Implementing Ability-Based Design: A Systematic Approach to Conceptual User Modeling

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The notion of *Ability-Based Design*, put forth by Wobbrock et al. [80, 82] as a solution to the challenge of creating accessible technology, has been discussed in human-computer interaction research now for over a decade. However, despite being cited as influential on various projects, the concept still lacks a general characterization of *how* to implement its required focus on abilities. In particular, it lacks a formulation of how to perceive and model users within an articulated design process. To address this shortcoming, we rely on conceptual user modeling to examine Ability-Based Design and propose a characterization of it that is not dependent upon a specific project or research effort but that enables the ability-based design of new technologies in a systematic manner. Our findings show that Ability-Based Design's focus on abilities requires important changes in typical user modeling approaches that cannot be met with current techniques. Based on the challenges identified through our analysis, we propose a first modification not only of current user modeling but also of current requirements analysis approaches to address abilities and their intertwined dependencies with tasks and contexts as core elements of conceptual models in Ability-Based Design. We thereby demonstrate not only the complexity of modeling users' abilities, but also draw out promising ideas and perspectives for future research, emphasizing the need for future evaluative work on our approach.

CCS Concepts: • **Human-centered computing → Accessibility theory, concepts and paradigms;**

Additional Key Words and Phrases: Ability-based design, conceptual user modeling, methodology

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1 INTRODUCTION

The challenge of creating accessible interactive technologies has been recognized and discussed for decades in human-computer interaction (HCI) and accessible computing, resulting in multiple guidelines and standards, theories, and methods—all trying to discover, enable, promote, and ensure accessible technology solutions that provide access to all users, whatever their preferences, needs, or abilities. The notion of Ability-Based Design (ABD) grew from within HCI as a response to three primary factors: (1) the deficit-oriented characterization of disabilities, (2) the predominance of devices and software oblivious to the abilities and contexts of their users, and (3) to the implicit assumption that people must adapt themselves to the "ability demands" of their technologies. With early successful demonstrations of ability-based user interfaces [24, 25], the formulators of ABD insisted that designers of technology focus on people's situated abilities and create technologies well suited to them [80, 82]. Today, ABD has been around for about a decade; the article from 2011 [82] is the most-cited ACM TACCESS article by some distance,[1] and ABD has been the basis for the 2017 ACM SIGCHI Social Impact award [81] and an article in *Communications of the ACM* [80]. However, despite ABD's influence, there has been no general characterization of any underlying methodology, that is, no specific instructions on *how* to practice ABD. Various projects have appealed to ABD's principles, perspectives, or motivation, but without any coherent formulation of an ABD design process or systematic methodology [1, 4, 69, 70, 75]. Thus, we are left with numerous examples of ABD's influence; However, to gain an understanding about how to practice ABD, we are forced to rely on inductive reasoning, trying to make inferences by looking for patterns that emerge from unrelated individual projects. In particular, what the current formulation of ABD lacks is a close examination of its core element, that is, the perception and modeling of users within the design process, how this differs from non-ability-focused approaches, and how it can be generalized as part of a coherent ABD methodology. Filling that gap is the chief purpose of the work described in this article.

Therefore, in this article, we employ conceptual user modeling approaches (i.e., non-technical abstractions of user populations) to examine ABD both theoretically and from various projects, and devise a characterization of ABD that is not dependent on the specific contexts of any one project or research effort, thereby making it applicable to a range of potential projects. Doing so with a focus on conceptual user modeling allows us to inspect the seemingly vague matter of designers' attitudes, approaches, or stances that are called on through ABD's focus on abilities [80, 82]. In this way, we illuminate a first step into designing new systems with ABD using a systematic approach that enables scrutinization of ABD apart from any specific research or design effort.

Our work reveals that ABD's focus on abilities requires significant changes in conceptual user models by turning such models from "user models" into "ability models"—a concept that has not been thoroughly discussed in the context of user modeling research and that raises previously unknown requirements and challenges. We address the inevitable contextualization of abilities and their dependence on specific tasks and activities, arguing that to create a systematic methodology for ABD, we must consider not specific abilities, tasks, or contexts in themselves but rather the relations that exist among them to remain versatile. We argue that a key to discussing highly contextualized constructs such as "abilities" in a generalized yet meaningful way lies in modeling relations and dependencies rather than isolated entities. We argue that current user modeling techniques are not well suited for modeling relations or dependencies and, therefore, offer no appropriate techniques for user modeling in ABD. Instead, a novel approach is needed that considers the relationship among abilities, tasks, and contexts that allows us to formulate abstract

[1] See *Most Popular* > *Cited* at: https://dl.acm.org/journal/taccess (last accessed on October 4th, 2021).

descriptions of a user population with its multitude of individual abilities sufficient in all regards to specific contexts and tasks. We pursue this objective with an ability-based requirements analysis approach, which demonstrates not only the complexity of the matter as a whole but also draws out promising ideas and touch points that contribute to research on user modeling for ABD. To demonstrate the applicability of our approach, the article presents two use cases based on existing research projects that exhibit what working with the approach might look like, reflecting on the added value of it as well as challenges encountered. Finally, a variety of open questions and issues are discussed, emphasizing that the proposed approach is a first idea on how to model users in ABD—an idea that needs to be complemented and consolidated with evaluative work throughout future research.

Our work contributes to the development of a guide for practically implementing Ability-Based Design at scale by framing a central issue of conceptual user modeling, how it changes within ABD, which challenges arise, and in which ways design solutions might be achieved in future projects.

2 BACKGROUND

Both Ability-Based Design (ABD) [80, 82] and (conceptual) user modeling [5, 7, 12, 34, 35, 49] are well-known concepts in human-computer interaction (HCI) research with their popularity being only strengthened by the growing emphasis on accessibility and human-centeredness in recent years. In this section, we set the stage for an ability-based user modeling methodology, which requires both an understanding of ABD and of user modeling separately, and of issues raised by their possible combination.

2.1 Ability-Based Design

Ability-Based Design [80, 82] is a design approach to accessible computing that refines former approaches by focusing on a user's abilities and the adaptation or configuration of interfaces, with the burden for accommodation residing on the system, not the user. Systems must become more aware of users' situated abilities and provide ways for users to interact successfully with them using whatever abilities users might have. For example, interfaces might adapt their layouts and widgets to be more usable to people with limited fine motor function [25] or for users not using hands, pointing might be enabled by use of their voice [29]. In its way, ABD offers a novel perspective on HCI design that aims to break away from previous deficit-based approaches:

> The appropriate question when designing accessible technologies is not, "What disability does a person have?" but rather, "What can a person do?" This question prompts a refocusing of accessible computing from disabilities to abilities, much as user-centred design refocused interactive system development from systems to users. [82]

ABD focuses on designing accessible interactive technologies, particularly on creating individually optimized systems for specific users in specific contexts. ABD is generally unconcerned with finding one universal solution for all. Rather, it wants to capture, model, and reason about the abilities of users in order to optimize the individual user experience [80]. Therefore, ABD is contrasted in some respects with universal design [51] in its focus on "design for one," as described by Harper:

> In this way, systems bend themselves to the interaction will of the user and absolve the software engineer of responsibility for trying to fulfil the design considerations of all users while enabling the system to respond in a more bespoke manner. We call this 'Design-for-One.' [30]

Table 1. The 2018 Principles of Ability-Based Design (Reproduced from [80])

Principle	**Description**
Ability	Designers focus on users' abilities, not disabilities, striving to leverage all that users can do in a given situation, context, or environment.
Accountability	Designers respond to poor usability by changing systems, not users, leaving users as they are.
Availability	Designers use affordable and available software, hardware, or other components acquirable through accessible means.
Adaptability	Interfaces might be adaptive or adaptable to provide the best possible match to users' abilities.
Transparency	Interfaces might give users awareness of adaptive behaviours and what governs them and the means to inspect, override, discard, revert, store, retrieve, preview, alter, or test those behaviours.
Performance	Systems might sense, monitor, measure, model, display, predict, or otherwise utilize users' performance to provide the best possible match between systems and users' abilities.
Context	Systems might sense, monitor, measure, model, display, predict, or otherwise utilize users' situation, context, or environment to anticipate and accommodate effects on users' abilities.

2.1.1 Principles of Ability-Based Design. Within their definition of ABD, Wobbrock et al. [80] offer seven principles to inform its practice (Table 1). The first three of these seven principles—Ability, Accountability, and Availability—are required for any ABD project, and describe requirements for designers and their "stance." The other four principles are to be understood as recommendations concerning the design of the interface (Adaptability and Transparency) and the type of data that could be captured and modeled to achieve individually optimized user experiences (Performance and Context) [80].

These principles form a valuable foundation for both designing ability-based systems and evaluating whether and to what extent a developed system might be found in conformance with the letter and spirit of ABD. Whether these requirements and their differentiation into "required" and "optional" bear fruit in practical applications of ABD is an open question for future work.[2] In this work, the 2018 ABD principles serve as a first set of central requirements that a systematic methodology should meet, as discussed later..

2.1.2 Positive Affirmation of Abilities. A central tenet that forms a foundation for ABD is the regarding of abilities as solely positive. As an "ability" is defined as the available option to carry out a task or activity [27, 28], it can exist only in a positive manner and, like strength or height, cannot become negative [80]. Therefore, "*dis*-abilities," as commonly understood, arise due to external

[2]For instance, it would be of interest to analyze the ways in which the principle of Accountability can be fulfilled for a broad group of people with a variety of abilities if not through adaptability and, therefore, whether the principle of Adaptability, although now "optional,"will inevitably function as required.

factors that prevent activities from being carried out using the abilities a person *does* have. This view of disability sits squarely in the social model [58].[3] ABD understands disability as barriers people encounter when the "ability assumptions" embedded in the design of an environment or technology do not match the abilities of the individual [80, 82]. This is a crucial perspective in understanding a core idea of ABD, because it highlights the responsibility that designers of an environment or technology have when imbuing their creations with conscious or unconscious ability assumptions. Furthermore, it demonstrates why abilities are best suited to be designed *for*, rather than disabilities being somehow "accommodated."

The intertwined concepts of the positive affirmation of abilities and disabilities arising from mismatches between people's abilities and designers' ability assumptions are applicable to human-computer interaction (HCI) generally. Systems, applications, and devices form the "environment" and individuals are "users" within that environment. Disabilities in HCI emerge from the interaction between users and systems[4] every time the design of the latter assumes abilities that users do not have. The responsibility for good interaction design lies in ensuring correct and explicit ability assumptions within systems, thereby minimizing the gap between assumptions and individual abilities, making systems accountable to the user, not the other way around [80]. In order to fulfill this responsibility and avoid making wrong assumptions based on biases or lack of knowledge, designers need ability-based user models that capture the correct abilities of intended users. These models require an understanding of what user models generally are and what they look like in ABD, that is, how they might be viewed from an ABD perspective.

2.2 User Models

Generally, a user model is a representation of a user or user group that captures information and assumptions about that user or group [5, 7, 12, 49]. User models can be related to standards [45], particularly when captured by "user profiles" [38, 40, 41] or "common access profiles" [37]. However, this basic understanding can be further differentiated. Prior research [46, 71] discusses attributing different user models to "phases."[5] Based on this idea, we draw a distinction among representations that are the actual users themselves, raw data about these users collected within user research in the analysis stage (i.e., in advance of the intended system being implemented), conceptual and technical models containing abstractions, and the individual data collected throughout the usage of an implemented system and stored in a user profile (Figure 1).

As this article addresses the issue of designing new systems in accordance with the human-centered design (HCD) process [26, 38], we focus in the following on conceptual user models employed by designers, who build a bridge between the first phase ("understand and specify the context of use") and the second phase ("specify the user requirements"). As such, they abstract knowledge gathered in the first phase into requirements defined in the second phase. For this transition from raw data to conceptual models, designers abstract the collected raw data of single users into synoptic descriptions of the user population as a whole (see Figure 1). Most common examples

[3]The medical model of disability focuses on disease, trauma, and functioning [59]; the identity model views disability as membership in a minoritized, marginalized, and oppressed class [10]; the economic model views disability as a barrier to productive citizenship and economic participation [3]. A more in-depth review of disability models is given in prior work [63].
[4]The interaction itself can also be influenced by external factors, or "context," which might affect experiences of disability.
[5]Other studies indicate a variety of other categorization schemes that can also be used to differentiate between types of user models. Distinctions have been drawn among the intended goal of the model [43], its result [64], whether the modeling procedure happens implicitly or explicitly [46], theoretically or practically [15]. Furthermore, one can distinguish between models based on their application context [18], depending on the expert defining them [15] or the type of information that is being modeled [64].

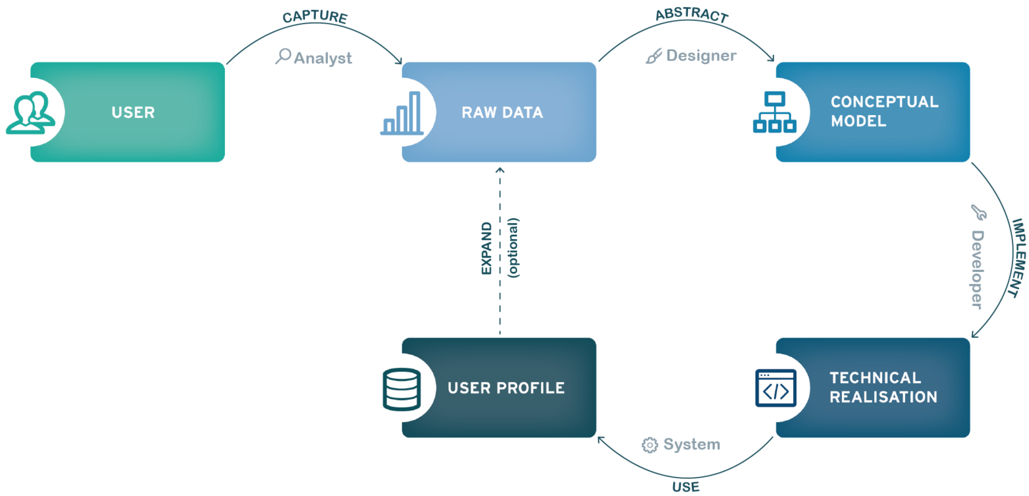

Fig. 1. User representation can be established in different forms. Users themselves can form the starting point, which, when analysed, allows for raw data to be captured that can then again be used by designers to create conceptual models. Implementing the intended system demands a technical representation of these former conceptual models while finally, the usage of the implemented system creates user profiles that represent individual users. These profiles can therefore be seen as a special form of raw data, creating a cyclic connection between the different forms of user representation that resemble the human-centred design cycle [38]. All of these can be considered user models, each offering individual tools, methods, and intentions.

of such conceptual user models are user groups, either in general [35, 55] or more specifically, like market segments [14, 35], plan libraries [46], or actors and roles [16], but also user stories [77], stereotypes and archetypes [49, 64], personas [15, 17, 35, 44, 61] or extreme characters [19]. Methods such as scenarios [61, 65] or user journeys [36] can also be regarded as conceptual user models, as they include aspects about the user but are more commonly known as interaction models due to their scope and content [61].

2.3 Ability-Based Conceptual User Models

Having reviewed both the definition and core ideas of ABD and of conceptual user modeling, we argue that conceptual user modeling techniques require important adaptations when applied to ABD. In contrast to other universal approaches, such as Universal Design [51] or Inclusive Design [47, 48, 56], which seek to design solutions that try to work for most everyone, ABD pursues a more tailored approach through the focus on individual abilities, thereby requiring ability-based user models. Demanding a shift in focus from disabilities to abilities incorporates, above all, specification of the way users are perceived, considered, and modeled. Therefore, ABD will benefit from conceptual user models that contain a specification of users' abilities as a core element. While user models can contain any assumption or information regarding a user (see Section 2.2), ABD requires a more specific form of model, for which designers must transform the representation of users in general into representations of a user's specific abilities. Thus, user models in ABD become ability models that contain a collection and description of individual abilities that a system should accommodate.

Although this modification might appear to be a clear and direct change to conceptual user models, the modeling of abilities raises a variety of challenges that are not easily addressed with current modeling approaches. How to model abilities has not been sufficiently addressed in the work on or use of ABD. We need to understand what it means to use "abilities" as representations of a user and how this understanding can be practically applied in conceptual user models.

3 STATE OF RESEARCH AND RELATED WORK

As stated in our introduction, ABD [80, 82] has been cited numerous times in the literature, indicating popularity of the concept. However, translating from concept to practice is another matter. In the following literature review, we take a closer look at the research on and use of ABD and examine the ways in which the concept has been relied on. By focusing on methodological aspects with relevance to user modeling, we address whether any research has previously characterized user modeling in ABD, highlighting the gap that this article addresses.

3.1 Systematic Review Procedure

To characterize the current state of research concerning ABD, we considered all citations of the two principal ABD papers [80, 82] listed either by Google Scholar[6] or the ACM Digital Library.[7] By examining publications that specifically cite either or both of the ABD papers, we ensured that only studies with a deliberate reference to ABD are taken into account. We executed our literature review in four steps—with the collection of data followed by a formal reduction and finished with two content-related reductions. This strategy allowed us to define our working corpus within the first two steps, and then analyze that corpus with respect to the issues of implementing ABD and user modeling.

3.1.1 Defining the Corpus. To collect our data, we focused on all citations of the foundational Ability-Based Design (ABD) papers listed by either Google Scholar or the ACM Digital Library. We also included the results from a keyword-specific search of the ACM Digital Library.[8] Altogether, this procedure produced an original corpus of 822 items (data received on September 26, 2021), which was corrected by removing overlaps and doublings, resulting in a collection of 438 items. In addition, we also reduced the corpus based on formal criteria, such as language or incorrectly listed papers. With this procedure of first collecting and then reducing the data based on formal criteria, we were able to narrow the corpus down to 348 references, which formed the foundation for the following content-related analysis and reduction steps.

3.1.2 Primary Content Analysis: Realization of Ability-Based Design. Our first goal was to understand the content of the references in our corpus in order to identify references that explicitly claimed the objective of realizing ABD so that we might assess the current state of ABD in practice. Therefore, all references in our corpus were searched for how they referred to ABD, then sorted into categories accordingly. We distinguished among four main categories (Table 2): (1) citations to the ABD papers with no mention of the ABD concept itself; (2) citations to the ABD concept with no intended realization; (3) citations to the ABD concept with implicit, but no executed, realization; and, finally, (4) citations to the ABD concept with deliberate and executed practical realization. The 55 items of the fourth category were analyzed in a subsequent content-related step to examine any use of user modeling within their realization of ABD.

3.1.3 Secondary Content Analysis: User Modeling. Continuing the procedure from the first content-related analysis, the corpus was once more analyzed to grasp the current state of research regarding user modeling within ABD. We inductively identified five main approaches to user modeling for ABD (see Table 3). These categories can be directly mapped to the different types of user

[6] http://scholar.google.com/.
[7] http://dl.acm.org/.
[8] "Ability-Based Design" was used as a search term in order to find only exact matches.

Table 2. Main Categories Identified within the Primary Content Analysis as Approaches to ABD, Distinguishing between Them in Regard to their Consideration of Realizing ABD

Category	Description	Items
No mention of ABD	Papers focus on topics other than ABD (e.g., accessibility, situational impairments, and so forth)	133
No realization intended	Papers focus on ABD from a theoretical perspective (e.g., as related work, motivation, and so forth)	142
Realization intended, but not executed	Papers mention the realization of ABD implicitly (e.g., as lecture content for HCI classes, planned realization, and so forth)	18
Deliberate and executed realization	Papers realize ABD explicitly and deliberately as an objective of the research.	55

Table 3. Main Categories Identified within the Secondary Content Analysis as Approaches to User Modeling in ABD from the 55 Items in the Bottom Row of Table 2

Category	Description	Items
No user model	Papers do not describe their approach to user modeling.	25
Raw data as user model	Papers focus on the analysis and/or data capturing phase.	2
Conceptual abstractions as user model	Papers focus on the design phase and the use of conceptual user models.	8
Technical realization as user model	Papers focus on technically realized user models and discuss fully implemented systems.	15
Individual profiles as user models	Papers focus on individual profiles that serve as user models.	5

models discussed in Section 2.2, as they include raw data, conceptual abstraction, technical realization, and individual profiles. In the following discussion, we focus on references sorted into the third category, "conceptual abstractions as user model," as these references deal with conceptual user modeling within ABD. Studies belonging to the other four categories, even though they are not further pursued in this article, might also contain important results for developing ability-based systems in the future.

3.2 Results and Discussion

The formal and content-related reductions undertaken in our systematic literature review reduced the starting corpus from 348 references to only 8 dealing with conceptual user modeling in ABD. This dramatic reduction demonstrates that even though the ABD concept has already been widely cited, conceptual user modeling is addressed rarely, and even then not in a generalizable manner. For example, some references focus on improving navigation systems for people with visual impairments [66], using tactile acuity for creating tangible user interfaces for web layouts [72], choosing the best-suited input technique based on users' oculomotor abilities [20], creating accessible toy designs for children with cerebral palsy [9], or optimizing keyboard designs and layouts [67–70]. All of these studies focus on a specific problem to solve, leaving the question of a *systematic* approach to conceptual user modeling in ABD unaddressed. In addition, even though they deal with the abstraction of raw data into representations of the user population, none discusses or makes use of existing methods for conceptual user modeling (e.g., personas, user classes). Instead, they view their target users (i.e., people with visual, motor, or cognitive impairments, as well as older adults) as one group, only identifying variable aspects within that group that can be used to personalize a system:

> Using qualitative data analysis, we found that an individual's choice of mobility aid (e.g., guide dogs or white canes) and their visual ability impacted the manner in which they used the system and the provided feedback. We captured this rich relationship between the information types and an individual's mobility needs in a design space for creating adaptive systems and presented a set of design implications for future camera-based AI systems for people with VI. [66]

This excerpt shows a typical context-specific approach in its degree of specificity that is distinct from our article's objective to develop a systematic approach to user modeling within ABD (i.e., one independent from the context of specific projects). The quote also highlights the type of abstraction, that is, the definition of a design space for capturing relations between information behavior and individual needs, which serves as a conceptual user model instead of common methods such as personas or user classes. The other studies mentioned earlier use similar approaches, which could be seen as a first indication that common conceptual user models are unlikely to work properly for ABD and are therefore replaced by non-standardized techniques, such as design spaces or, more often, informal collections of user traits that are used for driving the adaptation of the respective system.

Our results show that characterizing ABD in regard to conceptual user modeling has been neglected in research to date. Thus, we are left with a series of unrelated individual projects as examples of ABD's influence but no general perspectives on how to design systems for a variety of users based on their abilities. We now turn to remedying this shortcoming.

4 USER MODELING IN ABILITY-BASED DESIGN

Thus far, we have established that user models in ABD must represent the user population using *abilities* as the core dimension. To address this objective, the following sections first identify specific requirements posed by abilities as a modeling dimension, then present and discuss our approach, *ability-based requirements analysis*, as a methodological component for implementing ABD.

4.1 Requirements

Recall that an "ability" is defined as the available option to carry out a task or activity [27, 28]. Modeling abilities in order to ensure that a design is ability based thus means that the model accurately apprehends the possibilities for action that a user has for a given task or activity, allowing the designer to offer usage options based on these possibilities. In the analysis of the core definition of abilities as presented earlier and results from previous studies, however, we were, able to deduce a variety of challenges surrounding the modeling of abilities. Throughout the following three sections, we discuss the main challenges we identified and formulate them as key requirements for modeling abilities, which we argue need to be addressed by any project working with ability-based user models.

4.1.1 Include Dynamics. There are several factors that influence the abilities of an individual, rendering the construct of "abilities" itself as highly dynamic [23]. Taking also into account the idea of disabilities arising from unmet ability assumptions in technologies or the environment [80, 82], external factors can cause an ability to be "removed," that is, these factors can block or hinder an otherwise available option to execute a task. Wobbrock et al. [80, 82] therefore speak of disabling factors, meaning influences external to a person that hinder an otherwise available opportunity for action. These disabling factors can either originate from assumptions made by technologies or the environment or from those that arise in social situations due to the attitudes, opinions, or behaviors of other people. When it comes to modeling abilities, we argue that the great number of potential disabling factors exerts tremendous strain on user models that attempt to incorporate abilities within them. Furthermore, the expression of an individual's abilities changes, sometimes continuously, with environmental factors, medication, or fatigue. Therefore, we need to find ways of capturing and processing abilities that can accommodate this dynamic [23, 79].

4.1.2 Consider Levels of Fidelity. Because abilities are defined through a specific task or activity to be carried out [27, 28], we deduce that single abilities can be described with various levels of fidelity, that is, one ability can be separated into a variety of more distinct specific abilities depending on how specific the respective task or activity is defined. When using abilities as dimensions of user models, this varying level of fidelity can lead to multiple challenges — for one, apprehending these hierarchical structures emphasizes the immense broadness in the landscape of possible abilities to use as representations. Furthermore, choosing a level of fidelity that is either too high or too low can lead to barriers in technology design and to the eventual exclusion of certain users. If an ability is modeled narrowly (e.g., a user has "eyesight of 0.5 diopters"), some users who do not meet the narrow definition might be excluded. On the other hand, modeling users more broadly (e.g., as "able to see") risks forcing designers to rely on their own ability assumptions. Modeling all reasonable ability levels might sound like a promising solution to this problem but is impractical when considering large user populations with a broad spectrum of ability levels. Having users declare their own abilities is another option, but introspection is often inaccurate and stressful for users [52]. In addition, the dynamic nature of abilities, as discussed earlier, would require users to declare their abilities not once, but continuously as situations and contexts change. When viewed from an ABD perspective, such a repeated ability declaration would push the burden of achieving accessible designs onto users [80, 82], making them once again responsible for their own inclusion. Therefore, ability-based user models must find ways of addressing and mapping varying levels of fidelity while keeping implementation efforts practical.

4.1.3 Assess Coherence towards Tasks and Contexts. The definition of an ability as the available option to execute a task [27, 28] indicates that a specific ability can be defined only in relation to the task to be executed and the context of execution. We argue that only when we know what task is to be carried out in what context can we determine whether the option to do so is available, which makes abilities directly dependent on a specific task-context pair. In this way, the abilities of a person depend on which tasks are pursued in which contexts. This dependency sets abilities apart from previous dimensions of most user models, because abilities require a direct, mandatory relationship among user, task and context—the former cannot be created without the latter two, and the latter two are meaningfully created only in regard to the former. In ABD, all three models are inevitably intertwined such that any ability-based user model will change depending on which task and which context is (currently) modeled—an objective that demands consideration of user models coupled with analysis of the entire context-of-use structure (i.e., user, task, and context) [38] in general.

4.1.4 Summary of Requirements. Having deduced these requirements from the theoretical definition of abilities as well as from results and perspectives within previous research, we see that

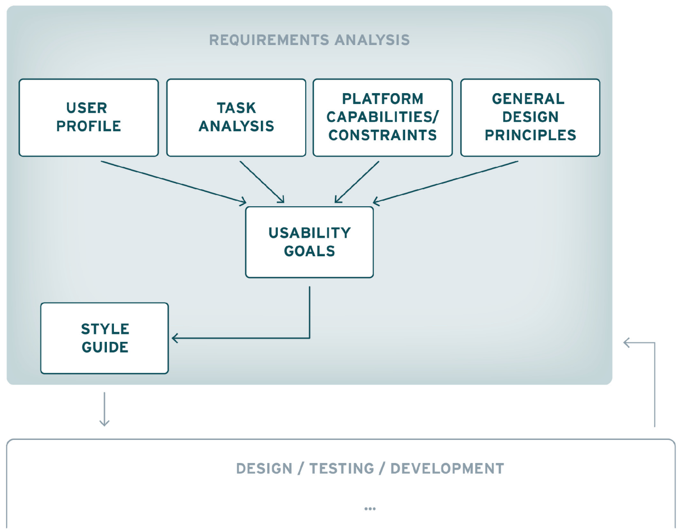

Fig. 2. Requirements analysis (illustration extracted from [53]).

modeling abilities is highly dynamic and contextual. Therefore, we propose to frame the *relations* between entities (i.e., abilities, tasks, and contexts) instead of modeling the entities individually. Such an adjustment allows for a dynamic and contextual alignment of user models, making them more suitable to the requirements posed by abilities as modeling dimensions. We argue that this objective cannot be achieved with common user modeling techniques because these, being applied as one aspect of requirements analysis, are typically only complemented by, but not combined with, task and context models [38]. Although jointly housed in the so-called context-of-use construct [38], the three entities of user, task, and context are practically analyzed separately with dedicated methods, as illustrated in Mayhew's [53] requirements analysis within the usability engineering life cycle (see Figure 2). Within such a separated approach, relations or dependencies between the context-of-use entities are not considered, for example, a change in the task model will have no effect on the user model, as both are considered entirely separated from one another. Regarding these requirements, modeling relations among abilities, tasks, and contexts will not be feasible within an approach like this, which is why it cannot work as a modeling approach for ABD. Therefore, in the following section, we propose a multi-faceted modification of this separated approach to make it more appropriate for modeling abilities, leading to the concept of an *ability-based requirements analysis*, and contributing to methodological groundwork around the issue of creating ability-based conceptual models combining users, tasks, and contexts.

4.2 Our Approach to Ability-Based Conceptual User Modeling

Our proposed framework consists of four main modifications to the common separated approach (see top-left corner of Figure 3)[9] leading to a conceptual remodeling of the latter in its core structure (see rest of Figure 3) to achieve a more integrated analysis of users, tasks, and contexts.

Prior research has addressed similar objectives, though not in terms of systematically offering a methodological approach to implementing ABD but instead focusing on adapting specific interface

[9]This illustration is based on the extracted illustration from Mayhew's [53] requirements analysis as part of the usability engineering life cycle (see Figure 2), but has been simplified and generalized to put more emphasis on the three context-of-use entities and their separate examination in current requirements analysis approaches.

and system designs for user's abilities. The SUPPLE system was designed by Gajos et al. [24] in this manner, offering solutions to interface adaptations in terms of changing layouts and font sizes based on visual and motor impairments. Work done by Biswas et al. [6, 8] took on similar objectives, demonstrating adaptations based on a variety of contextual factors and ability states. Other approaches considered optimized [69] or alternative [42] input methods, for example, gaze control, for people with motor and cognitive limitations.

What these studies share and what sets them apart from our approach is their "point of action," that is, the point within the design process that they address—the issue of adaptation based on already designed variants. Our approach, in contrast, steps in before this and considers the question of how designers can gain an understanding of the dimensions that require adaptation to meet users' abilities without relying on their own assumptions. Following this thought, it might seem obvious that, for instance, people with limited or no hearing require adaptations in terms of how auditory information is conveyed. However, many designers are unaware of the additional difficulties that text poses to the majority of these users, because it is acquired as a second language with local sign languages serving as "mother tongues" [2, 50, 54, 76]. How can designers gain an understanding that their solutions should adapt not only in terms of alternatives to audio but also as regarding text—again, without relying on their own assumptions? We argue that conceptual user models can help address this issue and, therefore, should be adapted to model abilities as a core user dimension—an objective that we propose to meet with the following four modifications, all of which are highlighted in Figure 3.

4.2.1 Modification 1: Integrate "Abilities" into "Task" and "Context." User models in ABD become ability models, and abilities are most clearly defined with respect to specific tasks and contexts. Therefore, our first proposed modification is to integrate the analysis of users and their abilities directly into the analysis of tasks and contexts. Following this perspective, detected requirements are no longer a mere concatenation of separate analyses of users, tasks, and contexts. Rather, they contain an assembled collection of abilities *relevant to the tasks to be performed in certain contexts.* Of course, a separate user model could still be maintained to capture user aspects besides abilities (e.g., background, demographics, preferences, etc.), but such models are familiar and well understood and, therefore, deemed beyond the current scope.

Considering fixed task-context combinations is necessary to prevent contradictions in the design process. For example, if verbal control and auditory feedback were provided as alternatives to manual control and visual feedback for a given task, but the relevant context does not allow such interaction due to high levels of background noise, *separate* examinations of task and context would not detect this problem. This example shows how different tasks in the same context and the same task in different contexts both need to be analyzed as separate combinations.

Similar approaches of such an integration can be found in prior research and methods for modeling interactions between users and systems [36, 39, 61, 65] as these, too, consider an integrated understanding of users, tasks, and contexts.

4.2.2 Modification 2: Articulate Technology "Ability Assumptions." In order to avoid considering "context" as one large domain of possible factors in a requirements analysis in which the central role that technology and its assumptions play in designing ability-based interfaces might get lost or overlooked, our second modification articulates *ability assumptions* made by technology as part of the analysis of user context. Just as the tasks, environment, or situation of users is part of their context, so too is the technology with which they work. This technology brings with it assumptions about a user's abilities—what abilities are required to operate the technology successfully—this is part of the context relevant to ABD. In addition, this modification allows for technology analysis to have a different level of impact with respect to a designer's scope. In contrast to tasks or

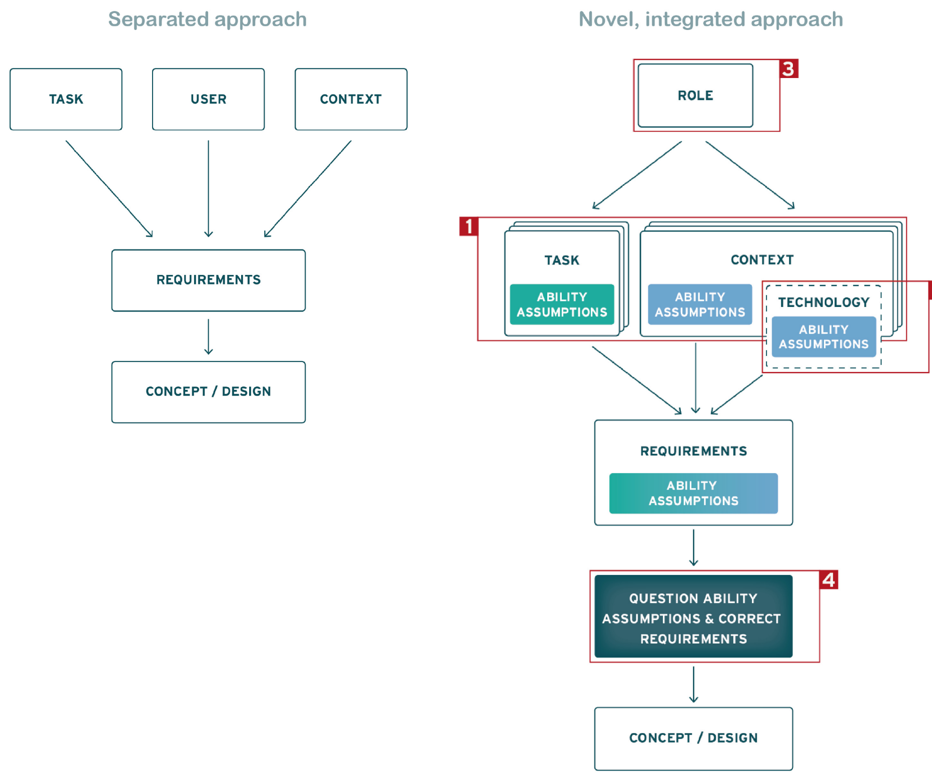

Fig. 3. Modified requirements analysis approach on the right in contrast to the common separated approach in the top-left corner. The modifications in our novel approach are indicated numerically and consist of the following: **1.** The analysis of users (and their abilities) is incorporated into that of tasks and contexts to allow for an integrated analysis of requirements and an examination of abilities in combination with respective tasks and contexts. **2.** In addition, ability assumptions made by technology are articulated as a specific part of contexts to emphasize the flexibility in the designer's scope. **3.** We extract the definition of functional user roles as the primary task to define (multiple) tasks, contexts, and ability requirements specifically for relevant roles. **4.** All assembled task- and context-based ability assumptions are critically reviewed for validity and, if needed, corrected to avoid mismatches between them and the actual abilities of the target group.

environments, designers creating new systems might have the possibility of influencing or choosing their technological context, for instance, by choosing a specific device or operating system on which their design is to be executed. The impact of these choices will differ depending on a project's specifics, conceivably varying between no imposed technology constraints on the one hand and rigid detailed specifications on the other.[10]

4.2.3 Modification 3: Consider Roles and Multiplicity in Task and Context. Our third modification includes the definition of functional roles, emphasizing that not all users of a system pursue the same tasks in the same contexts; rather, they have different intentions when using a system. These roles differ in their tasks and contexts and are defined in regard to their functional character [16], that is, based on their tasks and intentions and not by different characteristics, as is common for user groups or stereotypes. Following this modification, we propose that for each role, designers

[10]This range of flexibility in the designer's scope is visually represented with the dotted line surrounding technology and its ability assumptions in Figure 3.

define its tasks and contexts, recognizing that each role is likely to pursue not just one task in one context, but that often one role executes multiple tasks in different contexts. Therefore all roles should be captured and examined in regard to required abilities. With this third modification, we not only integrate a broader view of the abilities required to complete contextualized tasks but also encourage designers to define the actual intention of their designs in the form of different roles.

4.2.4 Modification 4: Question and Adapt Set Assumptions. To offer a solution to the problem of users not meeting the surfaced ability assumptions, our last modification introduces an additional step in the process in which those assumptions are to be challenged, questioned, and possibly corrected. For this, designers should address every surfaced task-context tuple with the respective abilities assumed and examine whether these assumptions actually hold, whether specific abilities might not be covered by users, or whether there are individual factors influencing specific abilities that should be considered within the design.[11] Based on this review, the corrected, extended, or reduced ability assumptions can then be used as a foundation for the following concept and design phase.

The precise execution of this final step is likely to vary among designers depending on the resulting abilities assembled in the previous steps as well as resources and overall aims of the project. One promising approach to addressing and questioning set ability assumptions lies in the direct inclusion of and discussion with target user groups to identify matches and mismatches between ability assumptions and actual abilities. Another approach is to offer multiple usage paths for each interaction (e.g., offer verbal controls for every manual control, and auditory feedback for all visual feedback) to anticipate and bypass mismatches between ability assumptions and users' abilities. Future research should address these issues in more detail to highlight their potential as well as their limitations and identify best practices to establish a solid foundation on which designers can base their work.

4.3 Conceptual Limitations

Although the modified approach we have presented offers a variety of improvements regarding the consideration of dependencies among users, tasks, and contexts, it still contains limitations and unsolved challenges.

First, the requirements we identified in Section 4.1 have not yet been reviewed or evaluated within the HCI community. Rather, they are the result of our own interpretations of and deductions from theoretical definitions and prior work. We propose these as requirements for modeling abilities because the latter in our opinion, cannot be achieved without addressing these issues. However, researchers apprehending our work should consider this lack of practical grounding and review the requirements from their own practical point of view.

Second, the proposed framework so far does not explicitly address privacy aspects, although these can pose a critical challenge in the framework's implementation. With this article's main focus on methodological aspects, questions surrounding the handling of personal data about individuals' abilities need to be discussed in future work.

Third, our approach does not offer a solution to the issue of capturing individual abilities while considering their variation caused by different disabling factors (see Section 4.1.1). Even though the modifications proposed allow for an ability-based creation of design and adaptation variations, they do not cover the assignment of specific designs to users based on their abilities. The latter needs to be discussed in future research, as it will require some form of calibration before an initial

[11]This task, although essential, does raise some concerns regarding scale in cases in which there are so many task-context tuples that addressing all of them becomes infeasible. We discuss this concern in Section 7.

use of the system as well as continuous updates of these calibration parameters throughout usage to detect changes in context and ability. Our concept does not yet offer a solution to this trade-off between high accuracy of captured situational data and low burden for the user.

Fourth, the analysis and modeling of tasks and contexts, similar to that of abilities, can vary greatly in their level of fidelity—a challenge that is not introduced by the presented ability-based modifications but that originates from the basic scope of any task- and context-analysis model. However, the complexity of fidelity in task- and context-models arises as an important challenge for this work because the fidelity with which the task-context tuples are described has a direct influence on the definition of abilities due to their interdependence. As the level of required granularity in describing tasks and contexts differs between systems, it is up to designers to determine a level that allows them to draw sufficient insights and implications, guiding them in their design.

Finally, as discussed in Section 4.2.4, there are no findings, guidelines, or best practices for determining whether ability assumptions are correctly identified. Designers have to rely to a great, and perhaps problematic, extent on their own judgment and experience, risking being misled by their own ableism and biases. This fundamental challenge of designing inclusive systems is already emphasized within the initial definition of ABD [80, 82] and cannot be solved merely by applying the proposed modifications when analyzing requirements. However, with our adapted approach, we aim to push designers increasingly toward considering and questioning their own assumptions, emphasizing that these might be misleading, to achieve a reduction of mismatches between assumptions and reality. Our approach does not solve the issue of wrong assumptions to begin with; however, it helps to facilitate a change of perspective among designers.

5 APPLYING THE APPROACH: TWO USE CASES

To provide a better understanding of how our proposed framework can be practically applied by practitioners, this section presents two use cases. Both use cases were carried out by two HCI experts who were involved in the initial research projects. In addition to the knowledge gained within previous project activities, the experts relied on insights from literature for both understanding context and the modeling of abilities. Thus, these use cases serve as example demonstrations of what applying the proposed framework can look like. Each is introduced with a short explanation of the problem case on the basis of the respective project and its goals, followed by a demonstration of conceptually modeling the context-of-use entities with our modified approach. The section closes with a discussion of the value our modeling approach brings to both project objectives and challenges in its application.

5.1 Use Case I: Communication for Weaning Patients

In many cases, intensive care unit (ICU) patients require artificial respiration because they are incapable of breathing on their own due to medical issues or surgical interventions. Recovering from breathing on a ventilator requires a weaning process—enabling the patient's body to breathe on its own again—a process that is exhausting and stressful for patients in part because verbally communicating their needs is impossible. The *ACTIVATE* research project [62] focuses on the development of a communication system used between weaning patients and professional caregivers as well as other medical staff members or relatives of the patient. The intended system is supposed to provide orientation, participation, and a sense of control among patients while supporting caregivers in their daily routine [33]. Thus, an ability-based requirements analysis executed for this project should emphasize the abilities of both patient and caregiver,[12] allowing designers to extract

[12]Other user groups, such as staff or relatives, have been omitted for this exemplified use case because they do not count as primary users.

insights about which technology and forms of interaction are best suited for supporting communication between these users.

5.1.1 Roles, Tasks, and Contexts. Considering the project scope, our novel conceptual model (Figure 4) distinguishes between the functional roles of "patient" and "caregiver," both of which are annotated with *input* tasks (i.e., communicate or share) and *output* tasks (i.e., receive or assess). Considering the execution of these tasks, we find that the patient remains in the same context (hospital ICU room) while the caregiver moves between the patient's room, other patients' rooms, and the hallway or kitchen when executing their tasks. To define the abilities required for these role-specific tasks, we relied on prior research [14, 60, 78] to distinguish between *interaction mediums* relevant for input tasks and *sensory channels* relevant for output tasks. Mediums or channels that could be ruled out were not considered throughout the remaining modeling procedure. In the case of the patient role, these discarded abilities all referred to interaction mediums inhibited by the inevitable ventilation tube (i.e., chin, suck/blow, tongue, and voice), while the only one discarded for caregivers was the brain as interaction medium due to the incompatibility of brain-computer-interfaces with the role's high demand for mobility.

5.1.2 Assumptions and Factors. Having collected this first set of assumed abilities, we continued to "question & correct" those assumptions by identifying enabling and disabling factors: external conditions that might influence each ability within its specific task-context frame.[13] Those factors were determined with regard to their respective task-context pair. Thus, we refrained from including *external* conditions set by these pairs. For instance, we found that any hand movement of the patient is likely to be hindered by cables or bandages (disabling) but can also be supported by a slight upright position of the patient, shifting the body in favor of hand movements while also moving the hand into the visual field, allowing for better hand-eye coordination (enabling). As an example of the patient's output task, we recognized that processing auditory information can be supported by repeated verbal communication from staff or relatives (enabling) but might also be hindered by surrounding noise, privacy concerns, or delirium (disabling). We assembled factors for each interaction medium and sensory channel. With regard to each task-context pair (see Figure 4), the more there were to consider the more challenging the model became. However, this paid off as it allowed us to capture situational dynamics and differences of one ability in varying contexts. For instance, caregivers processing auditory output when working in a patient's room can be disabled by the amount of surrounding noise from machines and alarms, which does not hold true for more quiet surroundings, such as the kitchen or hallway.

5.1.3 Open Questions and Next Steps. With the model so far focusing on motor abilities for input tasks and sensory abilities for output tasks, we point out that it lacks the consideration of cognition, that is, cognitive processes that take place during the defined tasks and impact the usability and understandability of the intended system. Just as for interaction mediums and sensory channels, these cognitive abilities should be defined and analyzed from the very beginning, extending the set of ability assumptions and requiring the consideration of enabling and disabling factors.

In addition, the factors modeled in this use case are confined to general, external factors. Specific influences—for instance, glasses or limited movements of the arm, finger, foot, hand, or head—have not yet been included but can be if the model were to be executed in more detail.

Following our proposed approach to conceptual user modeling for a communication system for weaning patients off ventilators and their caregivers offered a systematic overview of abilities

[13]Figure 4 depicts only factors for the role of the patient because listing all abilities with their enabling and disabling factors would have led to a confusingly cluttered visualization.

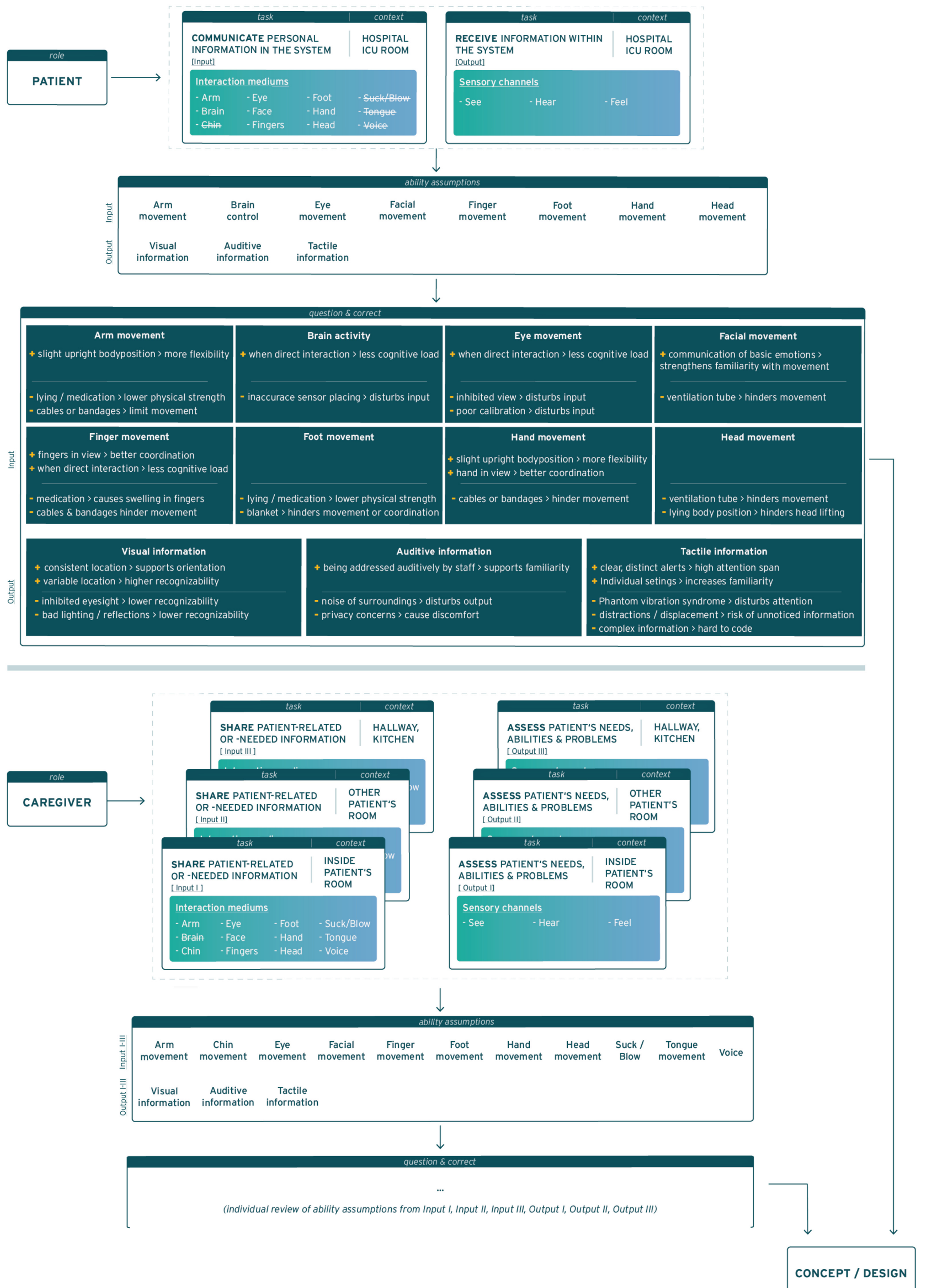

Fig. 4. The conceptual model created for *Use Case I*, designing a communication solution for patients weaning off ventilators, distinguishing between the functional roles of the patient and the caregiver.

relevant in this context. These insights can help project members to understand which abilities might be suitable under which circumstances. From here, successive concept and design phases can use the knowledge that we partially depicted in Figure 4 to either directly define specific interaction patterns and technology designs or iteratively pick up one or more of our modeled abilities, define subsets of them with respective to enabling and disabling factors, and achieve a more fine-grained analysis.

5.2 Use Case II: Travel Information for Sign Language Users

Traveling via public transit often involves changes in itinerary, delays, or other complications. As a result, correct real-time information is essential for travelers. However, often such information is communicated primarily through auditory channels, leaving Deaf and Hard of Hearing (DHH) individuals excluded. To address this concern, the *AVASAG* research project [13] is examining the development of an avatar-based system that automatically translates German text into German Sign Language with the goal of making real-time (travel) information accessible to sign language users [57, 76]. In this work, the ability-based identification of members of DHH communities [21, 22, 50, 54], who do not consider themselves disabled but rather as members of dedicated communities, each with its own culture and language, emphasizes the importance of pursuing an ability-based approach when designing technology for this target group. For this reason, an ability-based requirements analysis should reflect the user's perspective and help designers integrate this perspective into their work.

5.2.1 Role, Task, and Context. With the single functional role of the "traveler" defined for this use case, our conceptual model (Figure 5) focuses on the task of receiving information within traveling systems, which is why we included sensory channels based on prior work [14, 60, 78], but also included *language abilities*. This definition contrasts with our first use case as it moves away from what are commonly considered "basic" ability groups (i.e., sensory, motor, and cognitive) [14, 60, 78] and instead views abilities on a more holistic, contextualized level. In this way, our model defines five abilities for the traveler's task of receiving information, each focusing on a type of information design: graphic information (e.g., images or illustrations), tactile information (e.g., vibration patterns), signed information (e.g., German Sign Language), verbal-visual information (e.g., lip reading), and written information (e.g., text).

5.2.2 Assumptions and Factors. Again, to question our assumed abilities, we defined enabling and disabling factors for each assumption, for example, the disabling effect that long and nested sentences can have on the ability to understand written information, whereas short and structured text plus familiarity with the topic can serve as enabling factors. On the other hand, understanding signed information can be enabled by good Internet connections and adequate displaying of the signed content, whereas small screens, bad lighting conditions, or time pressure can disable this ability.

5.2.3 Open Questions and Next Steps. As with the patient and caregiver use case, in this use case, framing ability assumptions with the help of such enabling or disabling factors sharpened the understanding of what abilities a designer might rely on in a given environment. In contrast to the first case, which focused on interaction mediums and sensory channels, here we demonstrate the possibility of modeling cognition-related abilities, omitting interaction mediums. Extending the use case's scope to also include input tasks instead of just received output would certainly require this additional perspective, but was skipped for now for the sake of keeping the use case understandable.

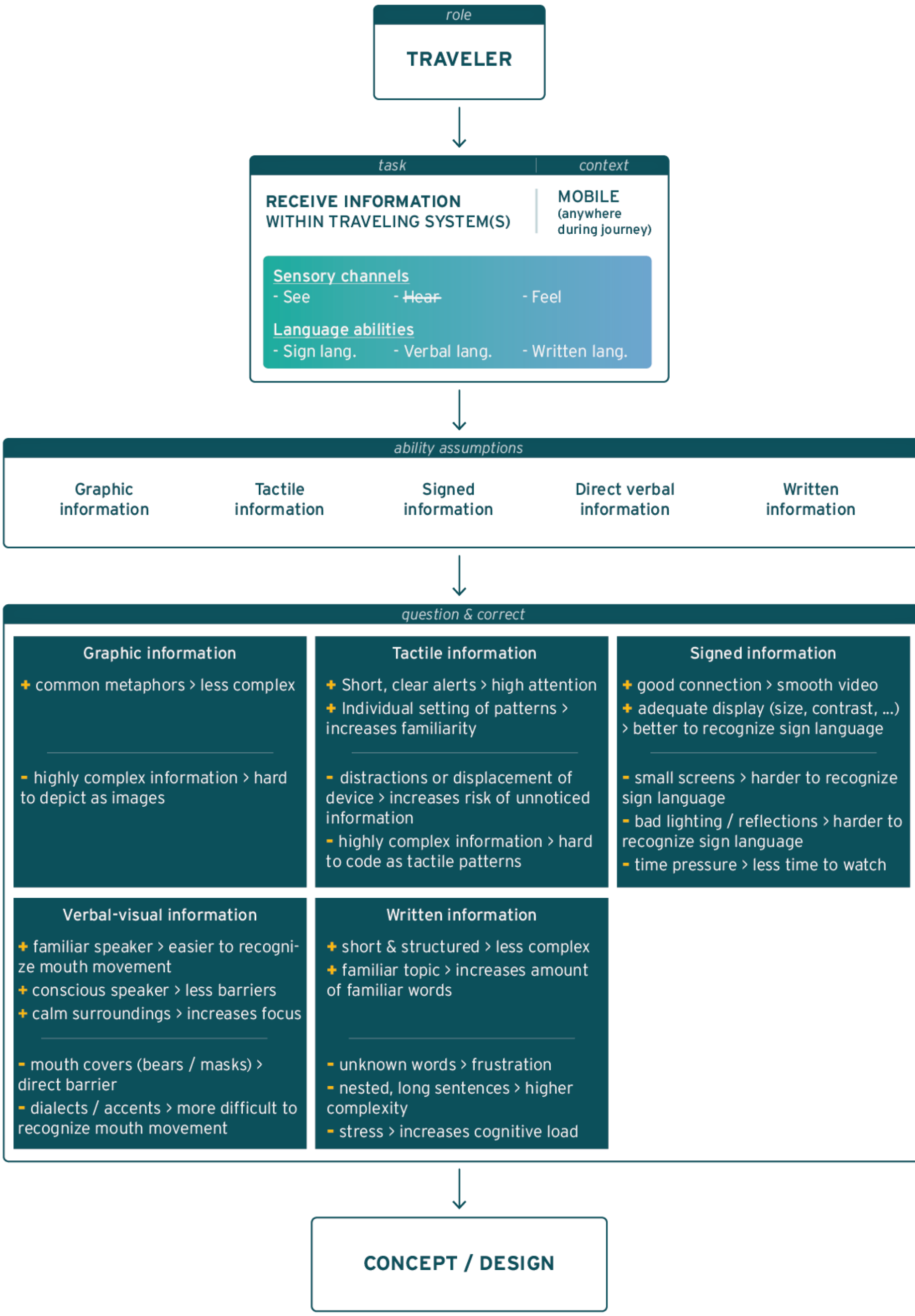

Fig. 5. The conceptual model created for *Use Case II* of designing travel information for sign language users.

5.3 Conclusion: Added Value and Challenges

Considering both use cases as example applications of our framework, we conclude that the second use case allows designers to distinguish between functional roles and identify task- and context-specific ability descriptions. Thus, in regard to the challenges of modeling abilities, as outlined in Section 4.1, our approach offers a way of handling dependencies between abilities, tasks, and contexts—with the resulting models referring not to single isolated entities but instead to a conglomerate of all three context-of-use elements. In addition, using the newly introduced phase of questioning and correcting ability assumptions to define enabling and disabling factors addresses another modeling challenge, that of highly dynamic abilities. Recognizing and listing these factors per ability acknowledges this dynamic and can help gain a better understanding of the "behavior" and availability of abilities that technology design might address—it helps designers (1) to identify suitable abilities to rely on in the design, and (2) to understand what contextual conditions should be supported and avoided in order to make the design even more accessible. This final modeling activity lays an important foundation for successive design work.

In terms of applying the approach for real requirements analysis in future projects, more and detailed knowledge of each role should lead to more accurate and detailed descriptions of tasks, contexts, and enabling and disabling factors. The use cases helped emphasize this scalability, demonstrating that our approach offers guidance and structure, but also allows for individual adjustments and interpretation when being executed, as any framework or tool should. In this way, it can be used for modeling broader groups of people, as done in both use cases. It also provides opportunities to create more individual models in which external factors might be extended by individual ones, integrating a single user's own perspectives, behaviors, or traits. With this adjustability, the approach also addresses the modeling challenge of variable fidelity in abilities. Although it does not solve the issue, the approach still allows for a project-specific selection and definition of abilities when assembling the abilities for each task-context pair. This is demonstrated by the differences in the two use cases—with the first referring to the more basic motor and sensory abilities, whereas the second considers more complex language abilities.[14]

In conclusion, both use cases have demonstrated that our approach does not pursue the ambition of suggesting final designs or concepts. Instead, it helps motivate and inform discussions among designers while also sharpening the view of assumed abilities.

6 DISCUSSION

Practically implementing ABD requires a fundamental understanding of how to describe and model users in view of their abilities. The accurate modeling of abilities is highlighted by Wobbrock et al. [80, 82] as one of the main priorities for future work in ABD. If this attention to abilities can be achieved and abilities are considered by designers in the early conceptual phases of system development processes, resulting systems should be more accommodating to users' abilities. Therefore, conceptually modeling the user in ABD should no longer be about only preferences, demographics, or attitudes. It should center on what the user is able to do and the contexts in which the user is able to do it.

In this work, we have addressed the matter of user modeling in ABD not only through an in-depth analysis of both core topics (conceptual user models and ABD) in terms of their compatibility but also by creating a systematic structure for an ability-based requirements analysis and applying it in two exemplified use cases. Our main argument and contribution here lies in the understanding of the highly contextualized nature of abilities, which requires any systematic ability-based construct to shift the focus from considering isolated entities to examining the integrated relations among users, tasks, and contexts. Current modeling practices fall short in this regard; we highlight and attempt to meet the need for a novel method for creating conceptual user models in ABD. Similar to the now widely practiced iterative user-centered design process [26, 38], achieving

[14]Using the terms "basic" and "complex" in this context refers to the notion that language abilities in themselves require sensory and cognitive abilities and, thus, can be considered more nested than basic motor abilities.

a standardized methodology for ABD would not only make variations of the practice comparable, it would also allow for the development of best practices and guidelines.

The understanding of abilities as being definable only in direct relation to a specific task and context brings us further in our development of ABD by showing that the practice of ABD would not just have to cover the area of conceptual user modeling but also that of task and context modeling, that is, all context-of-use entities examined in common requirements analysis [53]. Therefore, we must not only define ways and methods for modeling abilities but also for the entire requirements analysis in itself—a challenge that increases the already high complexity of the matter.

With our concept for an ability-based requirements analysis, we were able to outline a first idea of how to consider the dependency defining the relationship between abilities, tasks, and contexts. As such, we believe that our approach allows us, on one hand, to gain insight into possible ability-based modifications to current requirements analyses and their benefits, while highlighting, on the other hand, remaining limitations, barriers, and their consequences. However, it needs to be emphasized that this proposed approach still raises a variety of open questions and challenges—in particular that of evaluating the approach itself in terms of applicability and impact. This article presents a first idea of defining a context-independent methodology for ABD—an idea that needs to be complemented and consolidated with further evaluative work throughout future research.

7 FUTURE WORK

The original article describing Ability-Based Design [82] highlighted not only ABD's potential but also the research challenges that need to be solved to "make the universal application of 'design-for-one' a reality" (p. 9:19). Wobbrock et al. call for future studies to elaborate on the automatic detection and understanding of abilities as well as performance measurements, accurately sensing context, modeling abilities and integrating it all into working designs. They thereby lay the groundwork for years of future research. Our work takes up one of those original challenges: the modeling of abilities, integrating it into extant user modeling and requirements analyses approaches [53]. To highlight opportunities for future work, we now describe some of the remaining challenges *within* ability modeling.

Analyzing the ways in which user abilities can be effectively resolved is an important step within ABD, as it directly influences the possibilities for conceptual user modeling and the entire development process. It should be considered within future research as a basic condition for any modeling procedure within ABD.

Further, we emphasize the need for future studies to find ways of addressing individual abilities so that designers can avoid making certain specific ability assumptions. Although our approach offers ways of describing and including individual enabling and disabling factors, the essential challenge of creating individual designs while maintaining a feasible procedure for a broad practical implementation remains—the definition of a Design-for-One procedure [30] that is applicable to both small and discretionary large and diverse target groups. Following our proposed approach, after having defined individual influences on assumed abilities, research needs to find ways for addressing such individualities within feasible designs and for mapping the actual user to the best-suited design. This challenge should be extensively studied in the future in order to identify obstacles and potential approaches.

As already indicated earlier, future work should also analyze and evaluate the approach in terms of its broad applicability and impact. For this, studies should compare the results of applying the proposed approach with those of working with a common requirements analysis approach to determine whether it actually brings forth an improvement of applying ABD when designing and developing technology. Conducting such a comparison requires that the defined procedure is carried out by professional designers across several application scenarios to understand whether it can be used within actual design projects.

We also need to find ways of comparing design concepts such as ABD to others and evaluate their impact, strengths, and weaknesses. This will require a novel definition of metrics by which a design and its level of accessibility can be judged. To date, user-centered design has developed multiple methods for evaluating designs regarding their usability [11], performance [31, 32], experience [74], and other aspects, while lacking ways of evaluating the impact of more abstract factors such as design concepts, designer mindsets, or designerly stances. Further, with design itself being subjective in both theory and practice, the challenge lies not only in making design measurable but also in defining studies that allow for the comparison of outcomes from ABD versus no ABD. Comparative design studies have been conducted (e.g., [73]), of course, but remain relatively rare and challenging. Answers to these questions offer potential not only for the evaluation of ABD but also for related methods such as User-Centered Design [26], Inclusive Design [47, 56], and Universal Design [51] and, therefore, should be emphasized in future work. At the same time, this pursuit poses the most complexity, as it requires for each concept under inspection a precise and distinct definition for evaluation.

8 CONCLUSION

This work presents a first approach to characterizing user modeling in Ability-Based Design (ABD) in a systematic way that considers the relations between tasks, contexts, and abilities on a general level apart from any specific project. With ABD's central claim of focusing on abilities rather than disabilities when designing accessible systems, it is the perception and modeling of users that sets the concept apart from other approaches. Consequently, any characterization of ABD must primarily address this matter and find ways to formulate sufficient descriptions of user populations and their requirements based on individual abilities. This article reasons about the necessity of methodological specifications for ABD, demonstrating not only the need for ability models instead of user models but also discussing the interdependency between abilities, tasks, and contexts as a main characteristic of abilities. Our findings reveal that in order to model abilities, we must find ways of capturing the relations between abilities, tasks, and contexts instead of approaching these entities separately—a requirement that current modeling techniques do not meet. With our concept of a novel, ability-based user modeling approach, we examine the possibility of defining a new procedure by adapting previous ones—a strategy that identifies promising touch points while also revealing complexities and barriers that need further research effort.

With this work, we hope to call attention to the need for a systematic ABD methodology that can be applied in a broad, practical manner. We agree that a shift in the focus from disabilities to abilities, as required by ABD, offers a promising approach to accessible design. However, as this articlr argues, in order to realize such a shift in focus, we need a solid methodological foundation that provides a global perspective on exercising ABD. If achieved, the impact of ABD can grow decisively in regard to the establishment of broadly accessible systems and push current practices and techniques increasingly toward Design-for One [30, 80, 82]. With our presented approach, we hope to contribute to strengthening ABD in its practical feasibility and shift the focus in research and design from universally valid user modeling techniques toward acknowledging human diversity as a promising resource for the development of technology.

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