

Comparison of Required Competences and Task Material in Modeling Education

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Abstract. *The reform of the European academic landscape with the introduction of bachelor's and master's degree programs has brought about several profound changes for teaching and assessment in higher education. With regard to the examination system, the shift towards output-oriented teaching is still one of the most significant challenges. Assessments have to be integrated into the teaching and learning arrangements and consistently aligned towards the intended learning outcomes. In particular, assessments should provide valid evidence that learners have acquired competences that are relevant for a specific domain. However, it seems that this didactic goal has not yet been fully achieved in modeling education in computer science. The aim of this study is to investigate whether typical task material used in exercises and exams in modeling education at selected German universities covers relevant competences required for graphical modeling. For this purpose, typical tasks in the field of modeling are first identified by means of a content-analytical procedure. Subsequently, it is determined which competence facets relevant for graphical modeling are addressed by the task types. By contrasting a competence model for modeling with the competences addressed by the tasks, a gap was identified between the required competences and the task material analyzed. In particular, the gap analysis shows the neglect of transversal competence facets as well as those related to the analysis and evaluation of models. The result of this paper is a classification of task types for modeling education and a specification of the competence facets addressed by these tasks. Recommendations for developing and assessing student's competences comprehensively are given.*

Keywords. conceptual modeling • higher education • competence-oriented assessment • task analysis • graphical modeling

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1 Introduction

Assessments represent a central element in higher education and fulfill various important functions

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(e. g., certification of individual program achievement). At course level, assessments primarily have diagnostic and evaluative functions. With the help of assessments it is possible to determine the current learning status of students and thus provide feedback to lecturers and students with regard to individual learning outcomes (Schaper 2021, p. 87). To achieve this, it is required that assessments are consistently aligned to the intended learning outcomes and that they are closely inter-

linked with the teaching and learning activities, in terms of the constructive alignment concept (Biggs 1996). Learning outcomes refer to competences which students need to acquire during a degree program or course. This objective-based learning and outcome-oriented approach is supported by the European academic reform, which states that assessments should no longer serve as pure knowledge tests but rather focus on the assessment of competences relevant for specific vocational or job-related domains. Hence, this paradigm shift from knowledge-based to competence-based teaching, places new demands on the examination system in higher education (HRK 2015). The relevance of well-designed assessments, which are based on the intended learning objectives, is corroborated by the fact that students primarily direct their learning processes to upcoming exams (Biggs and Tang 2011). In this regard, assessments exert a central control function (Schaper et al. 2013, p. 27). If what is to be learned is actually assessed, then the students' learning activities will also be aligned to the learning objectives and the acquisition of relevant competences (Biggs and Tang 2011, pp. 197f.). However, studies show that in practice the crucial role of assessments is often neglected in course design and that assessments often lack an adequate diagnostic and didactic design (Schindler et al. 2015).

This study examines the common practice in the use and design of exercise and exam tasks in the area of graphical modeling in computer science in higher education and analyzes to what extent the tasks already meet the requirements of competence-based assessments. The study is conducted as part of the KEA-Mod project in Germany. The overall goal of this joint research project is to develop a competence-oriented e-assessment platform that enables automated assessment of graph-based diagrams including automated generation of feedback. The didactic subgoal of the project is to develop guidelines for the development and use of competence-oriented assessment tasks in modeling education. These guidelines will firstly specify which competence facets should be developed in modeling, secondly how these

competence facets can be assessed and thirdly how corresponding, competence-oriented feedback should be designed. These three questions are addressed in three different studies. A competence model for graphical model was developed in a first study (Soyka et al. 2022), to describe and structure competence facets relevant for graphical modeling in detail. The present study addresses the second aspect, i. e. which task types should be used in modeling education to develop and assess the required competence facets. The third study, to be conducted, will focus on the design of feedback and its effects on learning.

Both formative assessments and summative assessments are considered in this study. Formative assessments primarily serve to *develop* competences and to provide structured feedback on the student's current learning status. Summative assessments *examine* the acquisition of competences and are used for example for certification (van der Vleuten et al. 2017, p. 608). In this study these assessment forms are mainly represented by exercise respectively exam tasks.

By reference to the overall project, this study focuses on graphical modeling, which we define as a subarea of modeling in computer science, i. e. modeling with (semi-) formal modeling languages whose notation provides graphical modeling elements. Examples of such modeling languages for so-called graphical modeling are the Entity Relationship Model (ERM), the Unified Modeling Language (UML) or the Business Process Model and Notation (BPMN). In many cases, models created with graphical modeling languages also exhibit a graph structure to describe relations or control/information flow between modeled elements. Modeling in general, but also graphical modeling in particular, has a high significance in computer science and represents a cross-cutting topic in many IT-related disciplines (e. g., software engineering, business process management, data warehousing). Besides, modeling represents a complex learning task and in fact involves a variety of different cognitive processes (Ternes et al. 2019, p. 1984). These aspects may be the reason for the large number of publications that address

the teaching of modeling (e. g., see Börstler et al. 2012; Kuzniarz and Martins 2016) and the potential pitfalls (e. g., see Buchmann et al. 2019; Siau and Loo 2006), as well as the plenitude of reports and case studies that propose recommendations on teaching modeling content, teaching methods and modeling tool support (e. g., see Aljumaily et al. 2019; Borner et al. 2006; Daun et al. 2017; Recker and Rosemann 2009). However, only a few papers deal with the didactic aspect of assessments in modeling education (Brandsteidl et al. 2009). Especially, a profound examination of exercise and assessment tasks in modeling against the background of competence-oriented teaching and learning in higher education is lacking.

The main goal of the study is to develop a competence-oriented task catalog that describes in general terms task types in the area of graphical modeling as well as the competence facets addressed by each of them. The purpose is to comprehensively cover the competence facets relevant to graphical modeling through assessment tasks. This competence-oriented task catalog is targeted at lecturers of computer science and related disciplines who teach modeling in higher education. It should be understood as a supportive resource to help to better align assessment tasks with the intended learning outcomes (i. e., competence facets) in terms of the concept of constructive alignment by suggesting appropriate task types and design options. Thus, with the help of the task catalog, lecturers should be encouraged to reflect on and revise their own assessment practice, which in turn should contribute to a better competence orientation in modeling education.

Against the background of this research goal, we would like to provide answers to the following questions:

1. Which exam and exercise tasks are typically used in higher education in the field of (graphical) modeling?
2. What competences or competence facets are addressed by the tasks?
3. Which competence facets required for modeling are not or barely addressed by tasks so far?
4. How can the task material be adapted to increase the fit between tasks and intended learning outcomes or competences?

A further objective of this study is to apply the competence model for graphical modeling for the first time in the intended area of application (i. e. formative and summative assessments in higher education). This should contribute to the consequential aspect of validity according to Messick (1995). In terms of competence modeling, this means that the fit of the competence model and the intended use should already be considered when developing a competence model. That is, the competence model, which is the theoretical basis for competence-based assessments, has to be appropriate for the intended use. In order to improve the applicability of the competence model in the area of developing competence-oriented assessments, it may be necessary to adapt the model.

2 Theoretical Framework

2.1 Competence-based assessments

The European academic landscape has undergone a fundamental reform in the last two decades. One major shift is that teaching and learning activities as well as assessments are consequently aligned to the intended learning outcomes of a degree program or learning objectives of specific modules (Biggs and Tang 2011). Learning outcomes describe what students need to know or are able to do on completion of a learning process. They focus on the competences that students need to acquire (Bachmann 2018, p. 44) to master demanding tasks or complex problems in specific domains or specific vocational or professional contexts (Schaper 2021, p. 90). Consequently, competence-based assessments do not serve as pure knowledge tests but should focus on more authentic professional skills and should address competence aspects, which are relevant for a specific domain. This means, that the assessments

in higher education are to be developed as competence measurement instruments, which places new demands on the design and the content of assessments:

Given their context-specificity, competences have to be acquired and assessed in relevant, domain specific situations (Koeppen et al. 2008, p. 62). Thus, assessments should be embedded in realistic contexts or scenarios and should comprise action-related and problem-based tasks (Schaper et al. 2013, p. 31). This implies that tasks address competences that go beyond mere recall and comprehension (Anderson and Krathwohl 2001, p. 71). Thus, the tasks should require to transfer and address competences at higher cognitive process levels (such as apply, analyze, evaluate, and create). However, it should be noted that the reproduction of knowledge is considered an essential prerequisite for competent behavior, since this knowledge is used in more complex tasks and problem solving (Anderson and Krathwohl 2001). More authentic and complex assessments also allow to cover not only domain-specific cognitive competences, but also transversal and non-cognitive competence aspects (such as social-communicative skills, meta-cognitive skills).

Since competence is a latent construct, which is not directly observable and measurable, it must be ensured that valid inferences can be drawn from student's performance in an assessment to students' knowledge and skills as well as their understanding (Koeppen et al. 2008, p. 63; Walzik 2012, p. 23). Therefore, the assessment must actually measure (or assess) what it is supposed to measure. This is referred to as validity. The concept of validity is composed of various aspects (Messick 1995). For instance, the assessment tasks should be related to teaching and learning content and competence aspects that are actually relevant and representative for the respective domain (content aspect). Furthermore, it should be ensured that the intended cognitive processes are actually required and addressed while solving the assessment task (substantive aspect) and that the task cannot be solved by other strategies. At the same time, tasks should address competences at

the right or intended process level. For example, if according to the learning outcome students are required to *apply* certain techniques, exactly this competence should be targeted by the assessment task. Tasks which address competences at lower or higher cognitive levels would be misaligned to the learning outcomes and would not be valid. Finally, assessments should include a selection of tasks, which is representative and allows generalized conclusions to be drawn about the student's performance in the competence area in question (generalizability aspect).

To ensure that the quality criteria of validity is satisfied, learning objective taxonomies represent a useful tool (Lienert and Raatz 1998, p. 10). Traditionally taxonomies of learning objectives such as those developed by Anderson and Krathwohl (2001) provide a basic theoretical framework for defining and classifying learning objectives for specific courses. Such taxonomies are often structured in a two-dimensional matrix and classify learning objectives according to content or knowledge areas (e. g., factual, conceptual, procedural and meta-cognitive knowledge) as well as cognitive process levels (such as remember, understand, apply, analyze, evaluate, and create), which increase in their cognitive complexity (Bachmann 2018, p. 45). By assigning learning objectives to or defining them at a specific process level, it is determined what cognitive demands or requirements are placed on the students. This two-dimensional structure of the learning objective taxonomies was also adopted for developing competence models in higher education. Such competence models have proven to be suitable for describing the internal structure of competences required for a specific domain in a comprehensive and sound manner. They help to systematically define relevant competence aspects and structure them according to a content dimension and cognitive process dimension. By this means, they serve to operationalize competences as learning objectives and make them measurable by defining different levels of competences. Moreover, learning objective taxonomies and competence models help to visualize all theoretically possible competences and to consider

non-cognitive or transversal competences as well (Ulrich et al. 2021, p. 63). Thus, by developing assessment tasks based on the intended learning outcomes or competences, it is ensured that the assessment covers relevant content at adequate cognitive levels. This prevents the assessment from being one-sided and ensures that the competence area is covered and tested more comprehensively (Bachmann 2018, p. 49). It should be noted that several learning tasks can be necessary to acquire or assess one competence, and vice versa, one task can require the coordinated use of several cognitive processes as well as several types of knowledge (Anderson and Krathwohl 2001, p. 89; Zendler et al. 2015).

Summing up, competence models or learning objective taxonomies represent essential tools and a sound basis in the development of competence-based assessments (Koeppen et al. 2008, p. 66; Zendler et al. 2015). This theoretical basis is important, as well-designed, competence-based assessments strive to realize valid conclusion to be made about the extent to which learning objectives have been achieved.

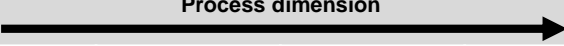
2.2 Competence model for graphical modeling

This paper draws upon the competence model for graphical modeling (CMGM) (Soyka et al. 2022). The competence model was developed in the context of the KEA-Mod project with the aim of providing a theoretical basis for the development of competence-oriented assessments in modeling education. With the help of the competence model, it should be ensured that the competences relevant for modeling are developed and assessed comprehensively and also at higher cognitive process levels.

Other competence models have integrated modeling in their frameworks. However, these competence models do not describe and specify the competence facets relevant for graphical modeling in depth, but rather superficially or only marginally (e. g., Gesellschaft für Informatik e.V. 2016; Linck et al. 2013), or they focus only on

cognitive competences or a specific area of modeling such as data modeling or metamodeling (e. g., Bogdanova and Snoeck 2019; Bork 2019). The CMGM builds on prior work in this area, but differs in that it is intended to provide a generic competence model and thus applicable in a variety of computer science disciplines and areas of modeling (e. g., data modeling, business process modeling, software modeling). In addition, both cognitive and non-cognitive competence facets for graphical modeling are described in detail.

The CMGM was developed following and integrating a theory-based and normative approach as well as an empirical approach. The process of competence modeling and competence model are described in detail in (Soyka et al. 2022). In a first study the structure of the competence model was developed based on theories and approaches of educational science. Specifically, it draws on the two-dimensional learning objective taxonomy of Anderson and Krathwohl (2001) as well as similar approaches that have adapted the taxonomy for specific contexts and purposes, such as Schaper et al. (2013) (s. Sec. 2.1). As a second step, competences relevant for graphical modeling were deductively derived from literature and from existing university course descriptions using techniques of qualitative content analysis. The result of the first study was a preliminary competence model. In a second study an expert rating was conducted using an online questionnaire in order to review the preliminary competence model by experts (n=79) both from the academic community and from corporate practice as well as from various disciplines related to modeling. The expert rating provided valuable input on the relevance and comprehensibility of the identified competence facets as well as on missing job-relevant competence facets, which was used to thoroughly revise the competence model. Additionally, subsequent discussions with three senior advisors of the project, which are experienced researchers and lecturers in the area of graphical modeling, were conducted to review and discuss the revised competence model. The empirical study could

Competence model for graphical modeling in computer science					
context / area of modeling in computer science					
Content dimension		Process dimension 			
		Understand	Apply & Transfer	Analyze & Evaluate	Create
Domain-specific knowledge and skills	Model understanding and interpreting	MU1	MU2	MU3	MU4*
	Model building and modifying	MB1	MB2	MB3	MB4
Values / attitudes / beliefs		VAB1	VAB2	VAB3	VAB4*
Transversal knowledge and skills	Metacognitive knowledge and skills	MC1	MC2	MC3	MC4
	Social-communicative skills	SC1*	SC2	SC3*	SC4*

Note: Two-dimensional structure of the competence model from *Toward a Competence Model for Graphical Modeling* by C. Soyka, N. Schaper, E. Bender, M. Striewe, M. Ullrich, 2022, ACM Trans. Comput. Educ. 23(1), p. 24. *No competence facets are defined for these competence areas.

Figure 1: Competence model for graphical modeling

thus contribute to improving the content validity of the CMGM.

The CMGM comprises of a content dimension with five content areas and a process dimension with four process levels (Fig. 1). This structure allows competence facets relevant for graphical modeling to be assigned to one cell of the competence matrix and thus to one specific content area and process level. This also serves to operationalize the competence facets as learning outcomes. The process dimension on the horizontal axis of the competence model distinguishes the process levels *understand*, *apply* and *transfer*, *analyze* and *evaluate* as well as *create*. It is used to describe and classify competences at different cognitive levels which tend to increase in their cognitive demand and complexity. On the vertical axis of the competence model lies the content dimension. In line with the definition of competence according to Weinert (2001), the content dimension includes not only cognitive aspects of competence but also motivational, volitional and value-related aspects, as well as social skills. The cognitive competences are represented by the two content areas of *model understanding and interpreting* as well as *model building and modifying*. These include domain-specific knowledge and skills for reading and comprehending existing graphical models and creating new models or model parts. In addition, the competence model defines transversal competence aspects in the areas of *value, attitudes and beliefs, meta-cognitive knowledge and skills* as well as *social-communicative skills*, which are relevant for graphical modeling.

Altogether, the competence model includes 74 competence facets that are relevant for graphical modeling; of these, 20 in the content area “model understanding and interpreting”, 28 in the content area “model building and modifying”, 8 in the area of “values, attitudes, beliefs”, 10 meta-cognitive competence facets and 8 social-communicative competence facets. The individual competence facets are formulated as learning objectives and consist of a content-related and an action-related aspect. Due to the large scope of the competence

facets, these cannot be discussed in detail at this point. To name but a few examples:

- The competence facet “*MB 4.03 Learners are able to create understandable and readable models based on known guidelines or conventions.*” is located at the process level “create” and the content area “model building and modifying” and refers to the aspect of pragmatics of graphical models.
- The competence facets “*VAB 1.03 Learners are convinced that modeling tasks can be solved through adequate procedures and the use of appropriate modeling techniques.*” is located at the process level “understand” and the content area “values, attitudes, beliefs” and refers to self-efficacy beliefs of the learner in the area of graphical modeling.
- The competence facets “*SC 2.07 Learners are able to check and constructively critique models or model parts of others and accept constructive criticism from others.*” is located at the process level “apply” and the content area “social-communicative skills” and refers to the learner’s ability to give and receive criticism.

Summing up, the CMGM was developed specifically for modeling education and therefore includes a comprehensive description of competence facets, which should be addressed and assessed using exercise and exam tasks. In addition, it represents a generic competence model, that can be used for different areas of modeling thus for a variety of modeling courses with different focuses (e. g., software engineering, business process modeling, data modeling). It therefore provides a suitable theoretical basis for our analysis.

2.3 Task analysis and task types in computer science education

Task analysis represents a useful method in university didactics for investigating the cognitive demand of exercise and exam tasks based on previously defined categories or criteria. They help lecturers to consider and reflect on the cognitive demands and complexity of the tasks and to better

adapt the tasks to students' learning levels. Hence, task analysis represents a well-established heuristic for planning competence-based lessons (Maier et al. 2014). They refer both to the analysis of specific tasks and the analysis of classes or types of tasks. In the latter case, it is necessary to classify task types first.

The logical task analysis proposed by Schlomske-Bodenstein et al. (n.d.) aims at determining if the assessment tasks are well-aligned with the intended learning objectives. Therefore, the intended learning objectives have to be defined in a first step and then organized into a content-behavior-matrix (i. e., learning-objective-taxonomy) (step 2). Based on didactic considerations, existing tasks are assigned to the intended learning objectives (step 3). The assignment should be explained and justified in written form (step 4). Subsequently, the fit between the task pool and the intended learning objectives is determined (step 5). Specifically, it is investigated whether all intended learning outcomes are covered by tasks and whether the tasks actually address relevant learning objectives. In addition, the distribution of the tasks to the learning objectives is considered. Thus, logical task analysis is used to optimize existing tasks in terms of their alignment with learning objectives (step 6). The need for improvement with regard to the intended learning objectives can also be identified by this means. In order to ensure the quality of the task analysis, it is recommended that it is carried out by more than one person and that cognitive labs are conducted additionally in order to check which cognitive processes actually take place in students during task processing (step 7).

With respect to modeling in computer science in higher education, there have been few attempts to analyze tasks and identify task types. Bower (2008) developed a taxonomy of task types in computer science with focus on programming education at universities. The taxonomy includes ten types of tasks, which build on each other hierarchically and which are oriented to the learning objective taxonomy by Anderson and Krathwohl

(2001). The tasks types increase in their cognitive demand level from declarative and comprehension task, to analytical tasks (debugging, finding errors), deeper understanding and application tasks (comprehending given code, providing examples or models), evaluation tasks up to the creation of code or models based on requirements or based on a problem. In addition, meta-cognitive aspects are considered through reflection tasks. Even if this approach deals with typical tasks in the area of programming, these considerations can be transferred to the area of modeling to a large extent.

A catalog of exercise classes for object-oriented modeling in secondary education was developed by Brinda (2004). The exercise classes have been derived from the analysis of exercises in textbooks of computer science. They are classified by the "informatics core" (static model, dynamic model, static and dynamic model), subject (concepts of object-orientation, model elements, models) and by exercise type. A total of fourteen task types were identified and then assigned to the process levels of Bloom's learning objective taxonomy. The first task type at the process level "Knowledge" are *knowledge questions*. At the process level "Understanding" the exercise types *comprehension questions* and *description task* are located. Furthermore, he distinguishes between *assignment task*, *specification task* and *arrangement task* on the level "Application". The task types *discussion task*, *analysis task*, *comparison task*, *validation task* and *identification task* each require cognitive processes on the level "Analysis". *Modification tasks* and *transformation tasks* have been assigned to the process level "Synthesis". *Construction tasks* are located on the highest process level "Evaluation" and require students for example to construct diagrams on the basis of a given text. Brinda (2004) also points out additional task characteristics as well as design options that influence task difficulty, like shape of data (textual, diagram), complexity of data (complexity of text/diagram), availability of details (given data vs. data, which need to be identified and added)

and application frequency of details (only relevant vs. relevant and irrelevant data).

Brandsteidl et al. (2009) reported their experiences in assessing the modeling knowledge and skills of their students and described typical tasks used in an introductory course on object-oriented modeling. They differentiate four main task types with further subcategories. The first task type are multiple-choice questions, either on theoretical knowledge about the syntax and semantics of an UML diagram type or based on a given UML diagram. This task aims at testing, if the underlying concepts and relationships are understood. Another type of task is embodied by error-finding tasks. Students are required to detect errors or inconsistencies either based on a model and a corresponding textual description, based on two corresponding UML diagrams or based on a UML diagram and corresponding code. Usually the students have to correct the errors as well. The third task type focuses on understanding UML sequence diagrams and assesses if students understand the chain of events presented, thus understanding the underlying concept. Finally, students are asked to model diagrams themselves, either based on a text describing the problem space or based on pseudo code. It is implied that the task types should require not only pure recall but should allow to assess if students understand the teaching material as well as if they are able to apply the concepts to realistic scenarios. Moreover, the authors state that the tasks should be aligned to the learning objectives and should cover the most important aspects of the lecture. However, they do not explicitly discuss the intended learning objectives or competences addressed by each task type.

The presented approaches to task analysis or description of task types in the field of computer science are based either on own teaching experiences and own teaching material or on the analysis of course books with task material. Overall, there are clear parallels between the respective categorizations of the task types as well as the classification with regard to the learning goal taxonomies. This means that these analyses can already provide a rough framework for categorizing task

types in the field of graphical modeling. However, the analyses focus either on other domains (e. g., programming) or are limited to object-oriented modeling, which is only a subarea of graphical modeling. In addition, task types are at most assigned to the cognitive process levels of a learning objective taxonomy. What is missing is a clear consideration of specific competences or learning objectives addressed by the task types to systematically develop and assess learners' knowledge and skills in the area of modeling in higher education.

3 Preliminary study: Task types in Business Process Modeling

Before we turn to the main study and the core objective of our study in the next section, we would like to refer to a preliminary study we conducted to identify task types in business process modeling education.

3.1 Pre-Study: Research method

We conducted an analysis of course books in the area of business process management and business process modeling. To this end, the university library catalog of a German university, offering courses of study such as computer science, business informatics or industrial engineering, was searched for the terms “business process management” OR “business process modeling” with a filter set to the resource type “course book”. The 45 resulting books in English and German language were screened to check whether they contain task material with regard to modeling. This was the case for four books only¹. This finding is consistent with a similar study conducted by Aubertin et al. (2012) which examine the state of the art of course books related to business process

¹ These books are: “Modeling Business Processes” (van der Aalst and Stahl 2011); “Fundamentals of Business Process Management” (Dumas et al. 2013) - Chapter 3, “Essential Process Modeling” and Chapter 4, “Advanced Process Modeling”, p. 63-152; “Modellierung und Analyse von Geschäftsprozessen” (Drescher et al. 2017); “Grundkurs Geschäftsprozess-Management” (Gadatsch 2020) - Chapter 5 “Modellierung und Analyse von Prozessen”, p. 87-150.

management and point out that only one book contains task material.² The task material in those course books was then thoroughly analyzed so that all tasks were selected, which involved concrete models (either in the task description or as expected task outcome). Mere knowledge questions like “Describe the basic elements of event-driven process chains” (Drescher et al. 2017, p. 51) were excluded.

3.2 Pre-Study: Results

The identified tasks could be classified to five different categories displayed in Tab. 1. “Model explaining” refers to tasks, in which a model is given whose statements are to be described in natural language or statements matching the model are to be selected (multiple-choice task). In the task type “Error finding” it is required to identify a specified type of errors for a given model and to justify them if necessary. Tasks of the type “model creation” typically involve the description of real world scenario in natural language, which is to be transformed into a model by applying a specified modeling language. “Model analysis” refers to task, in which a given model is to be analyzed with respect to specified properties or is to be evaluated with respect to certain criteria. “Model adjusting” includes tasks in which a given model is to be changed in a certain way. This is intended, for example, to express additional information about the described scenario with the model or to fulfill certain properties. The majority of the tasks that the course books contain are of the task type “model creation”.

3.3 Pre-Study: Discussion

The preliminary study served to develop a first categorization of task types specifically with respect to graphical modeling based on course books used in higher education. However, this study is limited to the area of business process modeling. Building on this preliminary study, the research approach

² This book is the one we also identified by Gadatsch (2020) in an earlier edition from 2020. The other course book on BPM by Dumas et al. (2013) that we identified additionally was only released after this study.

of the subsequent main study of this article was extended or adjusted to include the following aspects: We include tasks in relation to various areas of modeling and modeling languages; we examine task material which is actually used in lectures and seminars at German universities to investigate the common practice in modeling education and we additionally investigate the competence-orientation of the identified task types.

4 Research method

In this study, we conducted a competence-based task analysis. The methodological procedure is aligned with the four research questions and draws upon the approach of the logical task analysis (Schlomske-Bodenstein et al. n.d.). We took an iterative approach to identifying and describing task types and thus, developing a competence-oriented task catalog for graphical modeling. The development of the task catalog is based on a literature-based derivation of task types, a systematic analysis of existing modeling tasks, and a consultation with academics from computer science. By this means, the task catalog was revised and refined continuously.

4.1 Identification and description of task types

To investigate which tasks are typically used in modeling courses in higher education a content analytical procedure was applied adapted from Mayring (2019) using the software MAXQDA³. For this purpose, a large pool of task material was first gathered, with exercise and exam tasks that are actually used in courses related to modeling. The aim was to cover the field of modeling broadly and to consider many different areas of modeling. The analysis material should thus represent a cross-section of the task material in modeling education. The task material came from three

³ MAXQDA (<https://www.maxqda.com/content-analysis>) is a standard software for qualitative content analysis, which makes the analysis of documents more efficient due to computer-based coding, especially with regard to the computation of quantitative scores and inter-rater reliability coefficients.

Task types involving (business process) models					
Course book/Task type	Model explaining	Error finding	Model creation	Model analysis	Model adjusting
van der Aalst and Stahl (2011)	7	0	24	17	8
Dumas et al. (2013)	5	2	26	3	8
Drescher et al. (2017)	17	20	47	27	6
Gadatsch (2020)	3	0	2	0	0
Sum (Share)	32 (14%)	22 (10%)	99 (45%)	47 (21%)	22 (10%)

Table 1: Distribution of task types across course books in business process modeling/management

German universities (Karlsruhe Institute of Technology, University of Duisburg-Essen, Saarland University) involved in the KEA-Mod project, as this was easily accessible for this study. When compiling the task material, care was taken to ensure that it contains tasks from different courses of study (e. g., Applied Computer Science, Business Informatics, Industrial Engineering, Business Administration, Software Engineering) as well as from different types of courses (e. g., lectures, exercise courses, seminars). In total, 487 tasks from 15 Bachelor's and Master's courses related to modeling (e. g., Information Systems, Database design and management, Business Processes Modeling, Software Engineering, Modeling, Requirements Engineering and Management) were collected. Exercise, exam, case study, and project assignments were all considered. It must be pointed out that this collection of tasks also contained tasks that do not belong to the area of graphical modeling, since some exams and exercise sheets cover other topics besides modeling.

The aim of the content analysis was to examine and structure the task material into different task types, which refer to understanding, analyzing, modifying and building models. The central instrument for this kind of structuring content analyses is a system of categories, which determines under which aspects and according to which rules the text material is analyzed (Mayring 2019, p. 4). In qualitative content analysis these categories can be generated deductively, on the basis of existing theories or concepts, or inductively, on the basis of the analysis material. In this study, the categories of the category system represented the different

task types and variants. The category system was first developed deductively on the basis of related approaches (s. Sec. 2.3). Nine broad categories, i. e., task types that are typically used in courses for modeling in higher education, were derived from the literature: Knowledge questions, Comprehensions tasks, Model explaining, Syntactical error finding, Error finding based on a model and a corresponding text, Error finding based on two corresponding models, Model analyzing, Model building and Model modifying. Tab. 2 shows the nine categories, as well as the respective sources from which the category was derived. It should be noted that a generic approach was taken in identifying and defining the task types in modeling education. That is, the task types abstract from specific modeling languages (e. g., UML, BPMN, Entity-Relationship Model, Petri nets) and areas of modeling.

Another category called "not relevant" was used to filter out tasks that do not relate to aspects of graphical modeling. These are mainly tasks that ask for knowledge in the respective field of modeling (e. g., databases, business processes, software development), but without referring to any model or modeling, tasks that refer to the use or implementation of models (e. g., finding errors or creating a model based on a pseudo code), tasks involving non-graphical languages (e. g., SQL, XML, Java), as well as highly language-specific tasks (e. g., creating a reachability graph of a Petri net without further analysis, creating or transforming relational database schemas, formulating (UML, OCL) path expressions).

Categories of the coding scheme
Knowledge questions “Declarative tasks” (Bower 2008), “Knowledge question” (Brinda 2004), “Theoretical Multiple-Choice Questions” (Brandsteidl et al. 2009)
Comprehension tasks “Comprehension task” (Bower 2008; Brinda 2004)
Model explaining “Multiple-Choice Questions Based on a given UML Diagram” (Brandsteidl et al. 2009), “description task” (Brinda 2004)
Syntactical error finding “(syntactic) debugging task” (Bower 2008)
Error finding based on a model and a corresponding text “Error Finding Based on a Model and a Corresponding Text” (Brandsteidl et al. 2009), “(semantic) debugging task” (Bower 2008)
Error finding based on two corresponding models “Error Finding Based on Two Corresponding UML 2 Diagrams” (Brandsteidl et al. 2009)
Model analyzing “Analysis task” (Brinda 2004), “Evaluate task” (Bower 2008)
Model building “Modeling Diagrams based on a text describing the problem space” (Brandsteidl et al. 2009), “Construction task” (Brinda 2004)
Model modifying “Modification task”, “Transformation task” (Brinda 2004)

Table 2: Deductively derived categories for the content analysis

The analysis material is then structured by assigning the individual tasks to these categories. If a task could not be assigned to an existing category the category system was adapted and extended inductively. The result of this procedure is a category system, which defines and describes different task types and provides them with examples from the task material.

This first draft of the task catalog was adjusted iteratively based on the results of subsequent analysis steps as well as discussions among university lecturers in the area of modeling. When structuring the task catalog three hierarchical levels were distinguished. *Task classes* represent the highest level. They combine several similar task types, which primarily serves to provide a clearer structure of the task catalog. The main focus is on the task types, which represent the medium level. *Task types* describe typical exercises in the field of modeling in an abstract manner (i. e., regardless of specific modeling languages, contexts or similar). In addition, for individual task types, different variants can be specified. *Task variants* represent minor variations within a task type and refer to a specific task design.

The content analysis of the task material was performed by the lead author of the study. In order to check the reliability of the coding, the entire task material was coded twice at intervals of several months by the author (to determine the intra-rater-reliability) and additionally by a student research assistant (to determine the inter-rater-reliability) using the coding guide. The second coder had no prior knowledge of computer science or graphical modeling. She was introduced to the category system and the coding guide in a one-hour session. After she had coded 30% of the entire material, questions and ambiguities were clarified and, if necessary, corresponding coding rules were added to the coding guide. The cases in which the coders did not agree were analyzed in more detail afterwards and used to more clearly describe and distinguish between the individual task types of the category system respectively the task catalog. Inter-rater reliability and intra-rater

reliability were calculated according to Brennan and Prediger (1981).

4.2 Assignment of competences to task types

The next step was to determine which competences are addressed by the different task types. For this purpose, the competence model for graphical modeling was used (s. Sec. 2.2). First, three university lecturers with experience in modeling education separately assigned the competence facets of the competence model to the task types, and thus defined, which competence facets are addressed by the task types and their variants. The individual expert assignments were then contrasted and compared following a discursive approach. By this means, it was possible to identify further need for improvement both for the classification and descriptions of the tasks types as well as the competence model (e. g., by detecting misleading formulations, missing competence facets or overlaps in task types or competence facets). This need for adaptation was implemented immediately. Ultimately, consensus was reached regarding the assignment of competence facets to task types. The assignment of the competence facets was made according to three categories: Product-related competence facets that are addressed by the task in any case and that become evident on the basis of the task solution (central), competence facets that are addressed and measured by a specific variation of the task type, i. e., explicitly intended by the lecturer (optional), or process-related competence facets that are addressed but are not directly measurable based on the task solution or which are not primarily intended by the lecturer and therefore normally not included in the grading (marginal).

4.3 Gap Analysis

Subsequently, the fit between the competence model for graphical modeling and the task types was determined. In particular, it was evaluated which competence facets are not or only marginally addressed by tasks types so far.

4.4 Integration of further task types and variations

Based on the gap analysis, it was elicited and discussed which changes in the task catalog are necessary in order to increase the fit between task types and intended learning outcomes or relevant competences. The aim was to have each competence facet directly addressed by at least one task type or task variant. This also improves the content aspect of validity of competence-based assessments (Schlomske-Bodenstein et al. n.d. P. 20). Hence, it was first determined whether other task types or variants are known that address the yet unaddressed competence facets but were not included in the task pool, we examined previously. Additionally further task types or variants that assess the unaddressed competence facets were defined.

5 Results

5.1 Task types in modeling education

In total 275 tasks of the task pool were coded as relevant for graphical modeling. Of these, 240 were formative tasks used in exercises and 35 were summative tasks (mainly exam tasks). Based on these tasks, eight task classes (in bold) and a total of 16 task types could be differentiated (s. Tab. 3). The intra-rater reliability in the content analysis of the task material was $\kappa = 0.91$ and the inter-rater reliability was $\kappa = 0.79$, which could be interpreted as “almost perfect”, respectively “substantial” (Landis and Koch 1977). In particular, the non-agreements indicated that there were difficulties in distinguishing between “knowledge questions” and “comprehension tasks”, between “model building based on another graphical model” and “model adjusting”, and between “interpreting model content” and “check formal model properties”. Based on the results, the category descriptions were made more precise (e. g., by adding further sample tasks).

In the following, all task types are briefly described and illustrated with an example. These

Task classes and types	
Theoretical questions	57 (20.8%)
Knowledge questions	26
Comprehension tasks	31
Model explaining	12 (4.4%)
Identifying model elements	1
Interpreting model content	8
Model translating	3
Error finding based on a model	14 (5.1%)
Syntactical error finding	8
Error finding based on a model and a corresponding text	2
Error finding based on two corresponding models	4
Check formal model properties	23 (8.4%)
Example model building	17 (6.2%)
Applying a modeling language	3
Model building based on (formal) properties or criteria	14
Model building	124 (45.3%)
Model building based on a text describing a scenario	105
Model building based on another graphical model	19
Model modifying	19 (6.9%)
Model completing	7
Model adjusting	12
Case study	8 (2.9%)

Note: The task classes “Check formal model properties” and “Case study” contain only one task type.

Table 3: Distribution of task classes and types within the analysis material

descriptions refer to the categorization of the coding guide used in the content analysis including the category definitions and sample tasks.

5.1.1 Theoretical questions

The first task class represents **THEORETICAL QUESTIONS** to assess knowledge and understanding related to *general* facts, concepts, and procedures of graphical modeling. In contrast to tasks of the task class **MODEL EXPLAINING**, these tasks are at a more general level and do not refer to a specific model. This task class is basically not a task class specific to modeling, but can be found in all subject areas and didactics. The first task type are **knowledge questions**, which refer to familiar content from the teaching context (e. g., key terms, basic concepts and methods). The learners must either provide a short free-text answer (e. g., reproduce a definition or briefly describe a concept) or solve forced-choice tasks (e. g., single or multiple-choice tasks, matching tasks or cloze tests). Tab. 4 shows an exemplary multiple-choice question.

	true	false
The EPC		
a) is a semiformal modeling language		
b) is a DIN standard		
c) is used to describe business processes		

Table 4: Sample task of the task type “Knowledge question”

Comprehension tasks refer to tasks which examine if the course content has been understood in depth and include questions and tasks on specific terms and concepts of modeling as well as modeling techniques. These tasks go beyond the mere reproduction of knowledge. Typical task formats are free-text tasks in which learners are required to explain, or justify specific modeling concepts in their own words or provide examples. An example of a comparison task is: “*Explain the similarities and differences between the modeling languages BPMN and Petri nets.*” In addition, the following

exemplary comprehension task requires students to match and explain different UML association types to textual descriptions:

"For the following scenarios, decide what type of relationship each is, just simple association or special aggregation or even composition. In each case, indicate the strongest relationship present and give detailed reasons for your decision. Answers without justification get no points.

1. *A state has a government.*
2. *A computer is composed of different components (CPU, RAM, etc.).*
3. *Addresses are stored in a database.*
4. *A house is located on a street.*
5. *The parents have several children.*
6. *Many people work as security guards at an airport terminal."*

5.1.2 Model explaining

The task class **MODEL EXPLAINING** refers to task types in which a graphical model is given and which require learners to understand and thus describe the individual model elements as well as the statements and meaning of the given model and the underlying concepts. The task types can differ in their answer format, in that either the statements of a given model are to be described as free text in natural language or the correct statements referring to the model are to be selected by means of multiple-choice answer format.

Identifying model elements refers to a task type, in which learners are asked to identify and describe single elements of a given model (e. g., *"Define and describe all entity types and relationship types that are in the model"*).

Model translating means that learners are asked to translate the statements of a given graphical model into another, non-graphical notation (e. g., mathematical notation, path expression). An example task is: *"Please translate the given Petri net into mathematical notation."*

The task type **Interpreting model content** requires learners to understand the statements and semantics of a given graphical model, i. e., the

individual model elements and their relationships. We distinguish two variants: In the first variant ("context-free"), the individual model elements are only labeled with numbers or letters. An example of this task type can be found in Fig. 3. It should be noted that the answers to questions about the given model can be read directly from the model, i. e., it is not necessary to analyze formal model properties.

In the second variant ("with context") the model is embedded into a real-world scenario, which means that individual model elements have textual identifiers that refer to the modeled scenario. In this task variant, either multiple-choice questions about the model must be answered, i. e., statements about the model are given in addition to the model and learners have to check (and explain) which statement applies to the given model. Alternatively, learners have to describe the statements of a given model in natural language. An example of this task type with both alternative answer formats (i. e., free text vs. multiple-choice) can be found in Fig. 4.

5.1.3 Check formal model properties

CHECK FORMAL MODEL PROPERTIES is a task class/type, in which a given model is to be analyzed with respect to specific (formal) properties or conditions. While this task type also requires learners to understand a model, it goes beyond "interpreting model content" in that the model must additionally be analyzed based on given criteria. The task type includes for instance checking for model properties (e. g., cycles, deadlocks, liveness, boundedness), checking the reachability of markings/states under certain conditions, and identifying markings/states or sequences that exhibit certain properties. In the tasks analyzed, the given graphical model was not embedded in a real-world scenario, but was context-free. Fig. 5 shows a sample tasks of this task type.

5.1.4 Error finding based on a model

ERROR FINDING BASED ON A MODEL summarizes three different task types in which errors in a given

graphical model must be identified and usually marked and described.

Syntactical error finding refers to tasks, in which learners are asked to find (and explain) violations of syntactical rules of the modeling language used in a given model. The model elements are usually labeled without context (e. g., without identifiers or labeled only with numbers, letters, and expressions such as “Event 1”/ “Task 1”). See Fig. 6 for a sample task. The consistency to a model or described scenario is not considered in this task type.

Error finding based on a model and a corresponding text is a task type in which a graphical model as well as a text, that describes the scenario the model is supposed to represent, are given. The learners are required to find inconsistencies between the description of the scenario and the model, and usually mark the errors in the model and explain them. An example of a problem statement of this type is: *“A new colleague of yours asked you to review a UML class diagram in which he modelled the university’s new library system, based on a short description of the data to be stored in this system. He provided you on the one hand the description and on the other hand his diagram. Compare the given class diagram to the original brief system description. You should provide your colleague a detailed description of your observations.”*

In task type **Error finding based on two corresponding models** two graphical models are given, that represent the same scenario at different levels of abstraction or from different views. Learners are asked to identify inconsistencies between two models. Thus, two models are given and errors are built into one of them. The following exemplary problem statements belong to this task type: *“You are given the following UML Class Diagram. A modeler tried to create a corresponding Object Diagram. Unfortunately, the modeler made some mistakes. Please mark all errors and give brief explanations for them.”* and *“Can the following Petri net B have originated from Petri net A by coarsening, restriction, or folding? Justify your answer.”*

Tasks of the task class **ERROR FINDING BASED ON A MODEL** are often combined with the task “model adjusting”, in which the incorrect model is to be corrected afterward (s. Sec. 5.1.7).

5.1.5 Example model building

EXAMPLE MODEL BUILDING comprise task types in which learners have to create small, exemplary models independent of a specific scenario or context. This is intended in particular to illustrate or represent properties, rules, or concepts. **Applying a modeling language** represents a very basic task type of this category. It refers to tasks, in which learners are asked to create a small, exemplary graphical model to demonstrate and explain a specific modeling language (e. g., *“Which UML diagram type describes the flow of actions? Draw a small but meaningful example.”*). In addition, tasks in which learners have to create plausible, exemplary model elements or model parts based on domain knowledge (i. e., without a given scenario description) belong to this task type (e. g., learners have to create corresponding objects as an instance of classes of a given class diagram).

Model building based on (formal) properties or criteria means that learners are required to create a model that has certain formal properties or meets certain criteria and conditions. These include formal model properties (e. g., creating an unbounded Petri net that contains a deadlock) or formal notations (e. g., creating a Petri net based on its mathematical notation). In this task type neither a real-world scenario nor a graphical model is given.

5.1.6 Model building

MODEL BUILDING includes all task types in which learners are expected to create graphical models themselves from scratch. The most common task type here is **model building based on a text describing a scenario**. In general, there is a variety of design options for this task type, so that the task can be adapted very well to the learning level of the students. The degree of difficulty of this task type varies in particular by the complexity of the scenario or context, i. e., the size of the

model to be created (in terms of the number of model elements). Also, the task can provide the learner cues for building the model. These are, for instance, hints on types of model elements to be considered (“*Please model the classes and their relationships including their methods, attributes, and cardinalities in a UML class diagram.*”), cues on specific model elements to be considered (i. e., support in identifying types of model elements in the scenario, such as “*The underlined words should be the classes in your diagram.*”), guidance for modeling by structuring the scenario in a certain way (e. g., bullet points or paragraphs for different aspects, which have to be modeled) or hints and advice on procedural knowledge by structuring the task into subtasks (e. g., “*a) Identify the components mentioned in the description. b) Identify the interfaces of the components. c) Create a component diagram from the identified components and interfaces.*”). On the other hand, the difficulty of the task can be increased, for instance, by requiring learners to choose an appropriate modeling language themselves, to describe and explain their design decisions or to gather further information about the domain in question, when the scenario is not specified in detail. Model building-tasks may also differ in how the scenario to be modeled is presented. Mainly the scenario is described in a pure prose text form. Possible variants are, for instance, text in interview form, in document form (delivery bill, production order), as database structure or requirement specifications in natural language. The context or domain of the described scenario can be fictitious, from the everyday life of the learners or related to a specific application domain. In addition, this task type is characterized by the fact that usually several solutions are correct for a specific task. Fig. 7 shows an exemplary task including a sample solution from the area of Business Process Modeling, demonstrating one possible design option of this task type.

In addition, in the task type **model building based on another graphical model** a model is given and the learners are asked to create a model in another modeling language (e. g., UML activity

diagram to Petri net) or convert it to another diagram type (e. g., UML class diagram to object diagram or sequence diagram) to depict a different view of the scenario.

5.1.7 Model modifying

Compared to MODEL BUILDING tasks, MODEL MODIFYING tasks already have model elements or model parts given.

Model completing represents tasks in which a scenario and some model elements or a partial model are already given. The learners have to add the missing model elements either on the basis of a scenario description or on the basis of their own plausible assumptions. In contrast to the task type “model adjusting” only single model elements are added here. For instance, the relations/connections between model elements (e. g., by adding edges/arrows/arrowheads, cardinalities) or identifiers have to be completed or specified. A sample task is “*Complete the following class diagram by completing the lines to inheritance, association, aggregation, or composition.*”

Model adjusting requires learners to adjust a given (or previously created) model, e. g., in order to correct errors, meet new requirements, or other formal properties. This task type may thus require the addition or removal of model elements or parts. This task type is more complex than “model completing”, because here not only single missing elements are added, but also whole model parts have to be modeled correctly and integrated into the given model or the whole model has to be transformed to fulfill specific formal properties (such as “*Convert the following Petri net with capacities into a conventional Petri net without capacities.*”). A sample task which requires to adjust a model based on new requirement is: “*Your project manager Mr. Bauer had a second discussion with the university’s teaching representative Mrs. Foster to get a better understanding of the situation. In this meeting Mr. Bauer elicited new requirements, which can be found in the meeting minutes below. He assigned you the task to expand your class diagram from task 1 to include all the additional information given by Mrs. Foster.*”

5.1.8 Case studies

The task material also contained CASE STUDIES which basically represent very complex kinds of MODEL BUILDING tasks, that are embedded in a comprehensive, described real-world scenario. Case studies offer plenty of creative leeway and thus many variants. Usually, learners have to create more than one model (e. g. to represent different views or aspects of the scenario). In addition to the pure model creation, further tasks have to be completed, depending on the task design. Depending on the complexity, the case study is to be worked on in small teams and over a longer period of time (up to one semester). The models are usually created with modeling tools and then submitted and, possibly, presented.

5.1.9 Further results

Looking at the distribution of the task types within the analysis material (s. Tab. 3) it becomes clear that the majority (45.3%) of the exercise and exam tasks are assigned to the task class “model building”. For the most part, these are rather small and guided scenario descriptions (i. e., with little text or text which is well-structured in paragraphs or with bullet points). Moreover, many tasks contain hints helping students to identify relevant information (such as explicit instructions which modeling elements must be taken into account) and cues to solve the task in a targeted manner. This is especially the case with exercise tasks. The second most frequent task classes are “theoretical questions” (20.8%) followed by “check formal model properties” (8.4%). In this context, it should be pointed out that most of the tasks assigned to the latter task type refer to the analysis of properties of Petri nets.

5.2 Required competences

The result of the assignment of competence facets to the task types represents a competence-based task catalog. It demonstrates which competence facets are addressed by each task type. A total of 158 competence facets were assigned to the 16 task types (including multiply assigned competence facets). 27 competence facets from

the content area *model understanding and interpreting*, 39 from the content area *model building and modifying* were assigned as central competence facets. In addition, four competence facets from the content area *values, attitudes, beliefs* and one *meta-cognitive* competence facet of the process level understand are directly addressed by comprehension tasks (central). Transversal competence facets are primarily addressed optionally within case study tasks or marginally through different types of tasks. The most competence facets (41) were assigned to the task type CASE STUDY. Of these, seven are central competence facets, 22 are optional competence facets, and 12 are marginally addressed (primarily transversal) competence facets. This result underlines on the one hand the large scope of design options that case study tasks have and on the other hand the possibility to develop transversal competence facets by this task type in particular.

Due to the large scope of the task catalog, the competence assignments for each task type cannot be presented in this paper.⁴ Therefore, the results of the assignment of the competence facets to the task types are presented and illustrated using the task type *Model building based on a text describing a scenario* as an example, as this is the most prominent task type (e. g., according to the results of the content analysis, s. Tab. 3). In addition, model building represents a central aspect in the competence model for graphical modeling. With the help of this example, the assignment of the competence facets to the task types and the distinction between the three assignment categories (central, optional and marginal competence facets) should be clarified. Fig. 7 represents a sample task of this type of task.

Tab. 5 lists the competence facets addressed by the task type *Model building based on a text describing a scenario*. These competence aspects can be developed and assessed through exercise or exam tasks of this task type.

⁴ The entire task catalog including the respective competence facets addressed is provided as electronic supplementary material.

The task type primarily aims to assess whether learners are able to create methodologically correct graphical models to represent a particular scenario (MB 4.01). Specifically, the task type is used to determine whether learners are able to apply syntactical rules correctly (MB 2.04) and to meet the criterion of semantic quality by modeling the scenario completely and precisely (MB 4.02). During modeling, they should also choose and maintain an appropriate level of abstraction (MB 4.05) and develop appropriate identifiers for the model elements and use them consistently (MB 4.04). We have classified these five competence facets as “central” for this task type, because these are addressed by the task type regardless of the task design and they are measurable based on the student’s solution.

As mentioned above, optional competence facets are only addressed by specific variations of the task type either due to the specific task design or by explicitly stating the respective aspect in the instruction of the task. This means that the lecturer intends to additionally address these competence facets with the task and make them measurable and, eventually, also grade them. Based on the analyzed task material we have derived the following three optionally addressed competence facets: First, learners could be required to use a modeling tool for solving the tasks, which helps students to get familiar with such tools (MB 2.01). Second, the task type can be varied insofar as the learners are not instructed which modeling language to use. Thus, they must be able to make an appropriate selection on their own (MB 3.02). Third, it can be explicitly stated in the task, that learners have to describe and justify their design decisions (MB 3.05). This should help students to become aware of different design options and their purpose- or context-specific advantages and disadvantages.

Furthermore, the task type also addresses some competence facets, which are normally not primarily intended by the lecturer or which are hardly measurable based on the student’s solution. Both are reasons why these competence facets are not graded in the usual task design and why we refer to them as “marginal”. On the one hand, especially

in the case of more complex tasks of the task type “model building”, learners are encouraged to reflect on their own solution and compare it with the scenario described (MB 3.04) in order to submit a high-quality solution. That means, learners are not explicitly asked to reflect on their solution but while solving the task, they might verify their solution and check if it represents the described scenario adequately. In this context, they are also implicitly required to create well-structured models that are understandable to others (MB 4.03 and MB 4.06), since they have to submit them and at least the examiner or lecturer must be able to understand the model. In formative settings, when students have the opportunity to gather information on the relevant domain for a better understanding, they learn how to acquire relevant domain knowledge (MC 2.04). Finally, when students are asked to create a model based on a scenario description, they often use problem-solving strategies such as structuring the problem and extracting relevant information (MB 3.01).

It should be noted at this point that these marginally addressed competence facets can also be optionally addressed by a variation of the task instruction and by explicitly requiring students to do so. In this way, the addressed competence facets can be assessed more clearly on the basis of the task solution (product-related). For instance, the students could directly be required to create a model which is understandable and fulfills specific pragmatic criteria or which should be designed for a specific target group (such as non-native speaker, or non-IT-professionals). Moreover, students could be asked to reflect and discuss the suitability of their model with respect to the described scenario. Also, if the scenario described in the task is not specified in detail, the student could be required to gather relevant information about the domain of the scenario, for instance, by recommending specific sources of information (such as providing an URL). And finally, lecturers could instruct students to first identify (e. g., write down or mark) certain types of model elements in the described scenario before starting to create the diagram. In this regard, it should be mentioned

that the complexity and also the realistic design of the task can be increased by not only “listing” the aspects to be modeled in the scenario description, but by including irrelevant information as well, so that the student has to differentiate between relevant and irrelevant information for model building. But as our task material did not contain respective sample tasks and because it is not common practice based on our experience, these competence facets have been classified as “marginal”. In order to explicitly address marginally addressed competence facets, it is necessary that the corresponding aspects are directly required in the task and, if applicable, are also included in the scoring rubrics to make the task demands transparent for the students and/or to provide feedback on these aspects.

5.3 Unaddressed competences

Based on the assignment of the competence facets to the task types, the fit between the competence model for graphical modeling and the previously developed task catalog was then determined. Specifically, this means that a gap between the competence facets relevant for graphical modeling and the competence facets addressed by the task types was identified. The result of the gap analysis shows that already a large part of the competence facets (52 of 75 competence facets) are directly addressed by a task type or variant. Nine competence facets defined in the competence model have not yet been addressed by any of the task types (s. Tab. 6). These unaddressed competence facets belong to the content areas model understanding (3 competence facets), model building (4 competence facets), and meta-cognitive knowledge and skills (2 competence facets). Additionally, 14 competence facets are only addressed marginally by a task type so far. These primarily include competence facets from the content area “meta-cognitive knowledge and skills” (5 competence facets), three competence facets from the content area “model building and modifying”, and also two competence facets from each of the other three content areas.

Central

MB 4.01 Learners are able to create graphical models (such as UML diagrams, ER models, and Petri nets) themselves to represent a scenario.

MB 4.02 Learners are able to create a model that is semantically correct and complete with respect to a scenario, and limit themselves to relevant model content (conciseness).

MB 4.04 Learners are able to develop appropriate and consistent identifiers for model elements.

MB 4.05 Learners are able to select an appropriate level of abstraction in relation to the modeling purpose when creating a model and maintain it consistently within the model.

MB 2.04 Learners are able to correctly apply syntactical rules of the modeling language/s.

Optional

MB 2.01 Learners are able to apply and use modeling tools.

MB 3.02 Learners are able to check, evaluate, and select modeling languages or model types for their suitability for a specific application domain and modeling purpose.

MB 3.05 Learners are able to evaluate and justify their design decisions for a model they have created themselves.

Marginal (if not addressed by a specific task variant)

MB 3.04 Learners are able to reflect on and judge the suitability of a model they have created to represent a specific scenario.

MB 4.03 Learners are able to create understandable and readable models based on known guidelines or conventions.

MB 4.06 Learners are able to create a model in a way that is target group-specific, i. e., understandable to a specific group of people.

MC 2.04 Learners are able to acquire relevant domain-specific knowledge.

MB 3.01 Learners are able to derive relevant information and requirements (e. g., modeling elements, relationships, etc.) from a problem (task and scenario) and thus structure the problem.

Table 5: Competence facets addressed by task type “Model building based on a text describing a scenario”

Unaddressed competence facets

- MU 2.01 Learners use the information contained in a given model to solve a problem or situation in the corresponding application domain.
- MU 3.05 Learners are able to check the pragmatic quality (comprehensibility, unambiguity) of a given model.
- MU 3.06 Learners are able to differentiate given models with regard to their purpose-specific advantages and disadvantages and to judge which model better represents the considered scenario.
- MB 2.10 Learners are able to apply their conceptual knowledge of modeling to use cases of different areas of modeling.
- MB 2.11 Learners are able to translate general, abstract problems and objectives into concrete specifications and analysis questions.
- MB 2.12 Learners are able to transfer their acquired knowledge and skills to modeling languages and tools that are new to them.
- MB 3.03 Learners are able to select modeling tools based on relevant criteria.
- MC 2.02 Learners are able to control and organize their own learning process and development in the field of graphical modeling.
- MC 3.03 Learners reflect on and evaluate their own level of knowledge and skills related to graphical modeling.

Only marginally addressed competence facets

- MU 3.02 Learners are able to check and evaluate the suitability of a given model for the description of a specific scenario and in relation to a specific modeling purpose.
 - MU 3.09 Learners are able to evaluate a given model in terms of model quality referring to quality criteria.
 - MB 3.01 Learners are able to derive relevant information and requirements (e. g., modeling elements, relationships, etc.) from a problem (task and scenario) and thus structure the problem.
 - MB 3.04 Learners are able to reflect on and judge the suitability of a model they have created to represent a specific scenario.
 - MB 4.03 Learners are able to create understandable and readable models based on known guidelines or conventions.
 - VAB 2.02 Learners develop high intrinsic motivation for modeling and interest in its technical innovations and development.
 - VAB 2.03 Learners are willing to take on demanding modeling challenges.
 - MC 2.01 Learners are able to adapt and extend their own skills and knowledge in the field of graphical modeling according to changing situational requirements through independent learning.
 - MC 2.03 Learners are able to exert themselves and persevere when working on complex modeling tasks.
 - MC 2.04 Learners are able to acquire relevant domain-specific knowledge.
 - MC 3.01 Learners are able to analyze and consciously select problem-solving strategies according to the respective context with regard to their appropriateness and efficiency when working on modeling tasks.
 - MC 3.02 Learners reflect on their problem solutions and are able to learn independently from their mistakes.
 - SC 2.06 Learners are able to put themselves in the role of others (e. g., users, software developers, clients) and change their own perspective.
 - SC 2.08 Learners are able to divide complex modeling tasks into subtasks and structure them as well as organize and coordinate the completion of subtasks by different team members or teams.
-

Table 6: Unaddressed or only marginally competence facets as a result of the gap-analysis

5.4 Further task types and recommendations

Subsequently, it was determined how to close the gap and thus improve the fit between the competence model and the task catalog. In practical terms, this means that additional task types and recommendation regarding didactic methods have been added to the task catalog that target the competence facets that were not or only marginally addressed so far (s. Tab. 6).

Fig. 2 provides a broad overview of all task classes or types while relating them to the competence model for graphical modeling. This is to illustrate on which process level and in which content area of the competence model the task types are located and thus which competence facets from which competence area the task types primarily address. Task types at higher process levels also include competence facets at lower process levels. Different from what is indicated graphically, some task types also address competence facets from other content areas. The task types with the red edging represent the task types which were added as a result of the gap analysis. It is noticeable that especially task types at the process level *analyze and evaluate* as well as tasks types in the transversal content areas were added to the task catalog. These are discussed in more detail in the following.

Based on the gap analysis, four additional task types could be added to the process level *analyze and evaluate* in order to address further central competence facets: The task type *Compare models*, in which two models have to be compared with regard to their purpose-specific advantages and disadvantages, especially addresses competence facet MU 3.06. The task type *Check suitability of a model* requires learners to discuss to what extent the given model is suitable to represent the described scenario or modeling purpose and thus to fulfill the given requirements (MU 3.02). *Check pragmatic quality of a model* refers to tasks, in which learners are asked to analyze and evaluate a given model in terms of pragmatic quality (MU 3.05). This includes, for example, assessing

the unambiguousness of the model as well as the adherence to conventions or guidelines (e. g., in terms of a violation of internal company guidelines). The assessment can either refer to criteria known from the teaching context or the criteria are explicitly stated in the task. Furthermore, in light of comprehensive competence development and assessment as well as of the fact that students learn job-typical, practice-related modeling tasks, it is recommended to develop broader tasks that address several different aspects of competence. For example, a task of the type “error finding” may at best require students to analyze and evaluate a given model in terms of both syntactic, semantic, and pragmatic aspects, rather than examining these aspects separately. Competence facets at the process level “analyze & evaluate” in the content area “model building and interpreting” (MU 3.02, MU 3.03, MU 3.04, MU 3.05, MU 3.06, MU 3.09) could also be addressed by formative assessments such as *peer feedback*, in which learners have to evaluate the models of their fellow students concerning syntax, semantics, pragmatics and to compare them. In this way, they also learn to criticize and accept criticism at the same time (SC 2.07) and that there are multiple correct solutions to modeling tasks.

Evaluate model building represents an optional addition to a “model building” task and requires learners to evaluate their model with respect to certain criteria and/or justify design decisions (MB 3.04, MB 3.05). Additionally, a “model building” task could be varied by requiring students to develop formal analysis questions from the task text that can be answered using the model or that define the correctness of the model prior to model building. By this means, students should learn to translate general, abstract problems and objectives into concrete specifications and analysis questions (MB 2.11). MB 3.01 is always addressed marginally in “model building tasks”. For novices, it may be useful to provide them with helpful strategies for identifying relevant information and ask them to structure the problem or derive types of model elements before building the model (e. g., “Please identify all classes in the

Competence model for graphical modeling in computer science						
context / area of modeling in computer science						
Content dimension		Process dimension				
		(Remember)	Understand	Apply & Transfer	Analyze & Evaluate	Create
Domain-specific knowledge and skills	Model understanding and interpreting	Theoretical questions Knowledge questions Comprehension tasks	Model explaining	Problem-solving based on a model	Check formal model properties Error finding based on a model (syntax, semantics, pragmatics) Compare models Check suitability of a model	Peer feedback
	Model building and modifying			Model modifying Example model building	Evaluate model building (syntax, semantics, pragmatics)	
Values / attitudes / beliefs						
Transversal knowledge and skills	Metacognitive knowledge and skills			Reflexion tasks		Case study
	Social-communicative skills			Role play / discussion		
Complexity and contextuality of the modeling task						

Note: Red edging = Task type added after gap analysis

Figure 2: Task classes/types assigned to the competence model for graphical modeling

described scenario.”). Advanced students should be given more complex tasks that require filtering out relevant information.

Problem-solving based on a given model is a task type in the content area *model understanding and interpreting* and at the process level *apply and transfer*. In this type of task, learners are asked to answer problem-based questions in the relevant application domain based on a given model (MU 2.01).

Another key finding is that transversal competences, such as values, attitudes and beliefs, meta-cognitive knowledge and skills and social-communicative skills, are barely addressed or only marginally addressed by an isolated task. They can be addressed by knowledge questions and comprehension tasks. However, the competence facets of these content areas should also be addressed by transfer tasks, that require the application of knowledge and skills. In addition, transversal competences are mainly marginally addressed or developed by case study work, depending on the specific task design. For instance, when it comes to finding errors or inconsistencies in a model or to building a model, learners (implicitly) consider or get feedback on the quality of a model. They become aware, that the correctness and readability of a model are crucial factors in modeling and for understanding a model. Thus, the competence facet “VAB 1.02 Learners understand the relevance of high model quality (in terms of syntax, semantics, and pragmatics) for model understandability and subsequent model use” is marginally addressed in this task types.

However, it is often difficult to make these transversal competence facets measurable. Therefore, other assessment formats are necessary to develop and assess such competences. One type of task that can be used to develop and test particularly meta-cognitive competences (MC 2.02, MC 3.02, MC 3.03), represent *reflection tasks*, for example in the form of learning journals or portfolio tasks. These could be conducted in combination with more complex modeling tasks or during the learning process over a semester. Moreover, lecturers should encourage self-directed learning,

i. e., to enable learners to control and organize their own learning process and development in the field of graphical modeling, by providing voluntary formative assessments with direct feedback or further learning materials. Also, adequate problem-solving strategies in relation to various modeling tasks should be discussed and applied in the course (MC 3.01).

In regards to social-communicative skills learners could be challenged to simulate typical conversations that may arise in practice when working on modeling tasks by means of *role plays* (e. g., interviews in the context of requirements engineering). The learners should take on the roles of the various stakeholders involved (including people from outside IT) (SC 2.06). Additionally, potential pitfalls in the communication with various stakeholders during modeling projects should be discussed.

Since competences are context-specific, attention should be paid to the context of the task when designing modeling tasks. Learners should be able to transfer their acquired conceptual knowledge to other areas (MB 2.10). To make this possible, exercise, exam and case study tasks should be embedded in different realistic contexts from different areas of graphical modeling or different application domains. It is recommended to design a rich and varied task pool. In addition, the task context has significant motivational potential for learners, which is why tasks should be embedded in concrete real-world contexts and scenarios that are interesting and relevant for learners (VAB 2.02).

Some competence facets are addressed primarily when learners are given more freedom and less instruction. In order to support the transfer of acquired knowledge and skills to new modeling languages and tools (MB 2.12), students with practical modeling skills should be given the opportunity to independently apply a new modeling language in a “model building” task just after a short theoretical introduction. In addition, different modeling tools should be recommended and presented in the course and if possible, learners should be free to select a modeling tool (MB

3.03). Furthermore, learners should be given more complex and challenging tasks in their learning process while receiving individualized support and feedback to avoid overload and to motivate. This could foster learner's willingness to work on challenging modeling tasks (VAB 2.03) and they learn to exert themselves and persevere when working on complex tasks (MC 2.03). Also, learners should for example be challenged to work on their own on specific topics (e. g., learn a modeling language that is new to them or create a presentation/homework on current topics in the field of modeling) (MC 2.01) or to be required to first learn about the domain under consideration and to inform themselves (e. g., by means of literature, internet research, or discussions with domain experts) before model building (MC 2.04).⁵

6 Discussion

6.1 Task types and addressed competence facets

The study shows that a broad pool of tasks is already used in modeling education, which is composed of eight task classes and 16 task types. With regard to the number of exercise tasks assigned to each task type, the task analysis suggests that in educational practice the focus of the assessment tasks is on model building. It should therefore be positively emphasized that learners are given many opportunities to practice the actual creation of models in order to develop the relevant competences. Nevertheless, especially the formative, exercise tasks of the class MODEL BUILDING are often designed as very guided tasks or tasks that contain many cues. Against the background of scaffolding in teaching, it makes sense for students to learn and practice modeling and useful procedures step by step and from simple modeling considering just a few modeling concepts to complex modeling using the wide range of modeling concepts used in a particular modeling language. But for advanced learners, MODEL

BUILDING tasks should be designed with a higher degree of freedom, more complex and authentically, so that they require, for example, to select an appropriate modeling language or to filter relevant information, as these represent important job-related competences.

The results of the gap analysis indicate that most of the relevant competence aspects for graphical modeling (according to the competence model for graphical modeling by Soyka et al. (2022)) are already covered by typical tasks. However, there is room for improvement especially with regard to analyzing and reflecting activities, i. e., in terms of a critical evaluation of models. This result is consistent with an analysis by Bogdanova and Snoeck (2017) in domain modeling, who found that evaluation-related tasks are underrepresented in educational resources. To address the respective competence facets at the process level "analyze & evaluate" corresponding types of tasks have been added to the task catalog (e. g., *Compare models*, *Check pragmatic quality of a model*, *Evaluate model building*). The learners should be increasingly required to analyze existing and self-created models not only with respect to syntax errors, but also with respect to other quality aspects or the modeling purpose, because quality assurance also represents an essential success factor for modeling or the subsequent use of the models in professional practice. It is noticeable that the focus is particularly on syntactic and semantic quality aspects. However, the evaluation and the consideration of pragmatic aspects in model analysis and model building should also be taught in modeling courses. That implies, for advanced learners, an ERROR FINDING type of task should include the evaluation of syntactic, semantic, as well as pragmatic aspects. In formative settings, peer feedback is an adequate didactic method to let solutions of modeling tasks be evaluated and discussed by fellow students. In addition, it can be seen that theoretical questions account approximately 20% of the tasks analyzed, and that they thus have a relatively high importance in modeling education. There is no denying that students must first acquire a basic modeling knowledge, as this is necessary

⁵ An overall survey of all competence facets including the corresponding task types that address the competence facets is provided as electronic supplementary material.

to solve more complex, problem-based tasks. Nevertheless, we would like to emphasize that in the sense of competence-oriented teaching, it must be ensured that students also learn to apply and transfer this knowledge.

Another key finding is, that transversal competence facets are barely addressed by task types in modeling education. The reason might be that transversal competence facets are difficult to examine by means of single, isolated assessment tasks. One way of determining or measuring transversal competences for formative purposes is, to conduct self-assessments or assessments by others (e. g., by peers). In order to develop these competences, *complex model building tasks*, *case studies* as well as *reflection tasks* (portfolio, learning journal, project protocol), *group discussions* (e. g., on values and attitudes, meta-cognitive strategies) or *role plays* should be integrated into the teaching and learning arrangements. In relation to a comprehensive assessment of competence it is recommended to design more complex tasks, which address multiple competence facets and which are embedded in an authentic, practice-oriented context.

Lecturers should be aware of which competence facets they actually want to assess or develop with the task (central/optional competence facets) and design the task accordingly. In order for the task to fulfill its control function, the respective competence facets should also be included in the grading of the task or students should at least receive feedback (without scores) on the corresponding competence aspects.

6.2 Contribution

The main purpose of this work was to investigate how competences relevant for graphical modeling can be developed and assessed. The outcome of this study represents a task catalog in which task types in the field of graphical modeling and the addressed competence facets are described. The task classes and task types are largely consistent with what is found in literature (e. g., the classifications of Brinda (2004), Brandsteidl et al. (2009) and Bower (2008)) as well as with our preliminary

analysis of course books in the area of business process modeling. Nevertheless, this study goes beyond previous work because it is specified which competence facets are addressed by each task type. Thus, the reported results give important indications which competence aspects could be acquired and assessed by typical modeling tasks.

The task catalog is intended to provide support for lecturers to develop and assess the competences of their students in relation to graphical modeling comprehensively. For this purpose, the task catalog provides inspiration for adequate tasks as well as for task design by offering an extensive description of different task types and their variations and the competence facets addressed by these task types. That means, it should encourage the use of various task types to address competences at different process levels and different content areas and to systematically select task types according to the intended learning outcomes (resp. competence facets to be developed). This should prevent formative and summative assessments to be unbalanced, for instance, because analysis and evaluation tasks are neglected.

Along with this, the results of this study should encourage lecturers to thoroughly analyze and review their own exercise and exam task material and to develop didactically well-designed, competence-oriented assessments. The study shows that task analysis is a useful method for examining typical tasks regarding their competence orientation and for deriving need for improvement. The approach proposed by Schlomske-Bodenstein et al. (n.d.) was adapted in this study for competence-based task analysis and transferred to the field of graphical modeling. We suggest an analogous procedure for lecturers to analyze their own assessment tasks: First, determine which competence facets of the CMGM should be addressed in the course, i. e., what are the intended learning outcomes with respect to graphical modeling. The goal should be to address competence facets from different content areas and process levels. Second, classify task types based on your own task material. Third, map the previously determined competence facets to the

task types. Fourth, determine the fit between intended learning outcomes and task material (Have all competence facets been addressed? Do the tasks address additional competence facets, which were not intended? What is the distribution of the tasks concerning their cognitive process levels or content areas?). Fifth, try to close the gap to better align the assessment tasks with the intended learning outcomes and to improve the content validity of the assessments. We suggest using the task catalog for guidance and inspiration to select appropriate task types to close the gap.

6.3 Limitations and Future Research

When looking at the results of this study, the following limitations should be taken into account: The task material we have investigated for identifying the task types cannot be considered fully representative, since it represents a convenience sample. Thus, it cannot be ruled out that other universities use further task types that address other competence aspects. Furthermore, our research is based on assignments from German universities, and thus focus on a country-specific perspective. Therefore, it should be noted that the categorization of task types may not be complete and that this is not the only way to classify the task types. To make the categorization of task types more representative and extensive, the task material from other courses at other universities should be included, as well as exercise tasks from textbooks in various areas of modeling. In addition, the investigated task material contained mainly exercise tasks and only to a lesser extent exam tasks. Based on a larger and more balanced pool of tasks, the following aspects regarding the prevalence and use of the task types could be further investigated in the future: For which purposes (exam vs. exercise) are which task types used; in which courses are which task types used; which task types are used in which degree program or with which target groups. Nevertheless, our classification of task types is largely consistent with the literature (s. Sec. 2.3), i. e., with previous task analysis based on textbooks or course-specific task material. Hence, it can be assumed that exercise and exam tasks

are used in a similar form in other universities. Moreover, in this study we used task material from three different German universities and from different courses related to modeling. Thus, we have performed a cross-university analysis and have considered different areas of modeling (e. g., business process, data and software modeling). Therefore, the results can be considered as sufficiently representative to make a classification of task types in the field of graphical modeling. On the other hand, this also implies that the task catalog represents a generic categorization of task types. That is, these categories do not make any statements about specific courses yet, but can be used as a basis for a course-specific analysis.

Another limitation of the methodological approach is that the competence model for graphical modeling we draw upon in our study is not yet fully validated or established in the modeling community. Nevertheless, it has been theoretically based developed and was evaluated and reviewed by experts from the modeling community and adjusted accordingly. The development of a competence model and corresponding competence-based assessments represents an iterative process (American Educational Research Association 2014), which means, that the results of future validity studies could lead to further adjustments of the competence model and the assessment tasks. As indicated earlier, in this study the competence model is applied for the first time in its intended area of application, i. e., the development of competence-oriented assessment tasks. This should account for the consequential aspect of validity and reveal any need to adapt the competence model to improve its applicability. Hence, this study also allowed us to identify minor need for improvement for the competence model. For instance, two missing competence facets were added to the competence model, one competence facet was eliminated due to redundancy and few competence facets were rephrased, combined or separated to make the assignment of competence facets more accurate. By this means, the competence model could be improved regarding the intended use.

Further steps are planned to validate the competence model and the competence-oriented task catalog. In a subsequent study, it is planned to investigate, if the tasks types identified in this study actually address the postulated competence facets by means of think-aloud protocols. This empirical task analysis is especially important given that studies show that lecturers have difficulty mapping tasks to the cognitive process levels of learning goal taxonomies and that agreement among lecturers is often insufficient in such logical task analysis (Masapanta-Carrión and Velázquez-Iturbide 2018). Moreover the think-aloud study should provide evidence for the substantive aspect of validity (Messick 1995). In particular the method of thinking aloud makes it possible to identify process-related / marginally addressed competence facets that do not become evident in the task solution.

As a final point, the competence model for graphical modeling does not yet specify competence levels. In future research, the competence model should be extended by a third dimension, which represents the complexity of modeling tasks in terms of competence levels. An approach like the one proposed by Bogdanova and Snoeck (2019) would be conceivable by distinguishing between simple and complex models. With the help of defined competence levels, the difficulty of the different task types can then be systematically adapted to the learning level of the students.

7 Conclusion

This paper reports on the development of a competence-oriented task catalog for graphical modeling in computer science and includes recommendations for lecturers regarding the development and assessment of their students' competences. We hope that this study will create or reinforce awareness among lecturers in modeling education of the central role of exercise and exam tasks in the development and assessment of student competences and provides impulses for further research in this area.

This work serves as a first competence-based classification of modeling tasks providing hints for the development of competence-oriented assessment in terms of a competence measurement instrument. It should also serve as a starting point for further investigations or discussions within the modeling community. In addition, analogous to our approach, a specific course or program of study can be examined with respect to the use of competence-based assignments.

The next step of our research in the development of an e-assessment platform for graphical modeling is to determine the extent to which the task types defined here can be implemented and automatically evaluated. The design of (automated) competence-based feedback will also be explored within this framework. The competence-oriented task catalog provides the basis for the development of grading schemes and the formulation of feedback. One result of the project will be the publication of didactic guidelines for the use of competence-oriented assessment tasks including grading and informative feedback in the area of graphical modeling.

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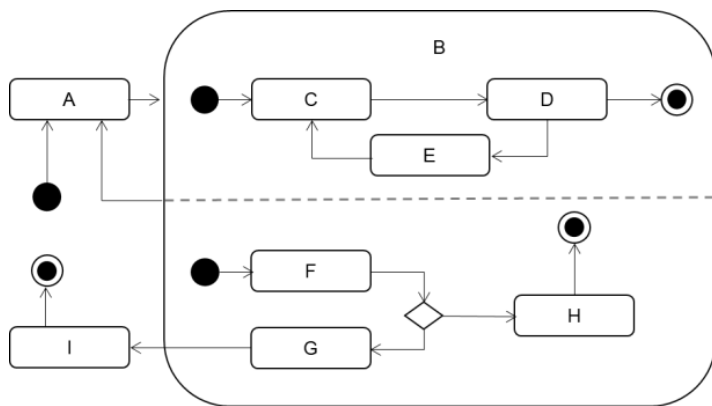
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Sample task



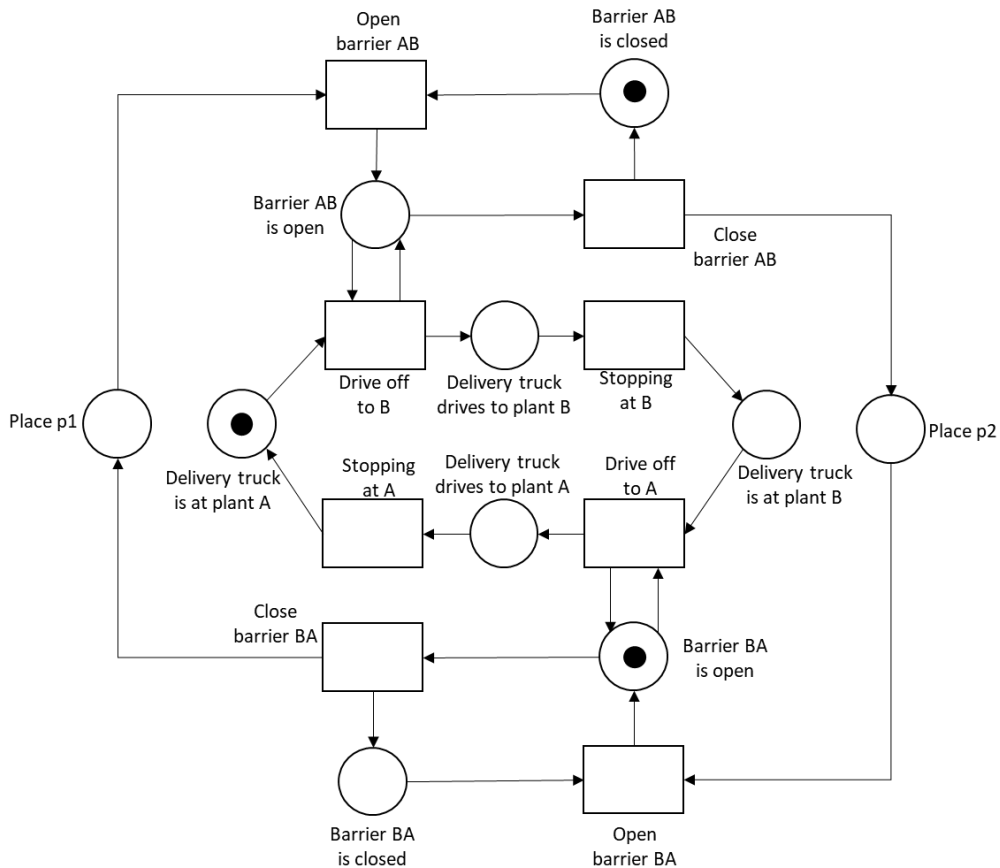
Consider the UML statechart shown above and check whether the following statements are true or false:

	true	false
The system shown terminates when state H has been exited.	<input type="checkbox"/>	<input type="checkbox"/>
The represented system can be in state G and H at the same time.	<input type="checkbox"/>	<input type="checkbox"/>
When state A is exited, the system is simultaneously in states C and F.	<input type="checkbox"/>	<input type="checkbox"/>
The system can remain in state B indefinitely.	<input type="checkbox"/>	<input type="checkbox"/>
The represented system terminates only when state I has been exited.	<input type="checkbox"/>	<input type="checkbox"/>

Figure 3: Sample task of the task type “Interpreting model content, context-free”

Sample task

Consider the following Petri net (P/T net). This shows the transport of goods by truck between two plants, which is regulated by various barriers.



version 1 - multiple choice:

Based on this P/T net, judge whether the following five statements are true or false and indicate your answer with a cross in the corresponding column.

	true	false
The barriers can be open at the same time	<input type="checkbox"/>	<input type="checkbox"/>
The barriers can be closed at the same time	<input type="checkbox"/>	<input type="checkbox"/>
The net models the states of two barriers	<input type="checkbox"/>	<input type="checkbox"/>
The delivery truck can drive from plant A to plant B as well as back.	<input type="checkbox"/>	<input type="checkbox"/>
If barrier BA is open, then only the journey from plant A to plant B is possible.	<input type="checkbox"/>	<input type="checkbox"/>

version 2 - natural language:

Based on this diagram, state in natural language and in understandable terms for a layperson (i.e., non-computer scientists) what conditions were modeled for a delivery truck and what common states the modeled barriers may have.

Figure 4: Sample task of the task type “Interpreting model content, with context”

Sample task

Check the following Petri net (P/T net) for the following properties and justify your decision in each case:

- It terminates.
- It is live.
- It has no deadlock.
- It is reversible.

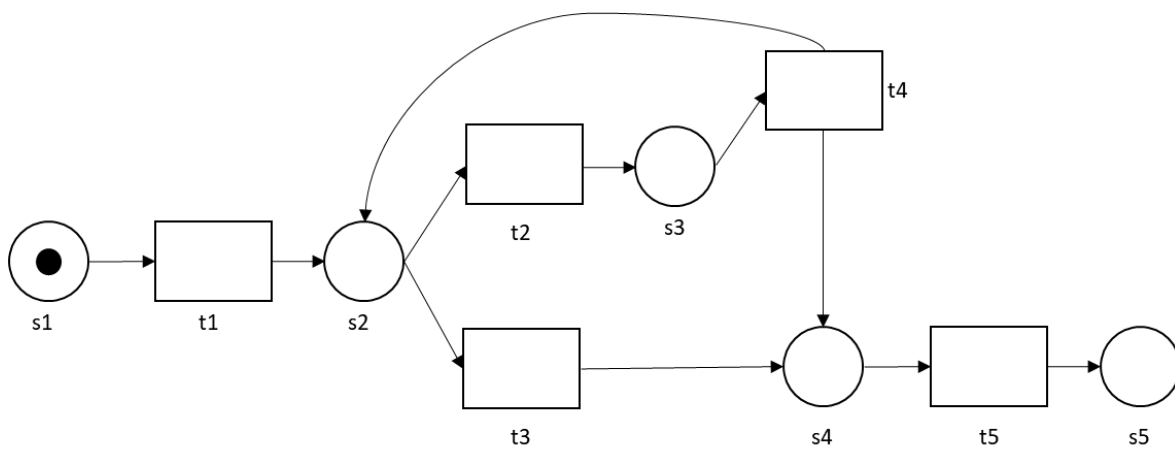


Figure 5: Sample task of the task type “Check formal model properties”

Sample task

The following eEPK contains several errors. Please indicate the error by giving the coordinates of the field where the error is located and briefly describe this error.

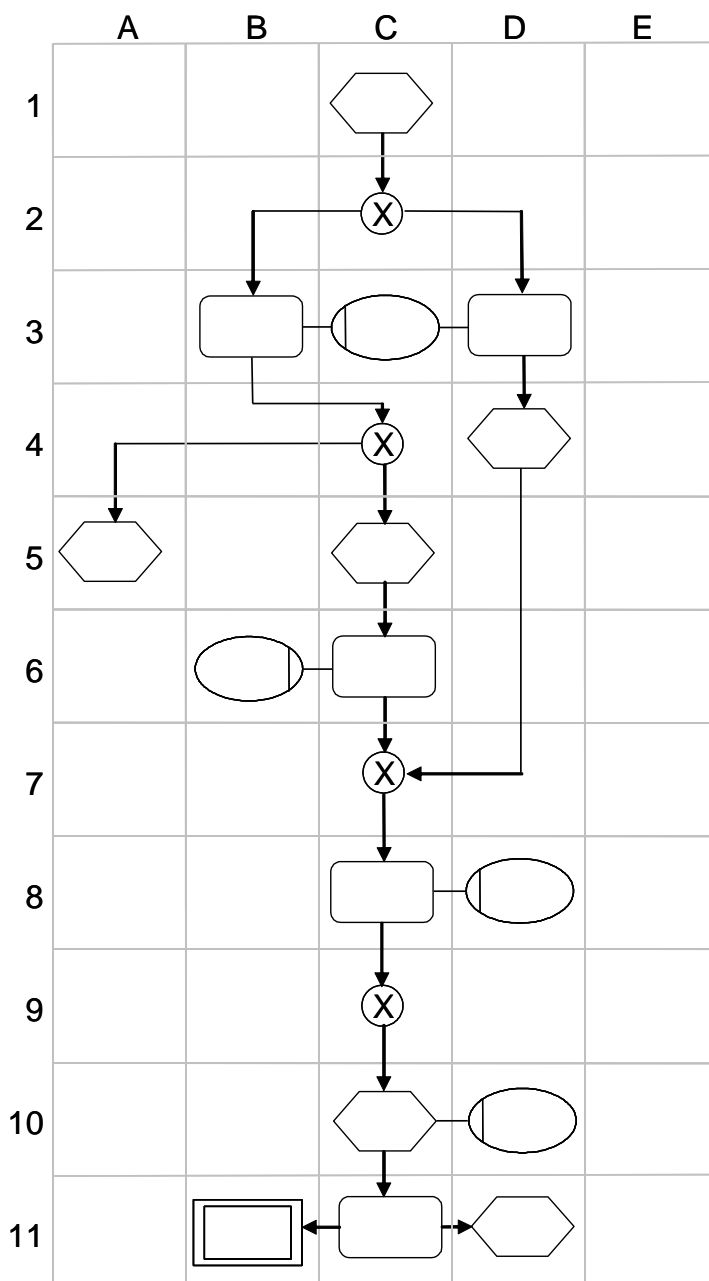


Figure 6: Sample task of the task type “Syntactical error finding”

Sample task:

The introduction of a combined CRM- and ERM-System requires the CoffeeFactory company to reevaluate the current process for material purchasing. This process is described as follows:

If an employee requires material for a request, he fills a requisition slip in the new system. If the material price is above or equal to \$100, the division manager is required to check the slip. If the division manager approves the slip or the material price is below \$100, the requisition slip is forwarded to centralised purchasing. If the requisition slip is rejected by the division manager, the process ends.

When centralised purchasing receives a slip, the availability of the requested material is checked. If the requested amount is not available, the material purchase is initiated. If the requested amount is available, the material is supplied and thus, the requisition slip has been successfully processed.

Please model the described scenario in BPMN. Use data objects where appropriate.

Sample solution:

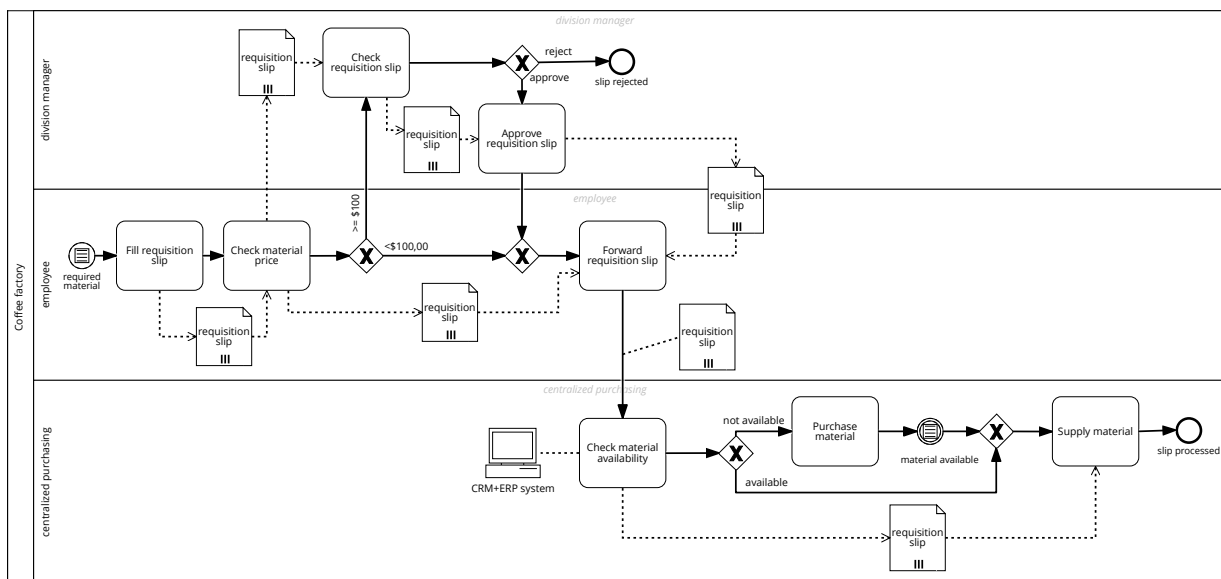


Figure 7: Example task and sample solution of the task type “Model building based on a text describing a scenario”