeling elements and non-IoT-related ones.

Table 15. Descriptive results concerning visual and label-based IoT aspects for novices (N = 183).

Question	Yes	No	Overall Identification		IoT Identification	
			Mean	SD	Mean	SD
PM6: Can you visually identify Internet of Things (IoT) involvement?	84 | 45.90%	99 | 54.10%	2/7	1/7	2/7	1/7
PM7: Can you visually identify the involvement of sensors?	139 | 75.96%	44 | 24.04%	5/12	2/12	3/9	2/9

Table 16. Descriptive results concerning visual and label-based IoT aspects for novices (N = 183).

Label	IoT	BPM	Modeling Element	Specified as IoT	Specified as BPM
Process Model 6					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Factory	✓	✗	Abstract Task	6 | 7.14%	78 | 92.86%
Start conveyor belt	✓	✗	Abstract Task	20 | 23.81%	64 | 76.19%
Detect color	✓	✗	Abstract Task	31 | 36.90%	53 | 63.10%
Workpiece arrived at warehouse	✓	✗	Abstract Task	26 | 30.95%	58 | 69.05%
Stop conveyor belt	✓	✗	Abstract Task	35 | 41.66%	49 | 58.34%
Transport workpiece to warehouse 1	✓	✗	Abstract Task	31 | 36.90%	53 | 63.10%
Transport workpiece to warehouse 2	✓	✗	Abstract Task	29 | 34.52%	55 | 65.47%
Process Model 7					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Light Sensor	✓	✗	Pool	48 | 34.53%	91 | 65.47%
Send Light events	✗	✓	Send Task	64 | 46.04%	75 | 53.96%
Lamp 1 Controller	✓	✗	Pool	43 | 30.93%	96 | 69.06%
Activate Switch	✓	✗	Abstract Task	36 | 25.90%	103 | 74.10%
Lamp 2 Controller	✓	✗	Pool	41 | 29.50%	98 | 70.50%
Activate Switch	✓	✗	Abstract Task	38 | 27.34%	101 | 72.66%
Smart Home Control System	✓	✗	Pool	30 | 21.58%	109 | 78.42%
Receive Light Sensor Event	✗	✓	Receive Task	66 | 47.48%	73 | 52.52%
Switch on Lamp 1	✓	✗	Service Task	74 | 53.24%	65 | 46.76%
Switch on Lamp 2	✓	✗	Service Task	63 | 45.32%	76 | 54.68%
Update Database	✗	✓	Abstract Task	37 | 26.62%	102 | 73.38%
Start temperature recording	✓	✗	Abstract Task	39 | 28.06%	100 | 71.94%

Table 17. Descriptive results concerning label-based IoT aspects for novices (N = 183).

Question	Yes	No	Overall Identification		IoT Identification	
			Mean	SD	Mean	SD
PM8: Can you textually identify Internet of Things (IoT) involvement?	139 | 75.96%	44 | 24.04%	3/6	2/6	3/6	2/6
PM9: Can you textually identify Internet of Things (IoT) involvement?	130 | 71.03%	53 | 28.97%	4/7	2/7	1/2	1/2
PM10: Can you textually identify Internet of Things (IoT) involvement?	118 | 64.48%	65 | 35.52%	1/7	1/7	2/7	2/7
PM11: Can you textually identify Internet of Things (IoT) involvement?	155 | 84.70%	28 | 15.30%	5/12	2/12	4/9	2/9

Table 18. Descriptive results concerning label-based IoT aspects for novices (N = 183).

Label	IoT	BPM	Modeling Element	Specified as IoT	Specified as BPM
Process Model 8					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Query temperature sensor	✓	✗	Abstract Task	91 | 65.47%	48 | 34.53%
Query humidity sensor	✓	✗	Abstract Task	89 | 64.03%	50 | 35.97%
Move x-axis	✓	✗	Abstract Task	47 | 33.81%	92 | 66.19%
Move y-axis	✓	✗	Abstract Task	47 | 33.81%	92 | 66.19%
Move z-axis	✓	✗	Abstract Task	47 | 33.81%	92 | 66.19%
Switch motor off	✓	✗	Abstract Task	60 | 43.17%	79 | 56.83%
Process Model 9					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Check heart rhythm	✗	✓	Pool	63 | 48.46%	67 | 51.54%
Sound emergency alarm	✓	✗	Send Task	66 | 50.77%	64 | 49.23%
Check COPD severeness	✗	✓	Pool	58 | 44.62%	72 | 55.38%
Administer oxygen mask	✗	✓	Abstract Task	20 | 15.38%	110 | 84.62%
Administer inhaler	✗	✓	Pool	17 | 13.10%	113 | 86.90%
Analyze result of treatment	✗	✓	Abstract Task	57 | 43.85%	73 | 56.15%
Update patient record	✗	✓	Pool	70 | 53.85%	60 | 46.15%
Process Model 10					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Factory	✓	✗	Abstract Task	15 | 12.71%	103 | 87.29%
Start conveyor belt	✓	✗	Abstract Task	32 | 27.12%	86 | 72.88%
Detect color	✓	✗	Abstract Task	62 | 52.54%	56 | 47.46%
Workpiece arrived at warehouse	✓	✗	Abstract Task	41 | 34.75%	77 | 65.25%
Stop conveyor belt	✓	✗	Abstract Task	45 | 38.14%	73 | 61.86%
Transport workpiece to warehouse 1	✓	✗	Abstract Task	41 | 34.75%	77 | 65.25%
Transport workpiece to warehouse 2	✓	✗	Abstract Task	41 | 34.75%	77 | 65.25%
Process Model 11					
Label	**IoT**	**BPM**	**Modeling Element**	**Specified as IoT**	**Specified as BPM**
Light Sensor	✓	✗	Pool	56 | 36.13%	99 | 63.87%
Send Light events	✗	✓	Send Task	74 | 47.74%	81 | 52.26%
Lamp 1 Controller	✓	✗	Pool	48 | 30.97%	107 | 69.03%
Activate Switch	✓	✗	Abstract Task	54 | 34.84%	101 | 65.16%
Lamp 2 Controller	✓	✗	Pool	48 | 30.97%	107 | 69.03%
Activate Switch	✓	✗	Abstract Task	52 | 33.55%	103 | 66.45%
Smart Home Control System	✓	✗	Pool	36 | 23.23%	119 | 76.77%
Receive Light Sensor Event	✗	✓	Receive Task	77 | 49.68%	78 | 50.32%
Switch on Lamp 1	✓	✗	Service Task	81 | 52.26%	74 | 47.74%
Switch on Lamp 2	✓	✗	Service Task	75 | 48.39%	80 | 51.61%
Update Database	✗	✓	Abstract Task	49 | 31.61%	106 | 68.39%
Start temperature recording	✓	✗	Abstract Task	44 | 28.39%	111 | 71.61%

Table 19. Effort and frustration for novices (N = 183).

Process Model 12 (PM12)—Question	Median	SD
The visual involvement of the IoT in the process model is clear.	2.84 | partially applies	1.15
I can distinguish IoT-aware tasks from other BPMN tasks.	2.33 | tends not to apply	1.04
It is difficult to clearly determine the involvement of the IoT in the process model.	3.79 | mostly applies	1.09
The larger the process model, the more difficult it is to identify the IoT.	3.62 | mostly applies	1.24
It is exhausting to clearly determine the involvement of the IoT in the process model.	3.74 | mostly applies	0.98
It is not possible to visually distinguish between IoT tasks and BPMN tasks.	3.03 | partially applies	1.14
Process Model 13 (PM13)—Question	**Median**	**SD**
The visual involvement of the IoT is in the process model clear.	3.36 | partially applies	1.13
I can distinguish IoT-aware tasks from other BPMN tasks.	2.90 | partially applies	1.01
It is difficult to clearly determine the involvement of the IoT in the process model.	3.34 | partially applies	1.07
The larger the process model, the more difficult it is to identify the IoT.	3.51 | strongly applies	1.21
It is exhausting to clearly determine the involvement of the IoT in the process model.	3.34 | partially applies	1.01
It is not possible to visually distinguish between IoT tasks and BPMN tasks.	2.74 | partially applies	1.08

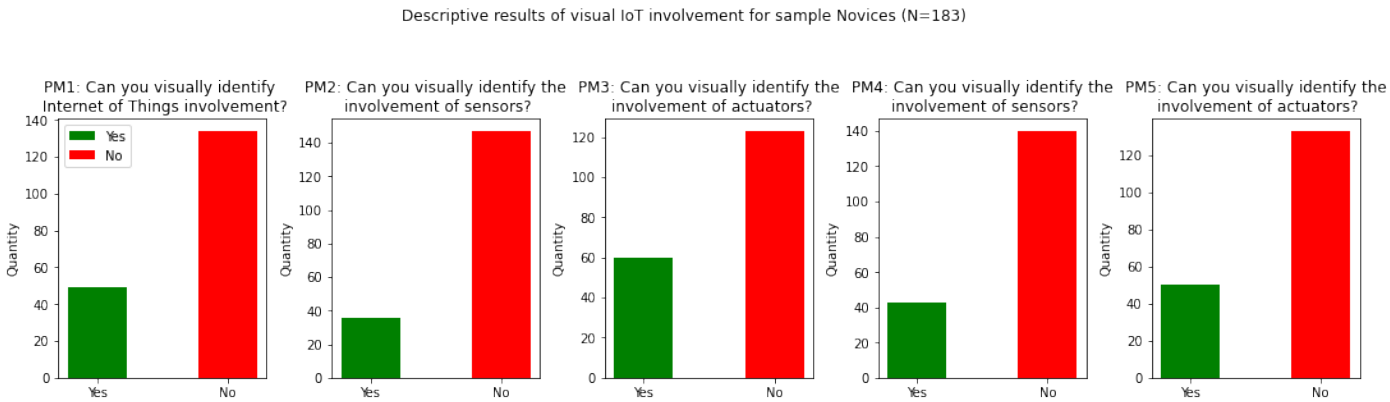

Figure 4. Descriptive results concerning visual IoT aspects for novices (N = 183).

5.2. Inferential Statistics

The insights presented in Section 5.1 are merely based on descriptive differences. A descriptive confirmation of the descriptive assumption was obtained using tables and figures for each combination of scenario and user group (i.e., all users, experts, and novices). To evaluate whether the differences in the descriptive results reach statistical significance for PM6–PM11, independent-sample *t*-tests [65] were conducted to compare the results of experts and novices. All statistical tests were two-tailed and the significance value was set to $p < 0.05$. Note that the purpose of PM1–PM5 is to determine whether IoT involvement, sensors, and actuators are visually discernible. More specifically, these process models were used to identify which task types make IoT involvement more discernible. As the subjective view of the study participants was obtained for PM1–PM5, these processes are not included in the statistical tests. To evaluate whether the differences reach statistical significance for PM12 and PM13, a Chi-Square test of independence [66] was applied to compare the results of experts and novices. All statistical tests were two-tailed and the significance value was set to $p < 0.05$. Table 20 summarizes the independent-sample *t*-tests for PM6–PM11. Moreover, Table 21 summarizes the Chi-Square test for PM12 and Table 22 for PM13.

Table 20. Two-sample *t*-test results for experts and novices.

Process Model	Experts		Novices		*t*	df	Sig(2-Tailed)
	Mean	SD	Mean	SD			
PM6	1.39	0.49	1.46	0.50	0.91	116.51	<0.36
PM7	1.77	0.42	1.76	0.43	−0.21	247.00	<0.83
PM8	1.88	0.32	1.76	0.42	−2.31	149.02	<0.02
PM9	1.65	0.48	1.72	0.45	0.98	247.00	<0.33
PM10	1.64	0.49	1.64	0.48	0.12	247.00	<0.90
PM11	1.95	0.21	1.85	0.36	−2.90	197.41	<0.01

Table 21. Two-sample Pearson Chi-Square results for experts and novices for PM12.

Question	Value	df	Sig(2-Tailed)
The visual involvement of the IoT in the process model is clear.	0.94	4.00	<0.92
I can distinguish IoT-aware tasks from other BPMN tasks.	2.98	5.00	<0.70
It is difficult to clearly determine the involvement of the IoT in the process model.	8.58	5.00	<0.13
The larger the process model, the more difficult it is to identify the IoT.	3.01	5.00	<0.70
It is exhausting to clearly determine the involvement of the IoT in the process model.	3.78	4.00	<0.44
It is not possible to visually distinguish between IoT tasks and BPMN tasks.	5.99	5.00	<0.31

Table 22. Two-sample Pearson Chi-Square results for experts and novices for PM13.

Question	Value	df	Sig(2-Tailed)
The visual involvement of the IoT in the process model is clear.	2.96	5.00	<0.71
I can distinguish IoT-aware tasks from other BPMN tasks.	9.04	5.00	<0.11
It is difficult to clearly determine the involvement of the IoT in the process model.	1.00	4.00	<0.91
The larger the process model, the more difficult it is to identify the IoT.	1.20	5.00	<0.95
It is exhausting to clearly determine the involvement of the IoT in the process model.	6.13	5.00	<0.29
It is not possible to visually distinguish between IoT tasks and BPMN tasks.	2.77	5.00	<0.74

For the scenario described by PM6 (visually expressed and label-based IoT aspects), the two-sided *t*-test revealed no significant differences ($t(116.51) = 0.91$, $p < 0.36$) in the responses between experts (M = 1.39, SD = 0.49) and novices (M = 1.46, SD = 0.50). This indicates that the response behavior of experts and novices is similar, and thus, both groups tend to be unable to identify IoT involvement (visual and label-based combined) in BPMN 2.0.

For the scenario in PM7 (visual and label-based IoT aspects), the two-sided *t*-test revealed no significant differences ($t(247.00) = -0.21$, $p < 0.83$) in the responses between experts (M = 1.77, SD = 0.42) and novices (M = 1.76, SD = 0.43). This indicates that the response behavior of experts and novices is similar, and thus, both groups tend to be able to identify IoT involvement (visual and label-based combined) in BPMN 2.0.

Regarding PM8 (label-based IoT aspects), the two-sided t-test revealed a significant difference ($t(149.02) = -2.31$, $p < 0.02$) in responses between experts (M = 1.88, SD = 0.32) and novices (M = 1.76, SD = 0.42). This indicates that the response behavior of experts and novices is not similar. Experts tend to identify IoT involvement in PM8 more than novices (cf. Tables 11 and 17).

For the scenario in PM9 (label-based IoT aspects), the two-sided t-test revealed no significant differences ($t(247.00) = 0.98$, $p < 0.33$) in the responses between experts (M = 1.65, SD = 0.48) and novices (M = 1.72, SD = 0.45). This indicates that the response behavior of experts and novices is similar, and thus, both groups tend to be able to identify IoT involvement based on labels in BPMN 2.0.

For the scenario in PM10 (label-based IoT aspects), the two-sided t-test revealed no significant differences ($t(247.00) = 0.12$, $p < 0.90$) in the responses between experts (M = 1.64, SD = 0.49) and novices (M = 1.64, SD = 0.48). This indicates that the response behavior of experts and novices is similar, and thus, both groups tend to be able to identify IoT involvement based on labels in BPMN 2.0.

Regarding PM11 (label-based IoT involvement), the two-sided t-test revealed a significant difference ($t(197.41) = -2.90$, $p < 0.01$) in the responses between experts (M = 1.95, SD = 0.21) and novices (M = 1.85, SD = 0.36). This indicates that the response behavior of experts and novices is not similar. Experts tend to identify IoT involvement in PM11 more than novices (cf. Tables 11 and 17).

For PM12, the distribution of Likert-scale responses regarding several aspects was as follows:

- For the clarity of the visual involvement of the IoT in the process model, there was no significant difference ($\chi^2(4) = 0.94$, $p < 0.91$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, the statement that IoT involvement is visually clear in PM12 *partially applies* (cf. Table 7).
- For the ability to differentiate IoT-aware tasks from BPMN tasks, there was no significant difference ($\chi^2(5) = 2.98$, $p < 0.70$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups it *tends not to apply* (cf. Table 7) that there is a clear differentiation regarding the ability to distinguish IoT-aware tasks from other BPMN tasks.
- For the assessment of the challenge in distinctly determining the IoT involvement in the process model, there was no statistically significant difference ($\chi^2(5) = 8.58$, $p < 0.13$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, it *strongly applies* (cf. Table 7) that it is difficult to clearly determine IoT involvement.
- For the challenge of identifying IoT involvement in the process model, particularly concerning the process model size, there was no statistically significant difference ($\chi^2(5) = 3.01$, $p < 0.70$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, it *strongly applies* (cf. Table 7) that the larger the process model is, the more difficult it is to identify IoT involvement.
- For the the fatigue associated with clearly determining IoT involvement in the process model, there was no statistically significant difference ($\chi^2(4) = 3.78$, $p < 0.44$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, it *strongly applies* (cf. Table 7) that it is exhausting to identify IoT involvement.
- For the the impossibility of visually distinguishing between IoT and BPMN tasks, there was no statistically significant difference ($\chi^2(5) = 5.99$, $p < 0.31$) in the responses between experts and novices. This indicates that the response behavior of experts and

novices is similar and, thus, to both groups, the statement that (cf. Table 7) it is not possible to visually distinguish between IoT tasks and BPMN tasks *partially applies*.

For PM13, the distribution of Likert-scale responses regarding several aspects was as follows:

- For the clarity of the visually expressed IoT involvement in the process model, there was no significant difference ($\chi^2(5) = 2.96$, $p < 0.71$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, the statement that (cf. Table 7) IoT involvement is visually clear *partially applies*.
- For the ability to differentiate IoT-aware tasks from BPMN tasks, there was no significant difference ($\chi^2(5) = 9.04$, $p < 0.11$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, it *tends not to apply* (cf. Table 7) that there is a clear differentiation regarding the ability to distinguish IoT-aware tasks from other BPMN tasks.
- For the challenge in distinctly determining IoT involvement in the process model, there was no statistically significant difference ($\chi^2(4) = 1.00$, $p < 0.91$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, it *strongly applies* (cf. Table 7) that it is difficult to clearly determine IoT involvement.
- For the challenge of identifying IoT involvement in the process model, particularly concerning its size, there was no statistically significant difference ($\chi^2(5) = 1.20$, $p < 0.95$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, it *strongly applies* (cf. Table 7) that the larger the process model is, the more difficult it is to identify the IoT.
- For the fatigue associated with clearly determining IoT involvement in the process model, there was no statistically significant difference ($\chi^2(5) = 6.13$, $p < 0.29$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, it *strongly applies* (cf. Table 7) that it is exhausting to identify IoT involvement.
- For the impossibility of visually distinguishing between IoT and BPMN tasks, there was no statistically significant difference ($\chi^2(5) = 2.77$, $p < 0.74$) in the responses between experts and novices. This indicates that the response behavior of experts and novices is similar and, thus, to both groups, the statement that (cf. Table 7) it is not possible to visually distinguish between IoT tasks and BPMN tasks *partially applies*.

5.3. Summary

This subsection answers the research questions RQ1–RQ4 (cf. Section 1). In many cases, existing works recommend [11,16,18–21,24,25,30–32] using different task types, such as service, script, and business rule tasks, to represent IoT involvement. However, to the best of our knowledge, the visually expressed and label-based discernibility of IoT involvement in BPMN 2.0 process models has not been empirically evaluated from a user perspective. For RQ1 and RQ2, the descriptive and inferential analysis in this study revealed that IoT involvement is neither visually discernible or discernible based on labels from a process model reader perspective. In particular, the finding regarding RQ3 and RQ4 (i.e., there are modeling elements in BPMN 2.0 that make IoT involvement clearer) delivers important insights for the design of IoT-aware business processes with BPMN 2.0 modeling elements. Furthermore, this study has shown that IoT involvement in process models is more likely to be acknowledged when label-based and visually expressed IoT aspects are combined. Another crucial finding of the study is that utilizing business rule tasks is not suitable for representing sensors. Instead, IoT aspects of both sensors and actuators are identified in service and script tasks. The study participants unanimously concur regarding the effect required and frustrating nature of identification. Identifying IoT aspects in BPMN 2.0 process models proves to be both exhausting and difficult.

6. Discussion

The existing literature on IoT-aware business processes emphasizes the importance of representing IoT involvement [3,11,16–18,21,24,25,30–32,35] in process models. However, they only suggest using already existing BPMN 2.0 modeling elements such as different task types, pools, and lanes.

Regarding RQ1, we evaluated whether IoT involvement in BPMN 2.0 process models is visually discernible. Our study has shown that the majority of the study participants cannot identify IoT involvement solely based on visually expressed IoT aspects, i.e., task types. However, participants recognizing IoT involvement identified it through various task types, specifically, the service and script tasks. Based on the study results, we learned that using business rule tasks is not suitable for representing the IoT, actuators, and sensors.

In the context of RQ2, we investigated whether IoT involvement in BPMN 2.0 process models is discernible based on task labels. The results revealed that the majority of the study participants can identify IoT involvement in BPMN 2.0 process models based on task labels. Across the four scenarios defined by PM8–PM11, no significant difference in the reactions of experts and novices was observed for PM9 and PM10. However, there was a notable contrast in the response behavior for PM8 and PM11. This significant result indicates that experts are more inclined to identify IoT involvement based on task labels compared to novices. For PM8–PM11, we used two key metrics to assess IoT involvement. The first metric assessed the accuracy of the overall interpretation, i.e., the extent to which BPMN modeling elements were correctly identified as IoT-related or non-IoT-related modeling elements. The second metric deals with the correct identification of IoT-related modeling elements within a process model. Despite the fact that the majority of the study participants identified IoT involvement based on task labels, the study participants only achieved mediocre ratings regarding the two metrics (cf. Table 5). The results show that the study participants were unable to identify all IoT aspects in the BPMN 2.0 process model.

RQ3 investigates whether IoT involvement in BPMN 2.0 process models is discernible based on a combined use of specific task types and task labels. The results revealed that the majority of the study participants can identify IoT involvement based on the combined use of task labels and task types. Across the two scenarios described in PM6 and PM7, there is no significant difference concerning the responses of experts and novices. For PM6 and PM7, we applied two key metrics to assess IoT involvement. Despite the fact that the majority identified IoT involvement based on the combined use of IoT-related task labels and task types, the study participants only achieved a mediocre rating regarding the two metrics (cf. Table 3). The results show that the study participants were unable to identify all IoT aspects in the BPMN 2.0 process model.

Regarding RQ4, we investigated whether there are BPMN 2.0 modeling elements that make IoT involvement clearer (PM6 vs. PM7 and PM12 vs. PM13). In this context, pools support the identification of IoT involvement (cf. Table 3). The results may be explained with the fact that pools represent a specific organizational unit, be this a department or a business partner. Furthermore, pools are usually labeled accordingly (e.g., smart factory, temperature sensor, or robot). Such pool labeling fosters identifying IoT involvement. Furthermore, we learned that study participants tend to better identify IoT involvement in the context of service and script tasks compared to business rule tasks and abstract tasks (cf. Table 2). Note that the service task, marked with the gear icon, triggers an automation response among the participants, similar to what can be observed to the script task. The visual cue of the gear icon seems to play a significant role in signaling automation, triggering participants to associate it with IoT involvement as well.

RQ5 investigates whether there are BPMN 2.0 modeling elements that reduce effort and frustration when reading IoT-aware business processes. For this purpose, we analyzed and compared the results of PM12 and PM13 (cf. Table 7). Note that across the two scenarios, there is no significant difference concerning the response of experts and novices (cf. Tables 21 and 22). These results reveal that the combination of IoT-related task types and pools might reduce the difficulty of identifying IoT involvement (cf. Table 7).

The findings may be explained with the fact that involved roles and objects can be clearly indicated through the use of pools.

6.1. Implications

The implications drawn from the presented study hold significant relevance for integrating IoT aspects within BPMN 2.0 modeling. The findings enable valuable insights for practitioners, researchers, and tool developers seeking to enhance the representation and comprehension of IoT involvement in business processes.

This study emphasizes the need for enhanced modeling elements beyond the standard BPMN 2.0 notation. While the existing literature recognizes the importance of representing IoT involvement using different task types, pools, and lanes, our study highlights the limitations of relying solely on BPMN 2.0 standard elements. Specifically, traditional elements like business rule tasks and abstract tasks were found to be less suitable for effectively capturing IoT aspects (including actuators and sensors). On the one hand, the study on the visual discernibility of IoT involvement revealed issues, e.g., when trying to identify IoT-related modeling elements solely based on visual cues (e.g., task types and task icons, respectively). This indicates the need for an improved visual representation of IoT aspects in BPMN 2.0 process models. On the other hand, task labels tend to ease the identification of IoT involvement. As indicated by accuracy metrics, the overall performance in identifying IoT involvement was moderate, highlighting the need for clearer task labels as well. Combining both proper task types and task labels has proven to be more effective when comprehending IoT involvement. Moreover, participants still faced challenges in consistently identifying all IoT aspects of a process model, indicating the potential for better aligning visual cues and labels. The use of pools has proven beneficial as a factor of representing IoT involvement. Pools, which represent specific organizational units, can provide clear labels (e.g., smart factories, temperature sensors, and robots), simplifying the identification of IoT involvement. Incorporating organizational context through the use of pools can further contribute to a more accurate interpretation of IoT-related processes.

Study participants showed a better performance in identifying IoT involvement in the context of service and script tasks. Particularly, the visual cue of the gear icon in service tasks triggered an association with IoT involvement among the participants. This indicates that the choice of specific task types has a significant influence on the correct identification of IoT elements in BPMN 2.0 process models. To reduce the effort and frustration when reading IoT-related business processes, different task types and the use of pools have proven to be effective. A process model with pools contributes to a more efficient and less burdensome interpretation of IoT-related process aspects. In conclusion, addressing these implications can lead to advancements in representing IoT aspects in BPMN 2.0 process models, fostering clearer communication and improving the usability of models in the context of IoT-related business processes. Further research and tool development are necessary to refine modeling practices and to enable a more intuitive understanding of the IoT's involvement in business process models.

In addition to the implications presented, this study has revealed several challenges related to process model comprehension. A deep understanding of the process model, particularly the individual modeling elements, is indispensable for an accurate interpretation. However, the use of standardized modeling elements (e.g., service tasks, script tasks, pools, and lanes) for expressing IoT aspects increases the process model's complexity. This might result in potential misunderstandings, affecting the comprehension of the process. Misinterpretation of IoT-related process poses a risk that influences every phase of the BPM lifecycle and potentially leads to undesirable results or even project failure.

6.2. Threats to Validity

The presented study reveals threats to validity that need to be discussed. First, the process models used in the study might not be fully representative regarding the complexity of IoT-related processes in the real world. It is therefore noteworthy that the used process models might become simple and this simplicity might not reveal the intricacies of complex IoT-related processes. Therefore, the applicability of the presented results in a more complex context should be considered with caution. Nonetheless, we were able to show that both experts and novices, even when facing simple IoT-related processes, have difficulties in completely identifying IoT involvement both visually and based on labels. However, we acknowledge that further studies with real-world IoT-aware business processes are needed to generalize the results.

Second, this study only explores specific combinations of BPMN 2.0 modeling elements, such as service tasks, business rule tasks, script tasks, and pools. It is noteworthy that the use of different combinations of modeling elements might yield varying results. We recognize the need for further research involving diverse combinations (e.g., events, data objects, and text annotations) to generalize and extend the findings.

Third, this study faces limitations regarding the participants' demographics. Although we aimed at a heterogeneous group of study participants, most participants were recruited from the Computer Science field. Participants from other disciplines, such as Management Science, might have different perspectives on IoT-related BPMN process models. This indicates the need for a more heterogeneous group in future studies to obtain a more comprehensive understanding.

Fourth, categorizing participants into novice and expert groups solely based on questions about different BPMN 2.0 task types might be an approach that is too simplistic and requires more precision. Including an additional expertise test might lead to a more accurate categorization, increasing the robustness of the results. We recognize the importance of further studies involving participants with expertise in both process management and the IoT to enhance the generalizability of our findings.

Fifth, the primary focus was on BPMN 2.0 task types (i.e., service, script, and business rule tasks) without task labels for evaluating the discernibility of IoT involvement in business processes. This approach might not fully encapsulate the multifaceted nature of IoT elements' representation within BPMN, as real-world applications often necessitate a holistic use of multiple BPMN elements (e.g., tasks, pools, lanes, message events, message flows) in tandem to accurately model IoT processes. Therefore, the insights gained from focusing on individual icons might not fully reflect how users perceive and grasp IoT integration within more detailed and realistically constructed BPMN models. However, it is crucial to note that the existing literature often cites service, script, and business rule tasks as suitable for depicting IoT involvement in BPMN 2.0 business processes [16,19,22]. This study conducted initial explorations to validate such claims, specifically aiming to discern which task type is most readily identified as IoT-related by study participants. We recognize the necessity for broader research encompassing additional BPMN 2.0 modeling elements such as events, pools, and data objects to fully evaluate the suitability of BPMN 2.0 for IoT-aware business processes.

Sixth, utilizing task labels to identify IoT aspects in BPMN 2.0 process models introduces variability that depends on the modeler's accuracy in defining IoT aspects. Although task labels help clarify task specifics, this aspect of the analysis may unintentionally emphasize the modeler's descriptive skills over the label-based expressive power of BPMN 2.0 elements. Nonetheless, the results of this study have provided some important initial insights. For example, this study showed that despite the use of typical IoT task labels such as light sensor, smart factory, or start temperature recording, they were not clearly identified as IoT-aware by the study participants. However, we recognize that this reveals an essential dimension of using BPMN 2.0 for IoT modeling: the essential impact of how well a process modeler can use task labels to complement the visual elements of BPMN 2.0. This highlights an important area for future research and development by improving the guidelines for labeling and documenting IoT-aware business processes to better support IoT integration. The results obtained from our user study can be used to improve the ability of modelers to effectively communicate IoT aspects through graphical and textual BPMN

2.0 elements to ensure a more intuitive and comprehensive understanding of IoT processes among all stakeholders.

Finally, the scenarios covered by the process models introduce an additional risk. Familiarity with specific process scenarios and domains might have positive effects on the participants' understanding of process models compared to scenarios with which they are less familiar. This potential bias could influence the interpretation of the results, highlighting the need for caution when generalizing results to other contexts or to scenarios the model readers are less familiar with.

7. Summary and Outlook

This paper presents the findings of a study that evaluated the comprehensibility of IoT involvement in BPMN 2.0 process models. This study considered 13 process models with various combinations of modeling elements and included 249 participants. With this research, we wanted to understand how IoT involvement in BPMN 2.0 models is perceived by process model readers. In the scope of the five research questions (i.e., RQ1–RQ5), three key facets for incorporating IoT aspects in BPMN 2.0 models were covered: visually expressed, label-based, and hybrid (i.e., visually expressed + label-based) discernibility.

The literature review highlighted the importance of recognizing IoT involvement in business processes. However, related works focus on the use of standard BPMN 2.0 modeling elements or extend BPMN 2.0 with specific IoT-related modeling elements. Concerning RQ1, the empirical investigation revealed that the visual discernibility of IoT involvement based on different task types (with different icons) is challenging for participants. While certain task types, such as service and script tasks, seem to highlight the involvement of the IoT, business rule tasks turned out to be unsuitable.

Addressing RQ2, the study revealed that label-based discernibility, specifically based on task labels, was more effective, whereby experts are more likely to be able to identify IoT involvement compared to novices. Participants achieved only a mediocre rating in correctly identifying IoT aspects for the models.

RQ3 examined the combined label-based and visual discernibility of IoT involvement, indicating that the majority of the study participants were able to identify IoT aspects based on both task labels and task types. However, the overall accuracy of identifying IoT aspects remained mediocre.

Regarding RQ4, this study has shown that the use of pools and specific labeling within IoT-related pools contributed to a better identification of IoT involvement. Additionally, service and script tasks turned out to be more effective in conveying IoT involvement than business rule tasks and abstract tasks.

Finally, RQ5 explored elements that could reduce the effort and frustration when reading IoT-related business processes. The combination of different task types and the use of pools were identified as factors contributing to reduced difficulty and exhaustion, indicating the importance of a clear representation to foster comprehension.

The results of this study revealed a limitation of BPMN 2.0 regarding the accurate representation of IoT-related business processes. The empirical study revealed that the visual elements of BPMN 2.0 did not provide a clear and recognizable representation of IoT involvement. The study participants faced the challenge of visually identifying IoT involvement based on task types. In particular, there might be ambiguities, as the service task can either be IoT-related (utilizing a standard service task for IoT representation) or represent a conventional BPMN 2.0 service task. Even though task labels have shown some potential for identifying IoT involvement, participants only achieved a mediocre score in correctly identifying IoT-related elements in BPMN 2.0 process models. As a major result, therefore, this study revealed the need for an appropriate modeling approach or the exploration of alternative modeling languages that are better suited to capture the intricacies of IoT-related business processes.

In summary, the presented research provides valuable insights into the challenges and opportunities associated with the representation of IoT aspects in BPMN 2.0 process models, offering guidance for practitioners and researchers for improving the visual and label-based representation of IoT-related business processes. The findings underscore the significance of carefully selecting modeling elements to enhance both the discernibility and comprehensibility of IoT-related BPMN 2.0 models.

In future research, we intend to enhance the scope of our study. First, we plan to incorporate eye tracking technology to gain more profound insights into the participants' behavior when identifying IoT involvement in business processes models. This will provide us with an understanding of the cognitive process of interpreting IoT-related BPMN 2.0 process models. Additionally, we aim to explore further combinations of modeling elements such as events, lanes, and sub-processes in the considered processes. With this, we aim to identify additional modeling element combinations that might enhance the understanding of IoT involvement. Finally, we will introduce more complex IoT-related business processes and measure the workload of participants. This approach will allow us to assess the impact of an increased model complexity on the comprehensibility and the efficiency of understanding IoT-related business processes within BPMN 2.0.

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