Understanding individual processes of conceptual modeling

A multi-modal observation and data generation approach

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Abstract: How conceptual modeling is performed by modelers, how modeling processes proceed, which modeling difficulties modelers face and why, and how to overcome these difficulties by tailored modeling support has received limited attention in conceptual modeling research so far. Studying individual modeling processes by observing modelers during conceptual modeling contributes to identifying modeling difficulties, and to understand whether modelers require tailored modeling support. Based on TOOL, a modeling tool and research observatory for studying modeling processes, we design a multi-modal observation and data generation approach and report its application to exploratory studies of individual modeling processes, and show how complementary modes of observation are integrated during data analysis for a richer and more complete understanding of modeling processes. Moreover, we discuss how the multi-modality of observations contributes to understanding modeling processes and modeling difficulties, and how observations during modeling feed back into the software development of TOOL.

Keywords: Conceptual modeling; Modeling process; Modeling tool; Research methodology

1 Introduction and rationale

Conceptual modeling as an activity involves an intricate array of cognitive processes and performed actions including abstracting, conceptualizing, contextualizing, associating, visualizing, interpreting & sense-making, judging & evaluating, and, in group settings, communicating, discussing and agreeing [RS19; RTS19]. Conceptual modeling involves mastering theoretical foundations, modeling languages and methods, applying them to practical problems, and, while performing a modeling process, critically thinking and reflecting upon an application domain in terms of its technical languages, the natural languages in use in the domain, their imprecision, ambiguities and related challenges [WO80]. Learning and performing conceptual modeling is, hence, construed as a complex task based on codified as well as tacit knowledge [SS17] guided by theoretical underpinnings and refined by reflecting practical experience.

Despite its obvious relevance, the process (or ‘act’) of conceptual modeling has received limited attention so far [HLP06; HPv05]. How conceptual modeling is performed by

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modelers, how modeling processes proceed, which modeling challenges and difficulties modelers experience and why, and how to overcome these difficulties by tailored modeling support has been subject to only a few studies [e. g., Se16; Ve96]. At large, surprisingly little is known about the actual act of conceptual modeling, about the reasoning of modelers and their deliberations (e. g., about modeling decisions), and whether different (idealized) types of modelers can be identified, e. g., by identifying patterns of modeling processes and/or difficulties, and whether these modeler types require different modeling support. Similarly little is known about how individuals learn conceptual modeling, about their learning progress, need for learning support and tool assistance [RTS19].

Studying individual modeling processes promises to shed further light on these largely unknowns, and, ultimately, to enable us to design targeted (tool) support for modelers at different stages of their learning and mastering of conceptual modeling. Observing the reasoning of modelers and the multifaceted cognitive processes carried out while conceptual modeling, however, faces a number of methodological challenges: Neither the relevant cognitive processes nor the corresponding deliberations on modeling decisions are directly observable. Hence, research on conceptual modeling processes has reverted to observable aspects of modeling processes such as modelers' interactions with software tools, modelers' eye movements, or their verbalizations of their thought processes ('think aloud' [ES93]).

Following this trajectory, this paper presents the design of a multi-modal observation and data generation approach to conduct studies of individual modeling processes—based on TOOL, a webbrowser-based modeling tool and modeling observatory we have been developing for the past six years [Te17; Te19; TS18]. Rather than relying on a single mode of observation, the multi-modal observation approach presented in this paper complements different modes of observation to provide a more complete picture of the phenomena under investigation [VBB13; VBS16]. Underlying our research is the fundamental assumption that modeling processes demand and deserve study from several complementary perspectives following Berger and Luckmann's remarkable view that "the object of thought becomes progressively clearer with this accumulation of different perspectives on it" [BL67, p. 10]. The richness of cognitive processes involved in conceptual modeling and the complexity of conceptual modeling as an activity is the main rationale for combining multiple modes of observation for studying individual modeling processes [cf. RS19]. Complementing different modes of observation is a research strategy common to mixed methods research designs [CP18], and assumed to allow us to identify a wider range of facets about the modeling process assisting us in better understanding individual modeling processes.

Analyzing think aloud protocols has shown promising results for understanding cognitive processes of subjects working on problem-solving tasks in general and modeling tasks in particular [e. g., BD92; ES93], and we consider verbalization of thoughts as the best available means of expression for achieving insights into modelers' reasoning as our spoken language provides us with a rich and flexible tool to express our thinking. However, reasoning of modelers will not always be observable from think aloud protocols alone, since modelers' movements and gestures entail important additional cues about their modeling challenges and difficulties, for instance. Hence, the approach presented in this paper complements think aloud (verbal) protocols with recording interactions of modelers with the modeling tool as well as videotaping modelers to allow for additional visual clues, e. g., regarding interaction with pen & paper or modelers' movements during modeling. Additionally, subjects are surveyed about their modeling process before and after they work on a (controlled) modeling task. This specific mix of observation modes is tailored to observing modeling processes using a modeling tool and is assumed to provide a more complete picture of modeling processes and to allow for identifying a wider range of modeling challenges and difficulties.

Indeed, to ask subjects to think aloud and to complement verbal protocols with observations from such recordings is a second-best approach, warranted only because it is not possible to directly access and capture cognitive processes and, thus, modeler reasoning while modeling. Modelers may have difficulties verbalizing their reasoning while modeling on principle accounts (because verbalizing own thoughts can be difficult) or on modeling-related accounts (e. g. because of the difficulty of finding the right words to express oneself). However, among all possible alternative modes of observation, think aloud verbalization promises the richest insights into important non-directly observable aspects of the modeling process.

Section 2 discusses related work before we introduce TOOL in Section 3. In Section 4, we explain the multi-modal observation and data generation approach and report on the accompanying data analysis strategy. First exploratory studies are reported in Section 5, followed by a discussion and conclusion in Section 6.

2 Related work

Prior work has investigated individual modeling processes (e. g., data or process modeling processes) using different modes of observation and different data generation approaches. Early contributions primarily focus on data modeling processes. Using verbal protocols, [BD92] identify similarities and differences between non-experienced and experienced modelers when constructing a conceptual data model. In a subsequent study, errors of novice modelers are investigated in two laboratory experiments [BA94]. This study evaluates errors in data models constructed by novices complemented with analyzing verbal protocols with the aim to achieve insights into why the novices committed the errors [BA94, p. 64]. The two studies led to suggestions for supporting novices in data modeling with immediate feedback in supportive tools [BA94, pp. 66f]. The behavior of modelers while constructing conceptual data models is investigated in [ST95]. Based on two laboratory studies using think aloud protocols, insights into how individuals use heuristics to perform their modeling processes are achieved. A more recent study investigates how ontological modeling guidelines assist modelers in constructing UML class diagrams [Be11]. In a laboratory setting, verbal data protocols of subjects creating UML class diagrams are collected and analyzed for numbers of encountered modeling difficulties.

This stream of research primarily strives to better understand how humans construct process models and how the result of the modeling process, i. e., the process model, is affected by different modeling styles [e. g., Cl15a; Pi15]. One prominent approach in this research stream is to record modeler-tool interactions, e. g., placing a representation of a notation symbol on a virtual canvas in a software tool, and to analyze the recorded modeling processes using data mining techniques and cluster analysis [Pi15, p. 1061]. The study leads to identifying three distinct styles of modeling that could be observed in modeling processes [Pi15, p. 1059]. An accompanying modeling environment supporting the analysis of modeling processes named Cheetah Experimental Platform (CEP) has been suggested in early contributions to the discussion on the process of process modeling [e. g., PZW10]. CEP is, in particular, designed to support the workflow of (controlled) experiments—each step in the experimental workflow uses components provided by CEP [PZW10, p. 15]. The tool offers different analysis functionalities, e. g., the Cheetah Analyzer that records the process of creating process models with Cheetah Modeler [PZW10, p. 17] and allows to replay the modeling processes with the integrated step-by-step execution functionality. While the step-by-step execution allows for reconstructing the process of process modeling, important thoughts and cognitive performances are not observed, e. g., when creating synchronizations/parallelizations. For further exploring behavior patterns incorporating modeler-specific and task-specific factors, it is envisioned to track modeler-tool interactions, complemented with think aloud protocols and eye movement tracking data [Pi14].

Further related work identifies cognitive process modeling techniques by observing and tracking modeler-tool interactions while working on process modeling tasks [Cl15a]. An approach visualizing how process models are created is introduced allowing for further analysis as, for example, specific pattern reconstruction, e. g., to identify patterns of delete operations [Cl15b, p. 158]. This approach bases on process mining and collects data of modelers while working on modeling tasks. Tracked data is analyzed using step-by-step replays of the modeling process and visualized in so-called PPMCharts [Cl15a, pp. 1404f]: Every interaction of a modeler with the modeling canvas constructing a process model is visualized in a specific color and shape depending on the type of interaction, e. g., change operation [Cl15a, p. 22]. The icons are positioned on horizontal timelines, each of which refers to a model element. The complementary use of replaying and visualizing modeler-tool interactions in [Cl15a] inspired the observation approach for modeling processes reported in the present work.

Hoppenbrouwers et al. take a communication-theoretic perspective and investigate the modeling process as a dialogue [HLP06; HPv05]. To capture modeling processes, especially, modeling decisions, a part of the meta-model of a modeling laboratory aimed at gathering empirical data on the details of modeling processes is proposed [HLP06]—closely related to the observation approach presented in this work. However, we were not able to find an application of the laboratory suggested in [HLP06] so far. In further work by Hoppenbrouwers and co-authors, business process modeling processes are analyzed with a focus on collaborative modeling [WHB17]. The work aims at generating insights into psychological mechanisms of modeling skills and related cognitive processes while modeling. For data generation, modeling processes are recorded on video while modelers are asked to think aloud in these studies.

A further related approach from the perspective of learning outcomes and with a focus on enterprise modeling investigates modeling processes of learners and develops a feedback approach based on analyzing individual modeling processes [e. g., SSD14]. JMermaid is used as experimental environment to analyze modeling behavior utilizing process mining analysis and pattern identification to study conceptual modeling behavior of novices. With a focus on improving teaching practices in the field of conceptual modeling, the approach aims to provide process-oriented feedback [e. g., Se16].

In a more distantly related approach, modeler-tool interactions are tracked and subsequently used to investigate software usability aspects of modeling tools [Th15, p. 153]. More specifically, process execution data is used for so-called usability mining. In addition to interactions of modelers with the modeling tool, interactions with the graphical user interface are recorded [Th15, p. 155]. The resulting approach is evaluated in the context of a modeling scenario with the ARIS Designer of Software AG.

3 TOOL – A webbrowser-based modeling tool and observatory

As prerequisite for understanding the multi-modal observation and data generation approach, this section provides background information, technical design considerations, and fundamental functions of TOOL. As part of the long-term research program, we have been developing a web-based modeling tool integrated with a modeling observatory for studying modeling processes since 2013 to explore design and implementation strategies for studying modeling processes, e. g., tracking interactions of learners with graphical editors (see Fig. 1) [Te17; Te19; TS18]. Two essential requirements drive the development: (1) Platform independence to the greatest extent economically viable as well as (2) usability (especially an intuitive user interface of the modeling tool based on the application scenario). Concerning the multi-modal observation approach, we implemented and combined selected complementary observation approaches ranging from conducting surveys to tracking modeler-tool interactions to recording verbal protocols—based on our fundamental assumption that modeling processes demand study from different, complementary angles. For the prototype, we opted for a web application with a JavaScript-driven browser frontend and a Java EE (Enterprise Edition)-based backend (see [Te19; TS18] for further background on TOOL). The modeling tool (frontend) is intended to support modelers, e. g., with ad-hoc syntax checking while constructing conceptual models.

The modeling observatory (backend) implements tracking algorithms and analytic components, including analysis and administration user interfaces. More specifically, the observatory implements an algorithm which tracks modeler-tool interactions while working on modeling tasks, by storing every modeler-tool interaction with the graphical editor as time-discrete event. Studying individual modeling processes is supported in the modeling observatory by providing multiple modes of observations and complementary analysis tools (see Sect. 4) as well as configurable parameters for the observation setup that, for instance, allow to select observation modes.

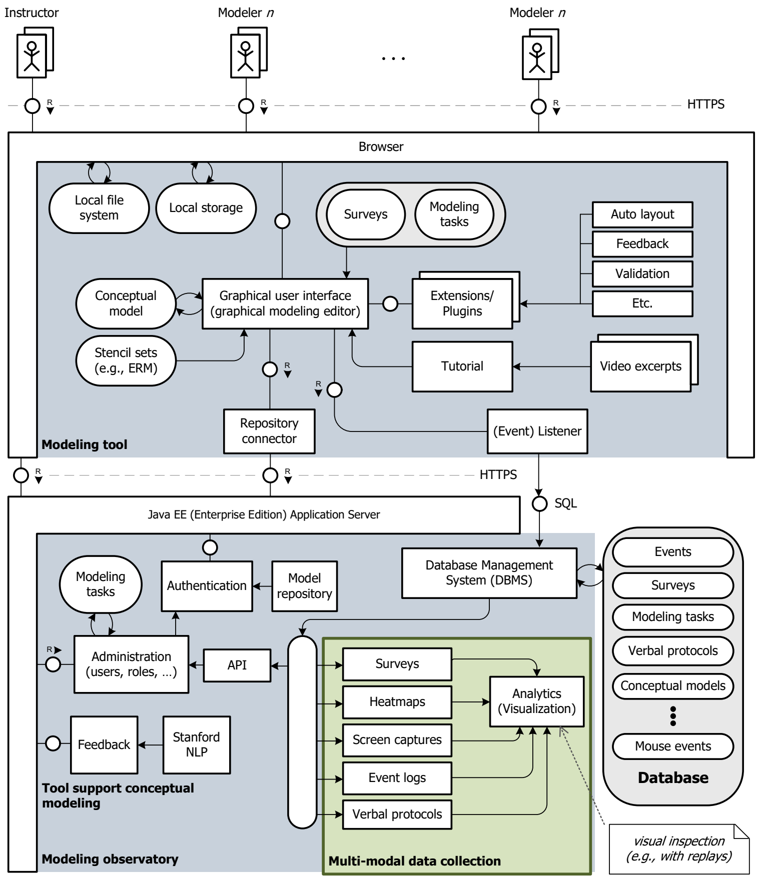


Fig. 1: Software architecture at the conceptual design level depicted using FMC (Fundamental Modeling Concepts [KGT06]). The green area represents the technical components of the multi-modal observation and data generation approach.

4 Multi-modal observation of conceptual modeling processes

In contrast to prior work, the observation approach to study individual modeling processes presented in this work aims to purposefully integrate complementary modes of observation, including the integration of verbalization of modelers during model construction (think aloud protocols, e. g., [ES93]). At present, the observation approach combines four modes of observation (see Fig. 2) complementing and tying in with prior approaches to studying individual modeling processes [e. g., Pi14; SSD14; WHB17].

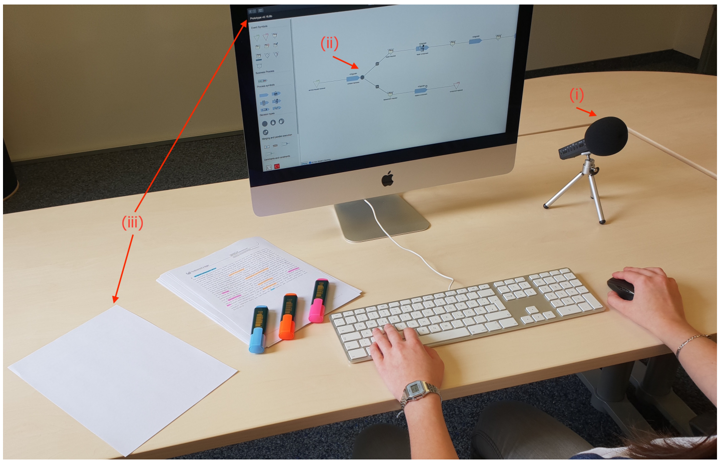
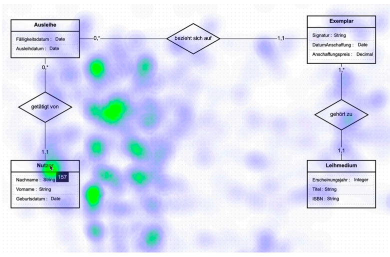


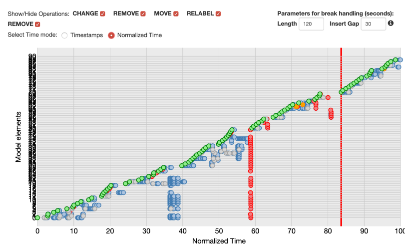
Fig. 2: Overview from the 'over-the-shoulder' perspective used for videotaping modelers (iv).

(i) Recording verbal protocols: This mode of observation targets the reasoning of modelers while modeling via verbalization (think aloud)—an approach that has shown promising results in observing subjects performing problem-solving and, particularly, modeling tasks [e. g., BD92; ES93]. It is aimed at understanding cognitive processes of subjects during conceptual modeling, e. g., by identifying cognitive breakdowns indicating modeling difficulties [RS19]. A component of the modeling observatory allows to collect verbal data by recording voice while subjects are working on a modeling task. Before the beginning of a task, subjects are instructed and informed to verbalize all their thoughts during the modeling. Subjects' comments during the modeling are recorded and can be downloaded as WAV file in the analysis interface of the modeling observatory. If a modeler stops speaking, a notification in the top right corner reminds the modeler to continue speaking—as suggested for gathering think aloud protocols [ES93, pp. 82f, 256].

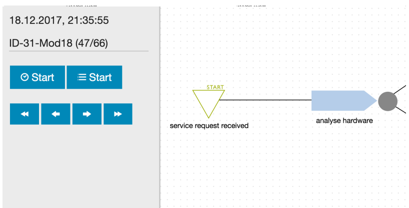
(ii) Tracking modeler-tool interactions: This mode of observation aims to observe modelers' interactions with the graphical editor of the modeling tool. Every interaction during the construction of a conceptual model is recorded as a time-discrete event. This mode of observation is supported by the modeling observatory and implemented with the modeling tool [see Te19] with which the subjects construct the conceptual model. We developed three complementary analysis interfaces for visualizing and analyzing modeler-tool interactions based on tracked data: (1) real-time and step-by-step replays showing the construction of the conceptual model on the drawing area (s. Fig. 3c–d): The step-by-step replay visually shows every step of model construction whereas the automatic replay shows model construction in real-time, both allowing for visual inspection of modeling behavior; (2) detailed and time normalized dot diagrams (s. Fig. 3b): The dot diagrams provide several configuration parameters that allow the visual appearance of the diagram to be tailored to the needs of the analysis, e. g., time normalization. The vertical axis indicates the consecutively numbered model elements that are created (green circle), changed (blue circle), deleted (red circle) or relabeled (orange circle). The red vertical line is a normalized time gap that can be adjusted. This visualization is inspired by the PPMCharts visualizing the process of process modeling [Cl15b] and the Dotted Charts suggested in [SA07]; (3) visualizing mouse-movements and mouse clicks performed by modelers in the modeling tool (heatmaps showing dwell time and mouse clicks, s. Fig. 3a). In addition, heatmaps allow insights into user behavior in the modeling tool, e. g., uncontrolled clicking. The analysis interfaces for the tracked modeler-tool interactions allow for further exploring situations identified as deviant or unclear in the audio and video protocols of modeling processes and for identifying anomalous modeler-tool interactions by manual inspection.



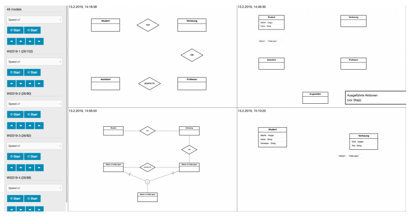
(a) Heatmap



(b) Dot diagram



(c) Single replay



(d) Multiple replay

Fig. 3: Visualization of modeler-tool interactions.

(iii) Surveying subjects pre- and post-modeling: The modeling observatory supports online surveys that the subjects can be asked to complete within the modeling tool before and after modeling. The aim is to gather additional data from subjects performing a modeling task, e. g., on experience and knowledge of conceptual modeling, encountered modeling difficulties and challenges, or the perceived familiarity and difficulties with the domain of the modeling task, or demographic information of the subjects [cf. RS19]. The surveys provide support for closed-ended and open-ended questions. In the modeling observatory, survey results are linked to the constructed conceptual models to support analysis, e. g., for identifying modeling difficulties.

(iv) Videotaping modelers: Subjects are videotaped from an 'over-the-shoulder' perspective (see Fig. 2) to capture the overall interaction with the modeling tool during the work on a modeling task and the subjects' behavior as movements and gestures entailing additional information on their modeling process, e. g., cues about modeling challenges and difficulties. Recording modelers' behavior outside of the modeling tool supports resolving ambiguous situations in the verbal protocols [Zu13].

Depending on the needs of a study, an observation workflow user interface allows configuring the selection and sequence of observation modes: (i) recording verbal protocols, (ii) tracking modeler-tool interactions, and (iii) surveying subjects pre- and post-modeling. Additionally, modeling tasks, display elements of the user interface, general information and privacy statements can be configured in line with the requirements of the respective study.

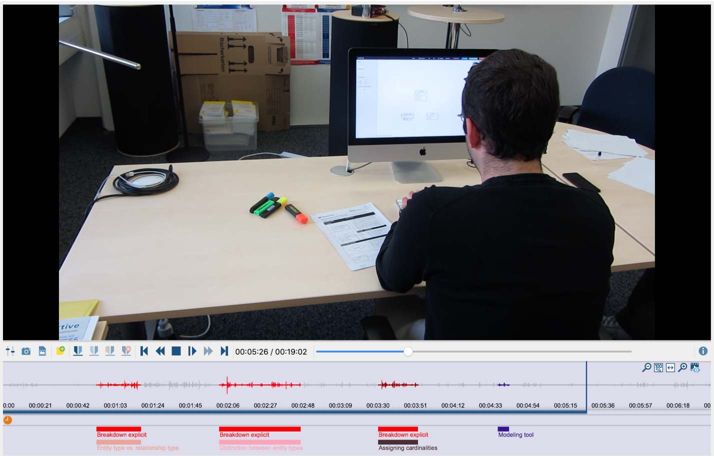


Fig. 4: Coding audio-visual protocols (screenshot from MAXQDA [VE18]).

The multi-modal observation approach integrates with the data analysis strategy. In the following, it is explained how the collected data from the complementary modes of observation is technically combined and how analyses proceed. The verbal think aloud protocol are linked and time-synchronized to the video recordings into audio-visual protocols comprising both observations. To add structure to the data, we code these videos by systematically assigning codes to video segments/clips (following, e. g., [MHS14, pp. 81f]) using a qualitative data analysis software (see Fig. 4 for an example from a pre-test). Directly coding the audio-visual protocols rather than transcribing the verbalizations allows to benefit from the complementary angles provided by the respective mode of observation. Following problem-solving research and the Cognitive Load Theory [e. g., Sw88], we use the notion of cognitive breakdowns [e. g., Be11; NS72] to identify modeling difficulties which modelers experience while constructing a conceptual model and, hence, use cognitive breakdown as deductive code. We define a cognitive breakdown as a cognitive difficulty which a modeler experiences when constructing a conceptual model based on a natural language description [Be11, p. 4]—"when a line of thought fails" [BM08, p. 768]. Such a cognitive breakdown can manifest itself in a modeler explicitly verbalizing a difficulty while modeling or in interrupting or terminating a modeling activity, e. g., a modeling activity which is not completed, but instead the modeler switches to another activity [Be11, p. 4].

Segments in which a subject encounters a difficulty or an obstacle are marked with the code 'cognitive breakdown', i. e., when the subject explicitly verbalizes a difficulty experienced during modeling or when the subject interrupts or terminates a modeling activity. This code is complemented with codes generally anticipated in think aloud protocols as, e. g., talking about non-task-related issues, evaluation of the task at a meta-level, silent periods and actions outside of the modeling tool (following, e. g., [SBS94, p. 122]). During coding, the coding scheme is complemented with emerging codes and sub codes—allowing for refinements according to the actual behavior exhibited in the modeling processes. We supplement coding audio-visual protocols with analyzing timed modeler-tool interactions allowing us to identify peculiar situations. Segments identified as unclear in the videos are submitted to closer inspection by analyzing the recorded modeler-tool interactions in the respective time period to better understand the observed situation, and to decide on assigning a code: Dot diagrams visualizing modeling processes and replays of model construction are used for further exploring situations identified as deviant or unclear in the audio-visual protocols. Vice versa, anomalous data in the recorded modeler-tool interactions is identified and further investigated through analyzing the audio-visual protocols: Modeler-tool interactions in the specific time frame are step-wise visually replayed as performed by the modeler, and, hence, visually analyzed (see Fig. 3c–d). In addition, dot diagrams are used for identifying anomalous modeler-tool interactions by manual inspection. Data integration is taken one step further by reviewing the pre- and post-modeling surveys and, thus, by supplementing another mode of observation (self-disclosure). This coding step proved valuable especially as the perceived difficulties can serve as indication for closer inspecting and deciding on assigning a code in the audio-visual protocols. We provide a more detailed description of the data analysis strategy and coding steps as applied in an exploratory study, see [RS19, pp. 8–10]. Please note that data analysis involving coding of videos, think aloud protocol analysis and visual inspection of different representations of modeling processes is recognized as a time-consuming and labor-intensive approach and, hence, is accompanied by relatively small sample sizes [e. g., Ni94].

5 Exploratory studies

The multi-modal observation and data collection approach has been applied in a first exploratory study in January 2019 into modeling difficulties individuals experience when constructing a conceptual data model [RS19]. Involving eight learners of conceptual modeling working on a data modeling task using TOOL, the multi-modal observation approach has been applied to observe the data modeling processes including recording verbal protocols, videotaping modelers, tracking modeler-tool interactions and surveying subjects before and after modeling. To achieve insights into the individual modeling processes, the collected data has been purposefully integrated and analyzed to identify modeling difficulties and to understand modelers' reasoning: Audio-visual protocols comprising the video recordings of the modelers' behavior and the think aloud protocols were coded for cognitive breakdowns serving as an indication for cognitive difficulties in performing the modeling task (using the software MAXQDA [VE18] that provides support for coding of integrated audio and video segments). In addition, the analysis was substantially deepened by dot diagrams and replays of the modeling processes. Exploring modeler-tool interactions and the audio-visual protocols revealed that the used modeling task shows a (surprising) complexity posing challenges to the participants though the task was deliberately designed to balance demand on subjects and modeling complexity and does not presuppose any particular domain knowledge (see Fig. 5 for a reference solution).

Data analysis led us to identify five types of modeling difficulties the observed subjects faced while performing the data modeling task: The types of difficulties relate to different aspects of constructing conceptual data models, i. e., entity types, relationship types, attributes, and cardinalities. The majority of difficulties encountered by the participants relates to modeling relationship types, i. e., deciding between modeling an entity type or a relationship type, developing sensible identifiers for relationship types and determining cardinalities [RS19, pp. 11f]. These exploratory results are intended as a starting point for developing a taxonomy of modeling difficulties—in the sense of a taxonomic theory (following [Gr06])—over the course of multiple studies as theoretical foundation for design science research on developing (tool) support for conceptual modeling.

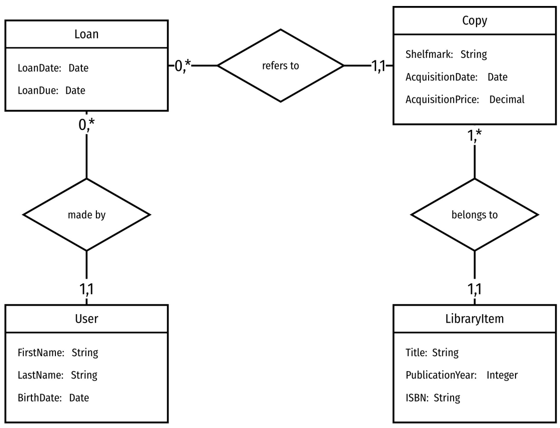


Fig. 5: Reference solution for the data modeling task from the library domain used in the first exploratory study (using a variant of the ER Model).

In a further exploratory study in May to June 2019, conceptual data modeling processes of experienced modelers have been observed following the same multi-modal observation approach as in the first exploratory study. The analysis of the modeling processes is still in progress. In both studies, participants were asked closed- and open-ended questions on problems they encountered when operating the modeling tool and regarding usability of the user interface of the tool after constructing the conceptual data model. Informed by helpful and constructive answers and suggestions of the participants, we implemented several adjustments to the modeling tool: For example, participants pointed to difficulties with regard to displaying model elements on the drawing area and in changing and deleting model elements. Altogether, participants' answers in both studies show a positive assessment of the operability and usability of the modeling tool for constructing conceptual data models.

6 Discussion and conclusion

Principle limitations relate to the suggested multi-modal observation and data generation approach: Regarding the analysis of verbal protocols it is assumed that thinking aloud does not interfere with thought processes. But as the modeling task includes a visual, non-verbal perceptual component, thinking aloud may slow down the thought processes and/or modeling performance [e. g., ES93]. Another principal limitation is that other, presumably equally essential aspects of the modeling processes, e. g., modeler motivation or the use of additional tools outside of the modeling tool, e. g., online tutorial videos, etc. are neglected in the present data collection design. Hence, we view it as an open question of whether and how to further enrich modes of observation on modeling processes with, for instance, eye tracking [e. g., We16] respectively video recording via webcam to be able to capture modelers' facial expressions [e. g., BM08, p. 768]. At present, the modeling tool supports constructing conceptual models in a variant of the Entity-Relationship (ER) model and for creating MEMO control-flow and decomposition diagrams [Fr11]. However, the graphical modeling editors can be extended by stencil sets, and we are preparing for future studies observing and analyzing, e. g., business process modeling processes with the Business Process Modeling and Notation (BPMN)—in consideration of the specifics of the modeling language used [e. g., HPv05].

Conducting two small-scale studies with experienced and non-experienced modelers demonstrated that the modeling observatory assists in observing conceptual modeling processes in an adequate way, e. g., to identify modeling difficulties (for first results, see [RS19]). In both studies we conducted so far, no principal or technical problems regarding data collection or data analysis occurred. In contrast to using a combination of existing tools, the modeling observatory of TOOL allows to integrate not only the supported data collection approaches but also data analysis and, hence, promises to keep data collection and analysis efforts to a lower level. However, for future studies we plan to technically combine the data collection for the observation modes of (i) recording verbal protocols and (iv) videotaping modelers to directly generate audio-visual protocols comprising both observations—in order to further reduce data collection and analysis efforts.

Analyzing the collected data in the first exploratory study showed that *only* the integration of the complementary observation modes allowed us to identify a wide range of modeling difficulties by identifying cognitive breakdowns: Supplementing the analysis of audio-visual protocols with analyzing tracked modeler-tool interactions allowed us to better understand ambiguous situations and to identify further deviant interactions while reviewing the post-modeling survey proved valuable especially as perceived difficulties served as indication for closer inspection of the audio-visual protocols [RS19, pp. 8–10]. Hence, our preliminary experience suggests that combining multiple modes of observation to study individual modeling processes contributes to achieving a richer and more complete understanding of modeling processes and modeling difficulties encountered during model construction. Informed by these exploratory insights, we are preparing for further small-scale and large-scale studies (e. g. as part of a university course with several hundred students) aimed at deepening and substantiating our understanding of modeling difficulties and identifying patterns of modeling processes. In addition, we intend to further investigate how modelers operate the modeling tool and—informed by modelers' feedback—aim to further enhance usability of the tool by aspiring a more intuitive user interface and by designing and implementing modeling support tailored to facilitate overcoming recognized modeling difficulties [cf. Te19].

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