How Engineers' Imaginaries of Healthcare Shape Design and User Engagement: A Case Study of a Robotics Initiative for Geriatric Healthcare AI Applications

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In the development of robotics and Artificial Intelligence (AI) for healthcare, human-centered approaches seek to meet the requirements of healthcare practice and address social and ethical aspects proactively. In this work, an important but neglected aspect of human-computer interaction (HCI) is how engineers understand and envision the healthcare context. Drawing on insights from STS on engineers' imaginaries and their role in shaping research and development of new technologies, we propose engineers' imaginaries of healthcare as a point of analysis and intervention for ethical and social aspects of AI and robotics for healthcare. To illustrate the utility of this lens, we use it to on report a case study of an engineering project that develops robotic and AI applications for healthcare. We followed and sought to advance an embedded ethics and social science approach, where ethicists and social scientists accompanied this engineering project using direct interdisciplinary collaboration, observations, and in-depth qualitative interviews with the project's engineers (n = 18). We analyze how the engineers imagine healthcare as an environment for robots, healthcare workers as potential users, and healthcare practices, and how these imaginaries connect to the design narratives that guide their work. Our findings provide pertinent input for HCI, STS, and engineering ethics related to healthcare AI and robotics, as they speak to prevalent narratives of "assistance" systems, aspects of how human healthcare practices are reframed and valued in the face of new technologies, questions of division of labor between machines and healthcare practitioners, and the implications of 'acceptance' as a frame for user-centered design.

CCS Concepts: • **Human-centered computing** → **Empirical studies in interaction design**; • **Social and professional topics** → *Codes of ethics;*

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1 INTRODUCTION

Healthcare has become an increasingly important field of application for robotics and **Artificial Intelligence** (**AI**),[1] making it an interesting object of study for **human-computer interaction** (**HCI**) and **science and technology studies** (**STS**) research [2]. As robotics and healthcare converge, challenges emerge regarding how to meet the requirements of healthcare practice. To address these challenges, many engineering and HCI projects tout a "human-centered" AI/robotics approach for design and implementation processes. While HCI would traditionally ask questions like "How can we build better, human-centered healthcare AI?" [cf. e.g., 2, 3], we take a step back and ask, "How is human-centered healthcare AI enacted in particular engineering practices and discourses?" In doing so, we aim at broadening HCI approaches to AI and health [2] and contribute to a practice perspective that has been gaining salience in HCI [45] and ethics in HCI [10]. In particular, we present an exploratory case study of engineers' *imaginative* practices and their role in shaping development trajectories [32] in a research project on robotics for healthcare. In the absence of complete information, engineers find themselves in a prefiguring position, as they need to develop an idea of the application contexts and users whenever they develop new systems [1, 26, 67]. We argue that engineers' perception of healthcare and its future(s), their anticipation of healthcare worker and patient behavior, and their vision of how their products might fulfill these needs shape how engineers approach healthcare AI and robotics applications. We illustrate the importance of imaginative work in HCI research [22] through a case study of the Geriatronics project, a multi-disciplinary academic engineering project focused on healthcare in older adulthood using care-assistance systems [28]. We trace the Geriatronics engineers' visions and understandings of healthcare. How do they imagine healthcare? And how do their imaginaries shape their design and development of systems?

Our study follows an embedded ethics and social science approach [56], where social and ethical analyses were integrated into the Geriatronics project. This article presents findings from a qualitative interpretive analysis of participant observations and in-depth interviews with 18 engineers of diverse disciplinary backgrounds such as mechanical, biomedical, and human factors engineering. We show how these engineers imagine healthcare as an environment for robots, healthcare workers as potential users, and their practices. As we focus on the engineers' perspectives on *healthcare workers* and their practices, we present novel research in the study of application context and user representations in healthcare robotics and AI, which has so far largely focused on engineers' representations of patients and elderly users [5, 65, 66, 71]. We use an empirical bottom-up approach to

[1]We understand robotics and AI as related fields which deal with the design, development, and implementation of intelligent machines [34]. While robotics is primarily concerned with the hardware implementation of embodied intelligent systems and their interaction with the physical world, AI is more concerned with the efficient computational processing of (sensor) data, synthesizing and inferring of information via machine learning techniques, used for example for machine perception, algorithmic decision-making, navigation, and action planning. Together, these fields are driving the development of intelligent machines that are able to perform a wide range of tasks and operate within complex socio-technical environments.

study engineers' imaginaries of healthcare; revisit HCI concepts of user-centered design, user acceptance, and shared decision-making; and show how these concepts are used in research activities such as design choice and engagement with prospective users. Imagined features and applications of robots covered in this article involve anthropomorphic hands as end effectors for robot arms for the manipulation of objects in human environments; automated ancillary care tasks; human digital twins to facilitate personalized robot-assisted limb rehabilitation and to aid health monitoring, diagnostics, and medical decision making; and social interactiveness of a humanoid service robot.

To grasp the Geriatronics engineers' conceptions and visions of healthcare, we use "imaginaries" as a lens that encourages us to explore the implications and tensions found in discursive and material practices in engineering [57]. Drawing on STS concepts of imaginaries [32, 40, 53, 57], we argue that engineers, when attempting to create human-centered AI and robotics for healthcare, do so with certain views on the world, ethics, and (care) relationships in mind [87]. They may or may not be aware of the specific social orders and relationships of care that their technological creations enable. Our analysis aims at revealing implicit understandings and normative commitments behind the engineering endeavors we observed. It invites reflections on how engineers' work frames future scenarios for use [26] and, upon implementation, inscribes certain values and procedures into healthcare practice [1, 96]. By presenting the futures that certain engineers invest their efforts in, we facilitate reflections that go beyond technological functionalities, which existing debates in both engineering and ethics have often been limited to [87, 88]. Thus, our healthcare imaginaries-focused approach can be understood as a contribution to care-centered, value-sensitive design [90] and embedded ethics and social science [56].

We see healthcare robotics and AI as a particularly promising area for empirically investigating this connection between imaginative and engineering practices because the field actively strives to collaborate with healthcare practitioners and establishes direct pathways for implementing the systems it develops [2]. In healthcare robotics, researchers tout the use of AI as a means to provide assistance in care tasks. AI promises to make predictions even in "the wildness of the daily life in healthcare," an environment that is considered much messier than what is seen in industrial robotics [87, p. 157]. Much is at stake if the promises of healthcare robotics and AI are actualized. Robotics and AI may monitor, diagnose, interact with, and document the health of patients. They may bring about groundbreaking shifts in healthcare ranging from work practices, education, and healthcare practitioner competence to the allocation of resources and responsibilities [92]. Yet, the challenges arising from novel divisions of labor between humans and intelligent machines need to be addressed proactively if robotics and AI are to be implemented into healthcare.

2 BACKGROUND: ENGINEERS' IMAGINARIES OF APPLICATION CONTEXTS

We aim at contributing to the research landscape at the intersection of engineering, HCI, medical and technology ethics, and STS. We utilize a practice perspective that marks a "practice turn" in the social sciences [74] and which has been called for across HCI communities [38, 45, 70, 77]. To build a theoretical frame that allows us to analyze the situated imaginative practices involved in an engineering project, we draw from a rich body of STS research that has shown that imagination and envisioning of the future play a significant role in research and technology development [32, 53, 55, 57, 75].

We use imaginaries as a lens [57] to grasp the engineers' conceptions and visions of healthcare. Imaginaries mark socially and culturally embedded patterns of visionary thought that have an effect on wider social processes [57]. In the words of Smith [2009]: "the imaginaries concept suggests that the world has been consequentially envisioned in certain ways at certain moments in time by actors who have the capacity to materialize these [visions]" [79]. The imaginaries constructed by the actors we are interested in here, i.e., engineers, have been studied under the framework of "technoscientific imaginaries" [53]. These encompass the reflective, visionary thoughts of scientists and engineers on the future that will be realized by their technoscientific innovations [53]. While future-oriented in nature, these imaginaries are constrained by the very present conditions of work in engineering and science. They draw from, respond to, and hold tensions between specific scientific practices and discourses [4, 53]. Imaginaries are comprised of discursive elements such as cultural references, stories, images, myths, and metaphors, which give insight into local understandings of sociotechnical changes [57]. Analyzing them allows us to explore how engineers understand healthcare and envision its future possibilities as manifested through the robots they develop. To open up imaginaries for debate and critical intervention, it is important to consider their normativity, performativity, and sociocultural dimension.

Normativity. Imaginaries have a normative dimension, making them an important locus of insight and intervention into the politics and ethics of innovation in HCI [54, 81]. As Jasanoff and Kim [2015] write, "imaginaries not only help to reconfigure actors' sense of the possible spaces of action but also their sense of the rightness of action" [40, p. 23]. They legitimize the pursuit of certain research goals and can influence engineers' motivations and sense of responsibility for their work. For example, a study has shown that understandings of ethical issues related to human-robot interactions have been influenced by mythical imaginations around the figure of the robot [59]. Mudry and colleagues [2008] argue that such imaginations shape "our motivations as roboticists and our inherent representation of a desirable society" [59, p. 568]. These representations, in turn, guide the work of engineers. They have certain views about the world, ethics, social interdependencies, and care relationships in mind when they design robot functionalities and appearances [1, 87].

Engineers' views influence their technological artifacts and scientific outputs, which in turn can be seen as "matters of care" [18]. This concept invites us to understand the engineers' prototypes and publications as situated and relational expressions of their commitments to actively engage in changing the sociotechnical assemblages in and through which healthcare is done. It emphasizes the deeply ethical and affective dimension of technological artifacts and scientific knowledge [18]. This perspective has been embraced in HCI approaches of "research through design," which use design interventions to work through complex and contested issues related to various aspects of everyday life [99], in some cases with explicit reference to the concept of matters of care [e.g., 19, 80]. This literature emphasizes that, through their creations, engineers enable specific social orders and relationships that they care about and which are rooted in their imaginaries.

It is for this reason that Vallès-Peris and Domènech [2020] have proclaimed imaginaries of care to be relevant issues for ethical debate regarding care robots [87]. In a recent study, which interviewed roboticists, they looked at two imaginaries of care in particular: one tied to AI and one to human-robot collaboration. They found that, in conceiving of and describing their robots, roboticists take examples and metaphors from industrial settings and translate industrial logics into care contexts. They show how AI-enabled care robots are portrayed as "rational agents" through which the "wild" and unpredictable range of care tasks and care relations that humans have can be rationalized, automated, and optimized to reduce uncertainty and inefficiencies in the care process. By instilling logics of rationality, predictability, and efficiency as positive imaginaries into care, care robotics contributes to a "process of care fragmentation" [87, p. 15]: care becomes conceptualized as a set of tasks that can be broken down into pieces made of smaller tasks, with some of those pieces being delegated to robots and others not. The differentiation of care tasks is performed by sorting them into two categories of hierarchical moral value: emotional, conversational, and affective caring (considered as valuable and to be done by humans); and the physical—heavy, dirty, or dull—work of caring (considered less valuable and to be done by robots). Vallès-Peris and Domènech [87, p. 15] conclude that these fragmentation processes implied in the imaginaries of the roboticists stand in stark tension with an "ethics of care" which represents a more holistic view on the concept of care that has been gaining importance in healthcare [86], the social sciences [94], and the design of healthcare robotics [91].

Performativity. Imaginaries are both performed (they are an effect) and performative (they have an effect). They are performed in the sense that they are enacted in various acts of sense-making and anticipation [25]. Engineers' imaginative worlds are entangled with and enacted through their research activities, as has been shown by a range of STS studies. Fischer and colleagues [2020] trace how robotics engineers enact user representations [26]. These engineers, by way of their everyday activities, draw up a certain implicit "user image landscape," a terrain of representations of users that are conceivable and perceptible to the engineers [26, p. 16]. Fischer and colleagues identify four such "image-evoking activities" [26, p. 16]: designing robots to be human-like, expanding technological possibilities, demarcating their proficiency, and universalizing the applicability of their technological creations. The concept of image-evoking activities sensitizes us to see imaginaries as co-constituted with everyday activities in robotics labs. It invites us to take into account how imaginaries' "components resonate with the tools and machines engineers and designers are working with, existing prototypes and technologies, their vocabulary and grammar, their biographies, circulating stories, dreams and ambitions" [26, p. 18]. Other descriptions of how imaginaries are performed come from analyses of engineers' work as practices of "visioneering" [55, 75], which are concerned with the future-facing elements of engineers' imaginaries. As a compound term, visioneering invites attention to the hybridity of engineers' work: Practices of visioneering are hybrid imaginative and technological efforts comprised of both envisioning futures and actively pursuing them by engineering novel technologies [55].

The perspective of performativity also sensitizes us to see engineers' imaginaries of healthcare as co-constituted with design narratives and choices as well as material practices and achievements in the development of healthcare robots and AI. In other words, imaginaries are performative, namely to the extent that they have an effect on engineering and design practices and, concomitantly, form and change innovation trajectories and sociotechnical futures [32, 43]. In designing and developing technologies, engineers build their visions and values into their creations [1, 93].

Related arguments about the performativity of engineers' imaginaries can be drawn from material-semiotic approaches, which have been developed most explicitly within feminist STS [35, 83] and have been taken up in HCI [e.g., 82]. They emphasize "the intimate connections of available cultural imaginaries within the possibilities materialized in technologies" [84, p. 153]. Imaginations of what healthcare looks like, or should look like, influence engineers' design choices. In turn, their research renders real specific worlds that resonate with the engineers' visions [12, 35]. Part of our analytical engagement is predicated upon this awareness of the "circuits" between the imaginative and the material [12], i.e., between the stated visions, promissory announcements, and wider cultural imaginaries tied to AI and robotics and the actual engineering achievements of healthcare robotics and AI. This brings us to the sociocultural dimension of engineers' imaginaries.

Sociocultural dimension. Because their practices and discourses are embedded in wider cultural and political contexts [32, 53], engineers draw from and contribute to the discourse circulating in policy, media, and the public arena [23]. This is where "technoscientific imaginaries," which are enacted by scientists and engineers [53], intersect with "sociotechnical imaginaries," which encompass institutionally stabilized visions of collectives such as nation-states [40]. A few analyses have focused on this sociocultural dimension of imaginaries related to healthcare [e.g., 49, 51, 66, 72]. Notable mentions are Lipp [2019] and Maibaum and colleagues [2021], who analyze the "discoursive "logics" of care robotics" [51, p. 1]. They argue that themes emerging from discourses in policy and care organization—such as consumerist care economies, active and healthy aging, independent living, and the nursing crisis—constitute the conditions within which care becomes constructed as a problem plausibly solved by robotics [51]. This line of inquiry invites us to widen our view when interpreting the narratives and scenarios articulated in engineering projects by holding them up against their political and sociocultural background.

Intervention. On a practical level, imaginaries have provided a framework for intervention [e.g., 41, 88]. The creative potency of imaginative practice in the development of new technologies has been recognized in HCI. Dourish [2006], reflecting on ethnographic approaches within HCI, contends that their "power lies in the ethnographic *imagination*" [21, p. 547, our emphasis] and that those analytic contributions that "provide us with new ways of imagining the relationship between people and technology" are those that can have particularly subtle but profound implications for design and even (re)shape research strategies [21, p. 548f]. Imaginations have further been explored as opportunities for intervention into HCI research in design futuring [e.g., 43], design fiction [e.g., 82], and other speculative design approaches [e.g., 16, 42, 68], value-sensitive design [e.g., 31, 64], and critical design [e.g., 7, 54]. As of yet, healthcare domain-specific imaginaries have barely been examined as points of intervention in HCI research. Notable exceptions are approaches that, in "seek[ing] to challenge our "sociotechnical imaginations,"" [41, p. 244], center the lived experience of health as an alternative design frame through which HCI researchers imagine new technologies [e.g., 41, 52, 69]. Other HCI studies of care robotics have incidentally, as part of their participatory or ethnographic approaches, called for "reframing" assistive robots [47, p. 1], "rethinking" the very concept of HRI in care [38, p. 9], or "co-creating futures of care with older adults" through "care-ful approaches" [95, p. 1, 3], but have not made imaginaries their central focus. We take on this task of unraveling the imaginaries of healthcare to make them tangible points for intervention as part of the approach we propose for interdisciplinary HCI research.

3 STUDY DESIGN AND METHODS

We follow and seek to advance an embedded ethics and social science approach [56], in which ethical, social, legal, and political analyses constitute integral elements of a product design process as well as in its field implementation. The study we report on here is from the early phases of our project focused on understanding and analyzing our case. We employed a qualitative, inductive, and interpretivist study design, following a grounded theory approach [13] utilizing an iterative process for data collection and analysis. This served the explorative purpose of unpacking healthcare imaginaries as they are being articulated and enacted by engineers in an ongoing robotics project, the Lighthouse Initiative Geriatronics.

3.1 Case Description: Lighthouse Initiative Geriatronics

The Lighthouse Initiative Geriatronics [28], based in Bavaria, Germany, was launched in 2018. Geriatronics, as defined by the Initiative, is

> the use of robotics, mechatronics, and information technology, in particular machine intelligence and 3D technology, in geriatrics, gerontology, and in the medical care of elderly people for optimal support and for the maintenance and improvement of self-determination in old age. [28]

The Initiative is an interdisciplinary, academic research project that involves a number of university departments, bringing together different engineering disciplines (e.g., robotics, machine intelligence, and biomedical engineering). Our participant sample, the full set of the 18 PhD and postdoc-level engineers of the Geriatronics Initiative, constitute a suitable empirical starting point for studying and advancing STS conceptualizations of engineers' imaginaries. Our understanding of "engineers" is derived from STS studies that have focused on the imaginaries of those who work in the development of technological artifacts and scientific knowledge production [32, 53, e.g.,]. These include a broad range of scientific and development practices. Our case suits this broader definition of engineers well because our participants are involved in both these activities:

They are part of an academic initiative, researching particular problems that are important to their respective scientific communities, but they also strive, and are expected by their funders, to lay the groundwork for the development of viable robots that can eventually be implemented into everyday healthcare [50]. While being situated in a specific research location, the Geriatronics engineers have heterogeneous disciplinary backgrounds; they mobilize specific discourses as they position themselves in the field, reflecting parts of the diverse and multi-faceted field of engineering and robotics research. Four of our participants have backgrounds in mechanical engineering, three in robotics, three in computer science, three in electrical engineering, two in mechatronics, two in biomedical engineering, and one in human factors engineering. They represent an international sample with 61% non-German nationals—a number that reflects the high degree of internationalization in engineering fields [39].

The Initiative's aspirations range across different application settings (people's homes, assisted living, nursing homes, hospitals), user groups (older adults/patients, physicians, physiotherapists, nurses), and products (humanoid assistance robots, rehabilitation robots, telemedicine stations), thus providing us a broad insight into different facets of the intersection between healthcare and robotics and AI. The Initiative's flagship project is GARMI, a humanoid service robot developed as a research platform to integrate a range of applications that provide interfaces for telemedicine, emergency assistance, and remote rehabilitation and diagnostics [85].

The Geriatronics case also serves our interest in investigating notions of human-centeredness. Human-centered and user-centered design terminology proliferates in engineering. However, there is a difference between how much knowledge about these approaches is present in different projects and how this research is conducted in practice. The Geriatronics Initiative, too, draws on this discourse, explicitly aiming at doing "target-oriented human-centered research" [27]. It thus gives us the opportunity to see how notions of human- and user-centeredness are enacted in situated practice—in a particular university research project animated by technical questions relevant to academic publishing in robotics, yet faced with high expectations for impact in healthcare. Another key part of the Initiative is its collaboration with researchers from the social sciences and ethics, from which the present study arises.

3.2 The Embedded Ethics and Social Science Approach

Thorough, long-term integration of social science, ethics, and engineering work lies at the core of our embedded ethics and social science approach. It draws on earlier work on "embedded ethics", which denotes "the practice of integrating the consideration of social, ethical and legal issues into the entire development process in a deeply integrated, collaborative and interdisciplinary way" [56, p. 1]. Our interdisciplinary research team, with backgrounds in STS and medical ethics, is united by an interest in the complex social and ethical challenges that arise in the development and implementation of robotics and AI for healthcare. In concert with research in engineering, we study new technologies as they are being researched, developed, and implemented in healthcare practices from a social scientific perspective. Prospectively, we aim at building practical tools and interventions, such as workshops and a toolbox for social and ethical guidance, that help to address particular aspects arising from our collaborations. Note, however, that material for the present study was gathered in early project phases dedicated to understanding our field and did not include dedicated interventions yet.

We aim at encouraging ethicists, social scientists, and engineers to "think more like partners in a team" [89, p. 311] and to inspire reflexivity. This includes reflexivity about our role and positionality in the team. The authors are STS and ethics researchers, which makes us particularly inclined to incorporate these fields into larger research projects. The pursued embeddedness, and the ensuing collegial relationship with the project's engineers, which are at the same time our study participants, gives us special access and insight into the perspectives and practices of these engineers. We ultimately aim for the interdisciplinary co-designing of healthcare robotics and AI applications, where ethical, social, legal, and political analyses constitute integral elements of design processes and workplace integration.

3.3 Data Collection

The present study is based on participant observations and qualitative interviews. Between April 2020 and September 2021, we conducted fieldwork at the Geriatronics Initiative, as overt, sometimes participating, sometimes non-participating observers [11] and kept detailed field notes of our observations. Following a grounded theory approach, we entered the Geriatronics project with a high degree of openness to possible lines of inquiry. As embedded ethics and social science researchers, we familiarized ourselves with the details of the technical tasks in site visits at robotics labs and online meetings. Due to Covid-19 restrictions, our access to the labs was limited to a total of 11 visits. SB was in all of these visits, in most of them together with MB or DT or both. Each visit consisted of between 2–8 hours of fieldwork. In some visits, the engineers showed us around in their labs and a showcase apartment, showed us what they are working on, demonstrated prototypes, and allowed us to try out some of them ourselves. In other visits, we accompanied user tests and engagement activities as non-participating observers, where our engineering colleagues guided physicians, visiting students, and other interested volunteers through interactions with prototypes. Additionally, we attended online talks and Q&As, directed toward an interested public. During this pandemic time, much of the communication within Geriatronics was moved online, allowing us to access meetings via video conferencing services. We regularly participated in milestone meetings, where teams reported to their funders; integration meetings, where engineers discussed their work across different subprojects; and sprint meetings, where subprojects were discussed internally. In these meetings, we observed, participated in discussions, sometimes presented our own work, and received feedback. We were also added to the Geriatronics mailing lists, slack channel, and notion workspace, and followed discussions there, and had occasional exchanges of e-mails and slack messages. These regular interactions created a safe atmosphere and opened up opportunities for informal exchanges on ethical and social questions as they arose in the Initiative.

This broad range of observation sites allowed us to see how our colleagues from engineering articulate visions and design narratives on various levels and to multiple audiences. As we compared different incidents of how they describe their work, we were struck by the general salience of articulations of healthcare futures with robots. We followed this line of inquiry, which we later conceptualized as engineers' imaginaries of healthcare robotics. In that line, SB concentrated her observations on user representations, use scenarios, design decisions, and the rationales for them, as well as the stories about healthcare and robots told to stakeholders outside the project. Regular exchanges among SB, MB, and DT about their observations, over time, helped sharpen the observational and analytical focus on representations of healthcare.

To complement our data from the fieldwork, SB, MB, and DT conducted in-depth semi-structured qualitative interviews with the Geriatronics engineers. For the interviewing method, we adapted the reflexive peer-to-peer interview [61] to our purposes, affirming the collegial relationship between ethicists, social scientists, and engineers. Interviewers and interviewees were peers; they were often both PhD candidates in research projects, sharing certain experiences and ambitions. This peer-to-peer relationship allowed for a conversational style of interviewing and created an intimate and safe atmosphere that allowed engineers to reflect on the societal relevance of their own work and ensuing questions of responsibility. At the same time, this relationship is prone to create certain silences in the interview, when aspects known to both parties go unspoken because they are taken for granted, and some statements remain unexplained because their meaning is assumed to be shared by both [60]. Cognizant of the benefits and potential problems of this method, we tried to stay sensitive to them as we conducted and analyzed the interviews. We tried to minimize silences by asking for explanations whenever we were told "you know how that is".

For the structure of the interviews, we followed Müller and Kenney [2014] [61] and asked the engineers about their scientific biographies, career motivations, and current research practices and their epistemic and social aspects. In the next part of the interview, we asked them to "zoom-out" and think about the wider societal implications their work may entail. Thus, the interviewer and interviewee acted as academic peers engaged in the joint (re)construction of knowledge about the values, experiences, emotions, and rationales that guide researchers' practices [61]. We conducted interviews with 18 Geriatronics engineers, differing in gender, country of origin, field of research, disciplinary background (see Section 3.1), and career stage (15 PhD candidates, 3 postdocs). The interviews were 66 to 130 minutes long. They were audio-recorded, fully transcribed, and pseudonymized. Depending on the preference of the interviewee, the interview was held in English or German. For the purposes of this article, direct quotes from the German interviews were translated into English.

3.4 Analysis

We employed a grounded theory approach, aiming to inductively develop a theory out of close empirical observations [13]. Adopting a practice-theoretical view [74], we treated the engineers' imaginaries as emergent in their discursive and material practices. We reconstructed imaginaries from our observations of those practices in the interviews, online meetings, and lab visits. Our analytical process involved repeated rounds of open, focused, and theoretical coding as well as integrative memo writing [13] and was aided by MaxQDA software. In ongoing meetings, SB, MB, DT, and RM discussed our coding and interpretations of the material.

Engineers' imaginaries of healthcare emerged as a sensitizing concept in the earlier stages of our analysis. In the initial coding, we noticed that the engineers often made sense of their research by drawing from application-facing themes of elderly care, rehabilitation, and telemedicine, indicating the importance of their understandings of these healthcare contexts. Our scholarly background primed us to explore these understandings through the lens of imaginaries, which is widely used in STS [57]. Adopting a stance of theoretical agnosticism [37], we rigorously scrutinized the fit between the concept and our empirical data [13, 15]. Throughout focused and theoretical coding phases, the imaginaries concept earned its way into our analysis: We found our engineer colleagues' understandings to be pronouncedly future-oriented, normative, performative, and contingent on a wider sociocultural context, and thus well represented through, and relevant to, STS concepts of engineers' imaginaries. Thus following a constructionist approach to grounded theory [14], part of establishing reconstructions of engineers' imaginaries of healthcare was to connect our empirical observations with existing literature on imaginaries, healthcare, and HCI—especially their intersection, as reviewed above.

We define engineers' imaginaries of healthcare as understandings, ideas, and visions of healthcare—including the multitude of the domain's specific sites, material arrangements, practitioners, and their practices—that are held by engineers and enacted as part of their work. Accordingly, we used the following questions to guide further focused coding and interpretation: How do engineers imagine healthcare as an environment for their systems? How do they imagine healthcare workers as users? How do they imagine the healthcare practices their systems should contribute to? And finally, how do these imaginaries shape the design and development of their systems? Corresponding to these questions, codes of the Geriatronics engineers' imaginative practices regarding healthcare were gathered into the categories of "imagining healthcare as an environment", "imagining healthcare workers", and "imagining healthcare practices". In theoretical coding phases, we drew out the relationship of these categories to another set of categories: those of particular design narratives and user test approaches for Geriatronics prototypes, like "emulating human skills", or "emphasizing user acceptance".

A central conceptual feature that thus emerged from our theoretical, integrative coding and memo-writing [13] was the interweaving of two analytical layers: engineers' design choices and everyday work practices in technology development and user testing, on the one hand; and their understandings of and visions for healthcare, on the other. This combination, we suggest, is crucial for understanding HCI engineering as a set of hybrid imaginative, social, and technological practices, and opens a new outlook on the motivations, concerns, challenges, and contextualized practices of reasoning of engineers.

Comparisons between different design narratives and use scenarios enabled us to discern overarching themes and tensions. In our initial coding, we frequently encountered terms such as "human-centered", "user-centered design", and "user acceptance", which seemed to carry significance in the engineers' work. Comparing different incidents of these terms in our interview data inspired us to focus further observations on user tests, where we aimed at looking behind their assumed meanings, notice tensions between story and action, and use our analysis to problematize, rather than reproduce, the engineers' usage of these terms and routine rationales for them [13].

Note that our analysis focuses on imaginaries as engineers' ideas and visions, which are often future-oriented and of a speculative, diegetic nature. The robotics and AI applications that appear in the stories we reconstruct are not necessarily currently under development, let alone in use. Nevertheless, visions of and expectations for future applications create a narrative environment that shapes present action [8, 32]. Our study investigates these imaginative elements of engineering practice in an early project phase in order to better understand the ways in which they contribute to defining development trajectories.

3.5 Limitations

Our analysis is based on an explorative case study of robotics for geriatrics. In this sense, our findings cannot be generalized to all healthcare robotics. We have been looking at our case from the perspective of embedded ethicists and social scientists. Working on a shared project with our study participants allowed for full field access to all aspects of their work practices and engendered trust in our presence as our work was clearly supported by the main PI of the initiative. At the same time, a collegial relationship with the actors in the field also always has to be carefully scrutinized because it might lead to omissions or blind spots in the interest of maintaining positive working relationships. In order to ensure that we can report openly about critical aspects of our analysis, we regularly discussed these findings with our colleagues in robotics and elaborated on the need to share these findings in order to work towards the shared goals of improving work practices in healthcare robotics. Still, we want to draw attention to our status as embedded researchers and colleagues of the engineers who are the central figures of this article.

Our analysis of the work practices of our project partners can be framed as convince sampling, a limitation of the study we are aware of. Furthermore, due to the labor market in the field of robotics, our sample of engineers is skewed towards younger engineers in the process of obtaining a PhD (15) and contains fewer engineers who hold a PhD and have longer work experience (3)—as PhD holders in Germany tend to move towards industry eventually. Generally, as there are few international studies at this point about the imaginaries that healthcare robotics engineers hold, it is hard for us to gage the influence of the German context on our results. Our study can only be a puzzle piece in the larger academic endeavor to understand imaginaries and how they shape and are being shaped in the diverse fields and practices of engineering and HCI. A larger number of cases in healthcare and other application domains, as well as other national contexts, should be explored in further research.

4 CASE STUDY RESULTS: HUMAN-CENTERED AI AND ENGINEERS' IMAGINARIES OF HEALTHCARE

As part of their work in a university research project on robotics and AI, the Geriatronics engineers conceptualize and envision healthcare—their main application context—in very particular ways. These imaginaries are co-constituted with the design narratives that guide their work, including general themes and stories emerging from their perceptions of the purposes of their products.[2]

4.1 Imagining Healthcare as an Environment

4.1.1 Healthcare as a Complex, Human Environment. Healthcare, as a field of application for AI and robotics, is seen to offer many intricate challenges for robotics and AI research to solve [see 51, 72]. The Geriatronics engineers explained that many unsolved challenges in robotics persist, for instance, related to perception, motion planning, and manipulation of objects, among others. They see these problems as highly relevant in the healthcare context and express their scientific interest in solving them. Challenges they see are often connected to the perception of healthcare as a particularly complex environment. They conceive of different healthcare settings—people's homes, care facilities, hospitals—as complex, chaotic, and unpredictable, which differentiates these settings from the simulations and lab conditions the engineers usually develop their systems in. Private homes or hospital rooms are often small, cramped, and dimly lit, making them challenging environments for robotic locomotion and visual perception due to the limitations of cameras and challenges facing robotic movement upon uneven ground. These unstructured environments contain countless object configurations generating ever-changing healthcare settings and unknown situations, resulting in an exponential complexity that poses great challenges for real-time systems to operate within.

These unstructured healthcare settings are conceived of as environments created by and for humans. Our colleagues from engineering illustrated many of the challenges for robotics by contrasting current robot functionalities with human abilities. For example, while humans can look at a room and instantly discern if the room is an office or a dining room and what the people in the room are doing, robots currently lack this kind of real-time understanding of a real-world scene. Another example was the ability to grasp variform and fragile objects, which is easy for humans yet currently a great challenge for robots. As a research group working on embodied AI [33, 34], the Geriatronics team is particularly interested in robots' physical interaction with the world, such as scene-recognition, navigation, and manipulation of objects, aiming at making their systems adapt as well as possible to the complex, human environment within the healthcare domain.

4.1.2 Emulating Human Skills. Following the imaginary of healthcare as a complex "human" environment, the engineers articulate design narratives that focus on developing systems that emulate human skills [63, 85]. This can be seen in the following two quotes:

> At the end of the day, the idea is to make this system so flexible [...] that it can operate anywhere where a human can operate and be of use. (PhD candidate 10)

[2]Working as a team on the same products, the Geriatronics engineers developed common imaginaries of application contexts and users, despite their different disciplinary backgrounds; we could not trace a particular relation between a particular background and a participant's understandings of and visions for healthcare. Therefore, what we reconstruct here is engineers' imaginaries that are largely shared within our case.

> In this project [...] we want to have a care-giving robot, which has to interact with a household environment, with the objects that are originally created for humans actually, for human manipulation, for human use. And that's why we have to adapt to these objects unless we change all the objects and all the environment and we adapt it to the robot, but it's harder, or maybe not harder but more expensive. So the robots should adapt to the human world, at least now, because the world is, yea, the society created this world all for human use and this is why [...] we have to have a robot similar to human or behaving like human, or manipulating the objects like human, [...] interacting like a human. (PhD candidate 4)

These engineers argue that to make a robot fit for operating in the human healthcare world, it needs to also possess the capabilities of the human body. Therefore, some engineers try to transfer insights from human physiology into their work on robotic functionalities. An important part of their endeavors to make robots human-like is to combine "robotics with neuromuscular modeling and human motor control modeling" and to "apply the models we find in the motor control research to robotics and use it with robotics" (PhD candidate 3).

One example of how they emulate human body parts is an anthropomorphic hand for GARMI [85], a bimanual humanoid service robot. As with human hands, GARMI's hands are supposed to fit objects of any shape, allowing the potential to perform a wide range of tasks in an environment created for humans. One engineer explained:

> So the idea behind it is that you adapt GARMI's hand to the human hand because it's supposed to be able to manipulate devices in the home. And manipulating devices implies a sensitive grasping of objects, actually, and handling of objects, that is what manipulation in robotics is, really. Dexterous handling of objects. [...] It should then already be the case that GARMI can actually use the current devices in every household and that the devices should not be adapted to the system. [...] Now it is really about tying shoes or cleaning out dishwashers—when you grab fragile things so that you don't apply too much pressure with the finger, so that you can also regulate the control accordingly well, with pressure sensors, or with estimates of the touch forces of the fingers. (PhD candidate 8)

These passages exemplify how everyday human tasks are translated into technical problems of a certain scope and technical complexity that is solvable by technical means. The handling of mundane objects in a social context becomes isolated actions, each of which is seen as a discrete problem that a technical system or certain parts of it (in this example, the manipulating fingers of the robot hand) must solve. The engineers identify the variables that need to be addressed in this problem-solving process (vision, pressure, control) and the system components needed to address them (controls, pressure and visual sensors, computing estimations). These translations allow the engineers to tackle the problems they imagine in healthcare through their technical work in their research.

4.1.3 "Understanding" Human Physiology for Human-Robot Interaction and Personalization. Another particularly prescient problem in Geriatronics is human-robot interaction. The engineers see humans themselves as a major contributing factor to the complexity and challenges for robotics in healthcare. Humans, as subjects to interact with, are conceived of as following certain patterns of general human movement and behavior, but with considerable variations between individuals. This is especially true in healthcare settings, where people are in various states of compromised health and physical ability. This view gives rise to endeavors to integrate medical knowledge into robots through AI-enabled real-time models of human physiology. Asked about the purpose of these models, PhD candidate 7 stated, if the system "can understand a body," this is "useful for human-robot interaction," for example, when the models inform system action planning in scenarios such as robotics-assisted mobilization and rehabilitation.

Central to the design narratives of applications like this is the concept of the "human digital twin". What sets the human digital twin apart from a traditional simulation is that it uses real-time data to create a real-time representation of an actual human. In contrast to other domains, such as construction work, where human digital twins have been developed to represent movement and force in human tool use [44], human digital twin technology in Geriatronics is developed specifically to "represent the body under various healthy and diseased physiological states" in care contexts, and is often explicitly linked to discourses of individualized medicine [29]. The Geriatronics engineers try to create these representations by integrating a multitude of models of different human bodily functions, including kinematic, motor control, musculoskeletal, and cardiovascular models.

One application of human-digital twins in human-robot interaction is rehabilitation. For robotics-assisted rehabilitation, the system is envisioned to model neuromuscular function based on real-time data (e.g., videos, electromyograms, kinematic data) and to physically assist a person through physiotherapeutic motions. Phd candidate 3 described the scenario like this: "We have GARMI moving the patient's arm, and we see the output of the patient, so we see the muscle activation of the patient and the joint position of the patient, and that's where the human digital twin or the musculoskeletal modeling comes in most." In this quote, the engineer is referring to a scenario where the robot's arms hold and move the arm of a patient while measuring muscle activation. The system creates a visualization of the patients' muscular system and highlights which muscles are activated in the movement, displaying it on a screen in real-time for a physiotherapist to see. This is imagined to give the therapist an overview of the health state of a patient while the physiotherapeutic assistance movements can be automated. This automation hinges on real-time processing of the physiological data and, based on this, the robot is envisioned to plan and execute the movements in attunement with the patient's body.

A further element of the design narrative of making systems understand human physiology is the focus on adaptive systems that are tied to promises of personalization. Based on the premise that "people are different" (PhD candidate 4)—in parameters such as their limb size, muscle positions, range of motion, or normal heart rate—the engineers see the need for their systems to adapt to individual users. As PhD candidate 1 said:

> Personalized learning and adapting to certain people is definitely a thing we need. [...] Think of personal flexibility. Each person has a [...] different range of motion than other people. Some people cannot reach their feet by standing, (demonstrates) some people do, (laughs) gymnasts can do the splits, and some people cannot do it at all. (laughs) So, yes, modeling behaviors and learning what you can do [...] is one thing I'm looking into, trying to develop a model that fits onto a person, molds onto you.

They imagine models that can continuously adapt, arguing that users will likely go through a range of different physical states over time. In the rehabilitation example, the system is supposed to model how a user's motion is altered in a state of injury, as well as throughout "rehabilitation, [which] should give [the person] the full motion range again. So you have to again adapt your model to know that the person can do the full motion again" (PhD candidate 1). This scenario implies that robots will emulate physiotherapists' understanding and responses to different states of mobility and health. However, there are doubts within the team that this is an attainable goal for the near future. PhD candidate 12 reflected:

> That GARMI would really grab your arm like that and can move it exactly the same as a therapist would do, I look at that very critically. Simply because I believe that a therapist is insanely well-trained to respond to feedback from the body and I can't imagine that the robot system can do that just as sensitively.

This quote is another example of how engineers reflect on the technical feasibility of their visions as they imagine how their systems can be integrated into the complex and human environment of healthcare. It also involves an image of physiotherapists as highly qualified professionals, which brings us to the next part of our analysis, the engineers' imaginaries of healthcare workers.

4.2 Imagining the Healthcare Workers as Users

A constitutive part of the engineers' imaginary of healthcare is their representations of healthcare workers. The multiplicity of their representations mark our engineer colleagues' complex and ambivalent relationship with these professions.

The engineers relate their work to various groups of practitioners from various professions within the healthcare sector. They mention physicians and nurses most frequently, but also physiotherapists and nursing assistants. Take the following example, where PhD candidate 7 told us about the advantages of their research location:

> We have a great infrastructure with <u>physicians, nurses</u>, a nursing school. We have hospitals here, we have relatively many <u>physicians</u>, and that is great—that you can get feedback, not only from the elderly but also from other users who can say: 'Hey, that's how it works. These are the problems in our job.' Then we can support. Let's put it this way: As a cared-for person, you see it differently than <u>the users, that is, the nurses</u> and <u>whoever else</u>." (our emphases)

In this quote, the engineer emphasizes the importance of the perspective of healthcare professionals, valued for the insight they provide into practical challenges in healthcare work, and which they see as differing from, and an important complement to, the perspectives of older users in the development of care robotics and AI. The quote also exemplifies that the engineers hardly differentiate between the groups of healthcare workers when speaking about "the users." As they commingle "physicians, nurses" and "whoever else," they paint their image of healthcare workers in rather broad brush strokes. Even when differences among the healthcare professions are observed, they often lead to reifying statements that support the similarities between them, for example:

> I know that these two things are not comparable, of course—yes, an *Altenheim* [engl. elderly care home] is not a *Krankenhaus* [engl. hospital] I would say—but anyhow, there are some similarities like there is, there are care, health care or, caretakers [i.e., care givers] in both places let's say. [...] these people—first of all, they are overburdened. (Postdoc 1)

As this engineer went on to talk about the working conditions of healthcare workers, they passed over potential differences between the tasks, working conditions, and types of expertise of different healthcare professions. This constitutes a undifferentiated view of the multi-professional space that constitutes the healthcare sector. More specifically, in the care of older populations, these engineers differentiate medical, nursing, and therapeutic practitioners vaguely, if at all, and assume that they have rather homogeneous experiences and problems in their work.

4.2.1 Healthcare Workers as in Need of Support. The most often mentioned problem that our participants associate with healthcare workers across their varying professions is that they are "overburdened" (Postdoc 1) and "overworked" (Postdocs 1 and 2, PhD candidate 6). When explaining this problem, these engineers often made reference to a political imaginary that is prevalent in the German context: the "*Fachkräftemangel*"—a shortage of skilled professionals in healthcare, sometimes referred to as "the nursing crisis" [see also 51]. Reconstructing their own version of the imaginary, they connect this labor shortage to healthcare jobs being unappealing. They attribute this to everything from a lack of respect, acknowledgment, and monetary compensation to physical strain and a healthcare system that increasingly subjects workers to bureaucratic burdens of documentation and imposes pressures of cost and time efficiency. All these factors are seen as making the job of healthcare workers "extremely hard" (PhD candidates 2 and 3) and "stressful" (PhD candidate 10). As a result, the engineers see healthcare workers as being in need of support. They hold that "it could be helpful to [take] some of that weight off the care worker's shoulders" (PhD candidate 19) and tout the systems they develop as a means for that: "That robot could help [the nurse] to, yea, realize the job [...] it's also helpful for a doctor to use it, well, I mean normally a doctor is overworked every day" (PhD candiate 6). Unsurprisingly, the engineers contend that healthcare workers would benefit from using their systems.

4.2.2 Healthcare Workers as Reluctant and Fearful. However, they see healthcare workers as generally reluctant and fearful when it comes to robotics and AI, as exemplified by the following quote:

> The debate [about robotics] is controversial. There are many pro and con arguments—with a tendency even more towards con, in my estimation. People, especially in healthcare, tend to reject it. (PhD candidate 2)

Healthcare workers' assumed reluctance was often associated with assumptions about general attitudes of fearfulnuess and skepticism or being cautious about technology. Healthcare workers' fears, as these engineers imagine them, relate to two main concerns: the safety of working with the systems and the danger of their jobs being taken away.

Safety concerns were often linked to a lack of understanding of robotics and AI. PhD candidate 5 put it like this:

> For the user, [who] doesn't know what's actually working, [it is] frightening [...]. For someone who doesn't understand anything about this, it's like, oh, you tend to be afraid of something you don't actually understand and know.

The engineers expect the healthcare workers to be unfamiliar with the technology and credit their potential fears to this assumed lack of technical knowledge. By contrast, the engineers attribute a lot of knowledge to healthcare workers when it comes to healthcare.

4.2.3 Healthcare Workers as Domain Experts. Our colleagues from engineering see healthcare workers as trained and experienced professionals, able to bring domain-specific expertise to the table. This view can be seen in the following interview excerpt, in which an engineer contrasted their own knowledge of healthcare with that of nurses:

> PhD candidate 7: They have knowledge. [...] They do their job every day. I... came from university and am now doing my [engineering] dissertation here. Yeah, what do I know about what goes on every day in a nursing home, assisted living, outpatient care, or anywhere else? [...]. There [i.e., in healthcare] is far too much knowledge to say, "Okay, great, we can do that." There is a reason why this is a training profession, sometimes a study program. It's not like, 'Oh, you go nurse then.'
> Interviewer: What does that mean for a project like yours?
> PhD candidate 7: That we have to communicate. We have to ask people. Application research means we have to get out. We have to go into the field or let them come to us.

This interview excerpt points to an interesting field of tension in the imagination of engineers, within which expertise and roles between engineers and healthcare workers get defined. Aware of the limitations of their own knowledge of healthcare practice, PhD candidate 7 acknowledges the importance of practice-based knowledge of healthcare for their research, which is expected to not only advance robotics scholarship, but also contribute to real-world applications in healthcare. This raises the question of where this practical real-world knowledge is located and how it can be incorporated into research. On the one hand, the engineers clearly acknowledge healthcare workers' expertise, emphasizing their practical and professional knowledge base, and at the same time, they draw a boundary between this area of expertise and their own work. This view implies that they do not see it as their job to inquire and learn more about this domain and become experts themselves, but instead need to receive knowledge second-hand from healthcare workers by, as the engineer said, "letting them come to us" and asking them for input. For example, the Geriatronics project invites healthcare workers to their research center for engagement exercises and consultations. On the other hand, there is this idea of "we have to go into the field," which implies a more active approach for engineers to acquire knowledge of healthcare practices first-hand. Initial efforts have been made in this direction, where some of the Geriatronics engineers have done nursing internships. For periods ranging from a few days to two months, they interned either at a care home, hospital, or in outpatient care, or a combination of these, following healthcare workers and helping in everyday tasks. While both approaches—soliciting healthcare workers' input on healthcare practices and engineers learning about that domain themselves—were considered and pursued to some extent, we saw more emphasis on the former, which is in line with their perspective that healthcare knowledge is outside engineers' expertise.

4.2.4 Pursuing Acceptance through User Engagement. The engineers also draw on the earlier images of healthcare workers as they devise their engagement with healthcare practitioners. To summarize the earlier images, our interviewees depicted healthcare workers as in need of support due to a lack of time and personpower, and insufficient support for their work. They also perceived a lack of understanding of robotics and AI as a barrier to healthcare practitioners' recognition of robotics and AI applications as welcomed solutions for their support needs. These engineers routinely invoke these deficits as they form their relationships with healthcare workers.

These images resonate with the notion of "acceptance," a term that has gained relevance in social robotics engineering [36] and beyond. As Postdoc 1 put it, they often think "from an acceptance perspective," which seems to be the most prominent frame available to the Geriatronics engineers for conceptualizing their engagement with application contexts. It implies that they think of healthcare workers as people they need to convince of the value of their products. In many of our interviews, acceptance was the first thing mentioned when we asked what conditions they think will be needed in healthcare for a positive implementation of their systems. PhD candidate 5 responded: "I think the most important thing is acceptance—that they actually try to integrate this." They see the success of real-world implementation of their systems as dependent on the healthcare workers' willingness to integrate them into their work. Such arguments, and the term "acceptance" itself, are constantly repeated by policymakers and senior researchers in the field, leaving an imprint upon how robotics researchers view and speak about their engagement with healthcare workers.

Accordingly, we found a focus on acceptance which strongly marks our interviewees' approach to user-centered design. PhD candidate 8 explained:

> So, we are very keen to get people's acceptance right from the start. That means that we also have this user-centered design approach. That is, you also want to get people involved in how GARMI—the design, the development. That they can get to know

> GARMI from the beginning, not that all of a sudden there's a new product on the market and you don't know what it's supposed to be.

The engineer associates "user-centered design" with "acceptance" as they explain that their aim is to gain acceptance for their products. Similarly, another engineer argued that exposing users to preliminary versions of the system early on would help them get comfortable with the idea of using the system as they "gain experience" with it and "see the robot grow" (Postdoc 1). Pursuing acceptance, the engineers frame their engagement with users in terms of trying to "break the ice," (PhD candidate 9) and informing and encouraging people to "take them on board" (PhD candidate 2).

We see this acceptance framing as being in tension with the engineers' view of healthcare workers as application-domain experts if we look at their implications for user engagement. While the former implies an emphasis on educating healthcare workers, the latter suggests engineers should seek to learn from healthcare workers' input. Seeing these competing outlooks coexist in the engineers' accounts raises the question of how they enact user engagement, both discursively and practically.

When our participants describe their approaches to and goals for user engagement, they use a strong acceptance framing. We give two examples. First, there are demos and open days, where the engineers invite the interested public, including healthcare workers, to their research center to give prototype demonstrations. PhD candidate 8 described them like this:

> So we are very keen [...] for them to already have experience and know how the whole thing works. So that we increase acceptance by showing them what we are developing now, in the form of demos and open days, with the help of public outreach. It's actually interesting that people actually see what's behind GARMI or what's actually going on in GARMI, so how GARMI works. And that's what we actually want to achieve.

Second, there is the "*Roboterfabrik*," a subproject of Geriatronics, where participants can interact with Geriatronics robots. The engineers described it to us as a "training program" for the use of robots, where users are instructed on how to interact with a robot and then allowed to play around with it (PhD candidate 7). As its goals, the engineers mentioned "education" and audience-specific "knowledge-transfer" (PhD candidate 7), as well as "the reduction of existing fears and prejudices against new technologies" [30]. In the first example, the engineers focused on demonstration and information; in the second, they moved to a frame of interaction and engagement. Still, both center on education and acceptance. These framings are evocative of the deficit models of public understanding of science [97] and public trust in science and technology [98], reinforcing an image of a deficit in user understanding of the systems and raising the corresponding idea that more technical knowledge would lead to positive attitudes toward the systems. A similar claim was made explicitly by PhD candidate 7: "Often you can do a lot against fear by informing people." However, such deficit approaches might not only be misguided given that information has largely proven ineffective in changing people's attitudes towards science and technology [24], but these approaches also deemphasize healthcare workers' role as knowledgeable and active dialog partners to potentially learn from.

Yet, when we look at how the Geriatronics engineers practically enact engagement exercises, we see a more complex picture, where the engineers combine education-focused activities with efforts to collect input from participants. For example, we observed a two-hour *Roboterfabrik* session with third-year nursing students, comprised of two parts. First, an engineer gave a presentation to introduce the Geriatronics project and particularly GARMI and its envisioned areas of application and tasks. Secondly, the students took turns interacting with two single-arm robots. The robots had two modes: one in which the students could move the arm and save different positions at the touch of a button, and one in which the robot would execute a series of commands, including, for example, moving to a pre-set position, and opening and closing the arm's gripper end-effector. Each robot was connected to a laptop with an app where the users could compile this series of commands. After instructing the students how to use the app and the arms' buttons, the engineer opened the engagement exercise by saying:

> We want to show you that robots are quite easy to control and that you don't have to be afraid of them. [...] You can teach the robot something now and then we'll see if it has learned it. (PhD candidate 12)

The students were given a series of assignments of progressing difficulty, in which they were asked to "teach the robot" to move through a zigzag course of toy bricks and to grasp and lift a mug, among other tasks. The engineer stood by, observed the interactions, and helped the students if needed. During and after the exercise, the engineer engaged in conversations with the students, answering their questions and asking them about their opinions on the robot arms they interacted with and the humanoid GARMI they had seen in the presentation. The engineers explicitly encouraged the students to share their thoughts by emphasizing how important it is for their research to get feedback from healthcare practitioners. Subsequent to the exercise, the students filled out questionnaires, where they were asked to rate, on a scale of 1 (fully disagree) to 5 (fully agree), statements about their curiosity, fear, interest, skepticism, and perception of the robots' usability, usefulness, accessibility, and safety, as well as their intention to use the robot in a range of application scenarios.

While the more informal conversations had an air of openness, with the engineer ready to learn about the nursing students' perspectives, many of the other elements of the event bore an acceptance approach, with the information provided at the beginning, training about how to operate the robot with a focus on alleviating fear, and a questionnaire that elicited views on acceptance-related themes, limiting the complexity of participant response by eliciting ratings of pre-formulated statements.

In sum, the engineers seamlessly integrated the dominant notion of acceptance with their imaginary of healthcare workers as a fearful and uninformed user group in need of support, explicitly describing most of their user engagement activities in terms of acceptance. At the same time, their activities do not exclusively seek passive acceptance; they also include more inclusive endeavors like nursing internships and asking healthcare workers for their opinions, which resonates with an alternative view of healthcare workers as domain experts. Still, efforts to collect healthcare workers' input remain largely framed in terms that imply deficit and acceptance framings.

4.3 Re-imagining Healthcare Practices

The engineers integrated their imaginaries of healthcare into their work on functionalities, system appearance, and in wider project-related activities. They invoked these imaginaries in particular narratives regarding design and workplace integration, through which they re-imagined healthcare practices. We present and constrast three of these narratives.

4.3.1 Designing Robotic Assistance for Healthcare Workers. The design narrative of the "care-assistant robot" is particularly salient in the Geriatronics project. We show how it builds upon the imaginaries presented above and analyze how certain activities in healthcare get valued and reframed to make possible and plausible the corresponding vision of robotics-assisted elderly care.

Creating robots as "assistants" for healthcare workers is a salient vision that guides the Geriatronics project's research. One aspect of defining their work is to explicitly dissociate it from care robotics ("we don't do care robotics," PhD candidate 7). For example, "GARMI is a care-*assistance* robot," as PhD candidate 2 stressed, "not a care robot". Into this design narrative play both their imaginaries of healthcare as a complex environment with major technical challenges for robotics as well as healthcare workers as in need of assistance, yet reluctant users. First, the technical challenges associated with complex healthcare environments lead many engineers to question the feasibility of popular visions of care robots. Speaking from"just a very practical point of view," PhD candidate 10 argued:

> I mean ideally, of course [the robot] would be a tool that just, you know, is in the background and it does stuff, but you barely notice it. [...] But more realistically, I guess that, especially for the first generation, there will be a lot of human intervention. So the robot won't know what to do anymore, or it will be stuck, or it needs instructions, or it needs an explanation of what is what, something like this. [...] And I guess there will still be some human interference in a sense and guidance. And then you could design this in a way that it's more intuitive.

Highlighting the limitations of robots' capacities to replace humans and operate autonomously, they see it as a practical necessity that humans intervene in the robots' operation, leaving them questioning the capacities of current robots to perform anything beyond assistive tasks. Consequently, robot design requirements aim at creating an intuitive interface to facilitate this necessary human intervention. Secondly, the engineers spoke of the social reasons for their design narrative of care-assistant robots, framing them in terms of acceptance. One part of the Geriatronics approach to "human-centered" AI is that they consider healthcare workers' fears and needs in their design and development work. Postdoc 2 told us that, "in assistance robotics," they see a lot of room for the notion of a "purpose pull" that lets engineers focus on "making it so that the people want it." They hope that "in this way [their project] can increase user acceptance if people see that their problems are actually being addressed now" (Postdoc 2).

In line with their image of healthcare workers as afraid of losing their jobs, a portion of their design narrative is concerned with defining what their work is not intended to do, namely, replacing humans who work in healthcare. Instead, the motto goes: "support instead of replacement" (PhD candidate 7). This is also reflected in the metaphors the team uses to describe their systems, namely generally as "tools" (PhD candidates 2, 7, 8, 9, and 11)—implying human use—or "assistants" and "assistant systems" (Postdoc 2, PhD candidates 5 and 8). They often argue that real care tasks—defined below—lie beyond their systems' scope even though they consider healthcare settings as the application environment for their systems. As PhD candidate 2 put it: "In real care, there is not really a place for GARMI unless as support for caregivers".

Accordingly, the engineers build design narratives based on technological limitations and social resistance against the replacement of healthcare workers, as well as on the perception of overburdened healthcare workers, and therefore focus on supporting healthcare workers via assistive robots. These design narratives are built on the premise that healthcare activities can be organized into two categories: assistance and "real" care. Such a distinction has been found too in Vallès-Peris and Domènech's [2020] study of roboticists' imaginaries of care robots, where they observed a binary separation of care activities into those delegable to robots and those reserved for humans and described it as a process of "care fragmentation" [87, p. 9].

"Real" care, according to the Geriatronics vision of robotics-assisted healthcare, is done by human healthcare workers. "Real" care comprises what engineers define as healthcare workers' "learned job," which is associated with "human values," "emotions," and "the social side," and held distinct from "ancillary activities" (PhD candidate 8). They earmark socializing and talking to patients as a group of tasks reserved for humans. Additionally, such tasks include giving physical affection and warmth, washing people, and attending to emotional and social needs by showing "understanding and solicitude" (original Ger.: "*Verständnis, Fürsorge*", PhD candidate 7).

"The advantage of humans" for these kinds of tasks, they argue, is "the emotional level, showing feelings—yes, empathy, [...] to interpret the emotional state of other people" (Phd candidate 8). In "real" care, as these engineers portray it, "human contact is indispensable" (PhD candidate 12).

The separation between human care tasks and the "assistance" tasks to be left to robots informs design narratives and functionality design choices in Geriatronics. PhD candidate 8 explained that the goal is to uphold this distinction:

> [What we are developing] is a technical system and we should actually use it more in the sense of an auxiliary tool, and that is why we are also taking the path of leaving the social competencies on the side of the human so that there is also more demarcation.

Speaking about what this means for their work on the functionalities of their systems, they then explained that, for example, when developing robotic manipulation of objects, they take inspiration from human skills,

> but especially in the direction of the social side, a distinction can clearly be made. Therefore, we currently also use the approach that our GARMI does not speak too much, or that he does not show too many actions, currently. (PhD candidate 8)

While, as discussed above, emulating human skills for the robot's physical operation in real-world environments seems to be unequivocally seen as a go-to research approach for their human-centered design, this is not the case for emulating human social, emotional, and conversational skills, which they refrain from implementing.

The functionalities and tasks the Geriatronics engineers imagine for their systems fall under the category of assistance. Their design narratives center around supporting healthcare workers, solving their problems, and freeing their time and physical and emotional capacities. In accordance with their undifferentiated view of healthcare professions in care, the engineers envision a broad set of tasks in which their systems could assist, spanning the task areas of nurses, physiotherapists, and physicians. They often seamlessly move between these areas, so their visions do not always reflect the specificities and differences between the professions and sometimes promote a blurring of the competencies and task boundaries, as we will illustrate below.

The assistive tasks the engineers envision for robots include cooking, carrying and fetching things, tidying and cleaning, feeding patients, lifting them, and reminding patients of appointments or to take medications. These tasks are associated with unskilled or low-skilled care work and are deemed outside the realm of "real care" that nurses are trained for, despite the complexity of many of these tasks. Feeding, for example, needs to be skillfully managed, both on the social and physical levels. Physiotherapy is another application where the engineers envision robots performing time-consuming, repetitive movements needed in patient mobilization and training, which can, as Postdoc 3 envisioned, "ease the burden on all nurses and therapists during rehabilitation." Here, their visions imply a blurring of the boundary between nursing and physiotherapy competencies. One of the ideas connected to this application is that the rehabilitation robot therapy sessions could be supervised by a nurse without the need for a physiotherapist to be present, which is usually required in rehabilitation in Germany.

Other application areas include health monitoring and assistance in diagnostics and medical decision-making. Assistive systems are envisioned to perform physiological measurements and feed them into data-driven monitoring of therapy progress and to provide treatment suggestions. Based on the individual patient's data, PhD candidate 11 suggested, the system could simulate different treatment options and evaluate which option has the best result in the simulation, which could then inform decisions on how to proceed with treatment or nursing interventions. Moreover, there are ideas of "diagnosis aids" for physicians that make a "preselection" of patients by checking markers of pathology, which was envisioned to help in prioritizing the order in which patients receive the attention of a nurse or doctor when capacities are limited (PhD candidate 7).

These ideas of robotics-assisted diagnostics, monitoring, and medical decision-making have implications for hybrid decision-making between humans and machines as an issue of assistance. In these engineers' accounts, they are often associated with the concept of human digital twins discussed earlier. These human digital twins are portrayed as a way to assist physicians by processing patient-specific, real-time data. The final decision, be it about diagnosis or intervention, nevertheless remains with human professionals, the engineers conclude. While the engineers propose shared decision-making (for example, when a system preselects patients), they constantly return to the idea that the system's part ought to be seen as merely assistive, regardless of which professional the system is assisting.

The narrative of the care-assistance robot has implications for how human care tasks are perceived and valued. Framing robotic systems as assistants implies a subservience of robots to humans, which carries with it a normative judgment that has implications that go further than the tenet of human-centered systems, i.e., that "we must always put people before machines" [17, p. 457]. Such framing also contributes to an ongoing evaluation of human practices in healthcare because it separates activities traditionally done by humans into categories of hierarchical value [87]. By sorting some activities into the category of "delegable to robots," which are seen as subordinate, they devalue these activities. This perpetuates a devaluation of tasks such as cleaning, which have long been regarded as work that requires no expertise and receives little societal acknowledgment.

Indeed, one of our interviewees alerted us to the very real consequences that arise when assistance tasks in healthcare are devalued, and human workers are no longer compensated for them:

> I can think of one more [danger]. Yes, how are they called? Nursing assistants or something like that, who do these helper tasks. That's just one of the few professions that still exist at the moment where you don't need a great deal of training. They will no longer be needed. One will have to see how to proceed there... (PhD candidate 7)

This quote hints at the fact that, despite care-assistant systems being advertised as support and not a replacement for humans, if certain tasks currently shouldered by humans are substituted by these systems, this might hit those people the hardest who have the least opportunities to begin with because they lack vocational qualifications. If robots contribute to the automation of assistive tasks and reinforce the devaluation of this kind of work, this could negatively influence the job security of supporting workers.

4.3.2 Designing Social Interactiveness into Robots for Elderly Care. Another design narrative and endeavor in the Geriatronics project stands in contrast to the narrative of strictly upholding this separation between human care and robotic assistance. Some of the engineers are working on making robot GARMI appear social, cute, and human-like. They envision and work on a "social behavior engine" for GARMI, a subproject that puts affective emotionality and social rapport at the center of human-robot interaction [85, p. 5858]. To do so, they give GARMI gestures like waving, beckoning, and turning towards the user, as well as friendly stylized facial expressions displayed on its head screen and "cute noises" (Postdoc 1). In regard to the noises, PhD candidate 2 explained:

> In the course of various demos, where we had to breathe a little bit of life into GARMI, we actually bought a sound library. [...] It's very extensive, and it simply offers small, short sounds that you can play to match the [robot's] eye movements. That's what we did. And the feedback was actually very, very positive. And people found it kind of

> funny and nice. Really to just evoke a little bit of sympathy from the users. And our goal is, our vision is, to present GARMI a bit like this clumsy helper.

These considerations were not part of their initial research plan, as the engineer explained: "To give GARMI this affective emotionality was never our research approach" (PhD candidate 2). It was presenting their robots to the public in demos that made them think about "breathing life into GARMI." Based on their assumptions about what might create positive attitudes towards their robot, they tried using robot appearance and behavior to elicit sympathetic emotional reactions, which they found to be effective in these demos. These efforts aim at creating acceptance, which PhD candidate 4 made explicit: "People also tend to accept it or think that a robot is similar to a human when the robot has this human-like appearance." In an attempt to charm users, they give their robot cute, human-like appearances and behaviors to appeal to human emotions and social instincts.

This is where we can see the narrative of care-assistance robots begin to crack, where keeping social competencies strictly to humans does not entirely hold up. A narrative tension emerges between two opposed design decision narratives, one standing against adding social interaction as a feature (due to the ontological commitment that their robot is 'not a social robot'), the other being in favor of eliciting emotional reactions. The existence of simultaneous yet diverging narratives and efforts shows the engineers' struggles to introduce their robot into a complex field where they see a range of demands that they try to address and balance. Despite stressing they do not want to replace human healthcare workers in their social competencies, they also envision a lot of interaction interfaces between the systems and the older people who inhabit healthcare spaces, which raises questions about the social interactiveness needed in robots.

4.3.3 Envisioning New Technical Tasks and Qualifications for Healthcare Workers. Another way in which the Geriatronics engineers re-imagine healthcare practice is by envisioning and creating new qualification programs involving technical skills for healthcare workers. They see this as crucial for the successful implementation of AI and robotics into healthcare. Continuing with engineers' concerns about negative consequences for the job situation of certain healthcare workers, some engineers in our interviews gestured at notions of up- and re-skilling, for example in the following excerpt:

> PhD candidate 6: [...] people need to learn more and more, definitely.
> Interviewer: What will they find when they learn more?
> PhD candidate 6: I mean, if some lower job is replaced by robots, then people need to know to learn more to a higher-level knowledge, like how to control robots, right?
> Interviewer: I see what you mean. Yea.
> PhD candidate 6: Yea. Then they will find a job.

They imagine healthcare workers will be required to extend the scope of their work beyond the social to encompass more engagement with technology. PhD candidate 7, speaking about "the healthcare system" broadly, put it like this:

> Thankfully it is already the case that people are saying "Okay, health[care] isn't just exclusively social." It is more that they are saying "You have to have some technical understanding too."

The engineer's perception indicates that only now there is a shift towards embracing technology in healthcare. What is striking here is how they are generalizing about technology in healthcare instead of addressing robotics specifically. From their expectation that healthcare workers have skeptical and fearful attitudes towards robots and AI, they shift to imagining healthcare as a merely social arena where technology has barely played a role and healthcare workers acquiring "technical" skills is a new expectation. This stands in contrast with understandings in STS, which has observed that handling a range of technologies has been part of everyday practices of healthcare workers for decades [58] and which sees healthcare as part of our "technoscientific" world where the social and the technical are already inseparably entangled [46].

Yet, looking at the specificities of care-assistance robots, we can identify some tasks connected to handling the systems that the engineers envision. These involve supervising, operating, and instructing semi-supervised systems in a safe way, providing feedback for learning systems, and maintaining the systems and "tinkering" with them to make them suit their local use context. Their vision of robotics-assisted healthcare includes not only support for healthcare workers in their current tasks but also creates new tasks and skills for them to master.

The Geriatronics project takes an active part in shifting the education of healthcare workers to make it possible to learn these skills. For example, the project engineers are involved in the development of robotics-related teaching modules for nursing students, where they can practice interacting with Geriatronics robots. One of their visions is to establish an entirely new sub-profession in the healthcare field: the robot operator. These operators would work in "control stations" to supervise humanoid assistant robots in people's homes and remotely control them when needed. We asked PhD candidate 2, who told us about this scenario, who these operators would be.

> They would be trained professionals, so to speak. So maybe emergency paramedics, paramedics, and so on, I imagine. This could also become a new job description yet to be developed. So this could also be developed as part of the project because we want to develop new training concepts or provide input [for training concepts]. I imagine someone who is medically trained in the basics, has technical understanding, and can then operate the whole thing.

This example shows that the engineer considers a broader engagement in the organization of healthcare-related services and infrastructures. They envision the project contributing to the establishment of new professions and training programs, not only indirectly, by providing new technologies to the healthcare system, but also by directly giving input for training concepts on how to use them. This is an example of how the imaginative work performed by engineers is not necessarily restricted to technical work but may become a productive part of larger societal efforts to reconfigure the healthcare sector.

5 DISCUSSION

This article had two aims. The substantive aim was to show how the imaginary of robotics-assisted healthcare came into being in a case study of Geriatronics, an engineering project in the context of elderly care, while the theoretical aim was to demonstrate the analytical utility of imaginaries as a point of analysis into the social, ethical, and political implications in engineering and HCI. We have presented the projects' engineers' imaginaries of healthcare and have shown how these are connected to design narratives and decisions as well as user engagement practices.

5.1 The Imaginary of the Care-assistant Robot

The dominant imaginary that guides the Geriatronics Initiative is that of robotics-assisted healthcare. It emerges from the confluence of different themes connected to how the engineers imagine healthcare as an environment for robots and healthcare workers as users. It gains dominance in a context where these engineers, first, seek to advance their field of research, robotics and AI, by entering the application field of healthcare, while they, secondly, view the current technological capabilities in robotics as being limited to an extent that raises doubt about the near-term feasibility of care robotics going beyond assistance tasks, which, thirdly, resonates with the engineers' view of healthcare workers as reluctant technology users fearful of losing their jobs. These aspects reinforce "assistance" as a narrative frame for robotics and AI research for healthcare, in which the care-assistance robot appears to be the only imaginary open to these robotics researchers at this point, for both social and technological reasons.

5.2 Imagining Application Contexts through Established Research Priorities

Our case exemplifies how imaginaries of application contexts say at least as much about the imagining actors as about the imagined sphere [cf. 62]. While engineers' imaginaries of healthcare are seemingly about healthcare, they also provide a window into the situatedness and self-image of the engineers. We learn where they see the possibilities and limitations of their own research and field when they limit the context of their current research to "care-assistance." We can observe how they approach healthcare from their own particular technological and research-focused perspective, framing healthcare as a challenge for robotics to solve. These observations concur with previous studies that have found that solutionist approaches prevail in care robotics [6, 48, 73]. Our case study adds to this body of evidence, reporting on particular strategies that emerged in the Geriatronics project's attempts to tackle challenges in real-world application settings. Thinking of healthcare as a complex and human environment made it plausible to implement design strategies for emulating human physiology and skills as a means of solving robotics challenges like manipulation and locomotion. The Geriatronics engineers work on transferring insights from human physiology into the functionalities of their systems (like grasping variform objects with an anthropomorphic hand) and facilitating personalization and physical human-robot interaction through real-time modeling of the individual user (like using human digital twins in robotics-assisted rehabilitation), which involves translating human tasks into problems solvable by technological means. Our analysis indicates the continued need for engineering to reflect on the relationship between engineers' established disciplinary priorities and their visions for application areas, given the persistence of technology and research-centered modes of imagining in some academic robotics projects. This is important if we want concepts such as user-centered and human-centered design to reliably go beyond legitimizing preconceived research interests.

5.3 Mobilizing Expertise, Widening the Imagination

Our analysis of engineers' representations of healthcare workers has shed light on themes of expertise, alerting us to the question: Which multiple forms of knowledge feed into engineers' imagination and how? Alongside technological knowledge, the Geriatronics engineers emphasized the importance of domain-specific and practice-based knowledge for application-focused engineering. At the same time, they expressed their awareness of the limitations of their own expertise in healthcare practice. We observed two complementary approaches for incorporating such knowledge into research: consulting with healthcare practitioners as domain experts and the engineers gaining knowledge of the domain themselves. The former feeds engineers' imaginations with second-hand knowledge, for example, through conversations where healthcare workers share their expertise and experience, while the latter gives engineers their own experiential knowledge of the domain, for example through internships at nursing homes.

In tension with both these approaches, much of the engineers' engagement with healthcare practitioners has a strong focus toward "acceptance", which is prevalent in social robotics. This notion is premised on the assumption of resistance—that healthcare workers hold irrational fears of robots based on insufficient understanding of the technology; it suggests that an important goal in engaging with healthcare workers is to convince them of robotic solutions.

When we look at how user engagement exercises are framed by the notion of acceptance, we see the importance of framings in shaping practices. The acceptance framing creates a narrow vision of the "human-centeredness" in the engineers approach, which may lead to participatory design efforts that constrain user contribution in important ways. As can be seen in the example of the largely education-focused efforts of public demos and the *Roboterfabrik* engagement format, pursuing acceptance implies a one-way flow of knowledge from the engineering team to the participants, with limited room for the participants to express their perspective. Alternative visions continue to play a role, for example when images of healthcare workers as bearers of valuable knowledge are enacted by engineers who invite open conversations with them. Yet, these remain underdeveloped due to the dominance of acceptance approaches.

Our point in highlighting engineers' imaginaries as potential sources of constraint is to inspire reflection on what might be neglected. There is a danger in the unreflecting perpetuation of limited imaginaries that hinder the inclusion of valuable knowledge and perspectives and lead to designs that do not align with needs in the actual application context. Here, an imaginaries-perspective can add a valuable point of reflexivity. Going beyond narrow acceptance framings might mean thinking differently about the engineers' responsibility to learn about healthcare practices and how healthcare workers can become involved with the project. Extended internships and continuous consultation with healthcare workers could help illuminate neglected practical and experiential healthcare knowledge. It is these kinds of reflections of the "ethnographic imagination" [21, p. 547] that inspire more active pursuits of as yet marginal perspectives that Dourish [2006] endorses as powerful contributions, which open avenues for considering widening views and approaches in HCI.

5.4 The Role of Widespread Societal Discourses in Engineer's Imaginative Practices

We have shown how more widespread societal discourses play a role in the imaginative practices of engineers. For example, they provide discursive building blocks with which these engineers make sense of the healthcare context and their contributions to it. This has become evident in our analysis of how the Geriatronics engineers imagine healthcare workers as a particular group of prospective users. Previous studies that have focused on representations of elderly people as users found that these representations are often based on ageist stereotypes [5, 66] and resonate with policy discourses casting aging populations as either a burden or an opportunity to grow a "Silver Economy" [49, 51]. We have found that representations of healthcare workers are similarly based on wider cultural and policy narratives, especially in the "nursing crisis" in Germany, which reinforces an image of healthcare workers as particularly in need of support. This crisis narrative serves as a frequent common reference, portraying healthcare as an issue to be tackled through robotics. Likewise, references to the nursing crisis were also made by nursing practitioners and nursing researchers interviewed in a recent study, who said that they see a role for robotics in addressing this crisis as well, but see it only as part of a solution that must also include social and political change [9]. For engineering and HCI, this highlights the importance of empirical research into, and researchers' engagement with, the actual application contexts and perspectives of future users to prevent design narratives being drawn from societal stereotypes. Furthermore, analyses like ours inform and invite reflexivity about the perpetual intertwining of the imaginaries of engineers with those from other areas of society.

5.5 Tracing Normative Commitments through Imaginaries

Our interviews have revealed engineers' reflexive potential for thinking about the wider implications of their research. Engineers' design narratives and imaginaries lend ethical and political significance to their work. They reveal how, to the engineers, their creations are "matters of care"

[18]: Through the Geriatronics project's dominant design narrative centering on care-assistance systems, these engineers create a particular vision of what healthcare could become once robots have found widespread uptake. This narrative expresses a commitment to refiguring healthcare practice in a way that unburdens healthcare workers and gives them more time to attend to care tasks that have an emotional, social, and/or interpersonal quality at their core. This vision resonates with what healthcare workers see as desirable outcomes for robotics in healthcare, as a recent analysis of interviews with nursing professionals indicates [9]. The engineers' further activities that go beyond technical development, like creating new training programs for healthcare workers to learn to be robot operators, further underpin their commitment to fostering transformations in healthcare practice. These findings show the productive imaginative work that engineers perform when they formulate new narratives for workplace integration.

Additionally, engineers' narratives have more subtle implications for healthcare practice. They contribute to the social processes through which care tasks are valued. When certain tasks, like ancillary and physical care tasks, are relegated to robots, these tasks risk becoming devalued as a form of human work, which may put humans who depend on doing these tasks at a disadvantage. Analyzing engineers' imaginaries helps us understand commitments that inform engineering work and their subtle implications. Considering their implications can help us to approach these imaginaries in a reflexive way, taking their performative effects on future healthcare environments seriously.

5.6 Plurality and Tensions within a Project's Narratives

Our analysis has pointed to the plurality of imaginaries within engineers' narratives. Multiple narratives can exist within an engineering project, as shown in the Geriatronics project's competing narratives about giving robots social interactiveness versus strictly keeping social competencies with human healthcare workers. This example illustrates that imaginaries can contain incoherence, ruptures, and tensions and that sociotechnical futures can be controversial and are indeed debatable. They indicate how challenging it can be to design systems for sociotechnical contexts as complex as healthcare. Drawing attention to competing visions and ruptures in narratives raises reflexivity in engineering and HCI projects by sensitizing our view to seeing "how it might be otherwise" [83, p. 6], be it in ascriptions of expertise between engineers and healthcare workers, the division of labor between humans and robots, or elsewhere.

The plurality of imaginaries also becomes visible when our observations are compared to previous studies. Fischer and colleagues [2020] found that, in their case studies, the activity of "making robots human-like" evoked images of users appreciating robots to replace humans or human work [26, p. 14–16]. Our findings, however, complicate and add nuance to the picture of the relationship between emulating human characteristics in robots and how the division of labor between robots and humans is envisioned. Our participants saw making robots human-like as a way of achieving motor skills needed in an environment made for humans and enabling intuitive and comfortable collaboration between humans and robots, with the robots usually being pictured as subservient assistants to their human collaborators. In this narrative, they largely refused the notion that robots should or could replace human work. This was, however, only true for certain kinds of human work, namely work that they consider qualified work, work worth doing, the social and emotional components of care, but not the work of unskilled staff. Further exploring the plurality of imaginaries in engineering and HCI across different case studies could be a fruitful avenue for research to go beyond individual cases.

5.7 Considering Imaginaries' Implications from Early Project Phases on

The implications of engineers' imaginaries' should be traced throughout the whole project lifecycle. Because the initiative we have studied was still in its early stages, we could only see the beginnings of how engineers' imaginaries guide research and design activities and manifest in technological artifacts. Although we cannot yet know the exact effects that the present understandings and visions we analyzed will have in the future, we are already seeing robotic materializations of the engineers' imaginaries of healthcare, as in the Geriatronics' GARMI prototype [85] and their haptic telemedicine station pilot [76]. Part of our ambition is to continue following the project to trace these systems' further development and implementation. But should we not wait to see what actually happens in such projects before we analyze them? We maintain that waiting would mean missing out on opportunities to make more reflexive and ethically informed decisions in engineering. As we have shown, even in the early phases, imaginaries have an effect on the directions a project takes—from how domain-specific knowledge is incorporated, to how users are engaged, to what functionalities and system appearances are chosen for development—which has downstream effects on the eventual applications implemented in healthcare. We see it as an important step in the analysis of ethical, social, and political aspects of AI and robotics to trace emerging imaginaries at their inception in early project phases.

5.8 Outlook: Engineers' Imaginaries as Points of Intervention

We propose using engineers' imaginaries not only as points of analysis, as we did in this study, but also as points of intervention. Further research is needed to further develop and empirically test interventions that aim to critically and constructively engage with the imaginaries and narratives that guide engineers' research, design, and user engagement practices. In the remaining project duration, we will use our analysis of imaginaries to guide structured interventions that will critically and constructively discuss researchers' imaginaries with them and address specific issues we identified, such as that there is not only a need for healthcare robotics and AI research to include knowledge about the lived experiences of patients and older adults [41, 52, 69, 95], but also that of healthcare workers.

We plan to hold workshops where we bring engineers and healthcare workers together. A disciplinarily diverse composition of participants—spanning the range of engineering backgrounds in the project and a range of healthcare workers from therapeutic, nursing, assistant, and medical occupations—will allow participants to get to know different perspectives from the other fields, which might challenge the engineers' vague undifferentiated view of healthcare workers. Since refining imaginaries is a continuous learning process, these workshops should be held on a regular basis throughout the research project. The workshops should facilitate open exchange and mutual learning to counteract the effects of limiting imaginaries—to provide a counterweight to the prevailing education-focused engagements, overcome limitations connected to the acceptance framing, and break through discursively reproduced stereotypes (e.g., about healthcare workers, older adults, or robots). These reflexive sensitivities we gained through our imaginaries analysis thus help us to re-think participatory engagements. They add to the repertoire of reflexive modes, which have been called for in HCI [20, 43, 78].

6 CONCLUSION

Intrigued by the call for this special issue to explore questions of HCI work in Human-Centered AI in healthcare, we contribute a consideration of engineers' imaginaries of healthcare as an analytical lens to increase reflexivity in collaborative HCI projects. In healthcare robotics research, "the wild" of healthcare [2] is present through engineers' imaginaries. Looking at engineers' imaginaries is particularly important in fields like robotics research at universities, because many researchers are in search of applications for their research in order to secure funding, but often little time is invested in actually getting to know the application domain. Therefore, from the early project phases on, a major way in which engineers connect to the real-world contexts of their systems is through their imagination [32, 53]. Their imaginaries influence how they later navigate their interactions with these real-world contexts, for instance in user tests with healthcare practitioners, and shape how they design applications. Incorporating reflections on the connection of imaginative and technological work can thus broaden our scope of what engagement with the "real world" can mean in healthcare robotics and AI.

We have reported on an explorative case study of Geriatronics, a robotics research project for elderly care applications. Our results show how the imaginary of robotics-assisted healthcare came to shape development and design of robots in this context. Beyond the analysis of a particular, situated case study, we illustrate how imaginaries as a theoretical lens can be utilized in interdisciplinary collaborative work at the intersection of engineering, HCI, STS, and embedded ethics and social science. It can be used to trace the social, ethical, and political implications in this research and inform reflection on design narratives, choices, and practices. Our findings reflect on the roles that disciplinary research interests, domain-specific knowledge, wider societal discourses, and implicit normative commitments play in the imaginative practices that influence engineers' work. We call for future work to explore ways to approach imaginaries as points of intervention into research practice. For projects pursuing Human-Centered AI in healthcare, we suggest interdisciplinary workshops with engineers and healthcare workers that create a collaborative environment where technological possibilities, practical knowledge, and healthcare needs come together to form visions for a desirable future for healthcare.

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