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Barriers & Enablers to Transdisciplinarity in Practice: Emerging learnings from a pilot project exploring the potential for robotic capabilities to improve nursing work

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Transdisciplinary (TD) knowledge integration is required to tackle complex societal challenges, such as shaping the future of work for nursing care in the face of workforce shortages. However, moving from theoretical considerations on what makes TD work to real-world practice is hard and often case-specific, leaving little room for actionable methodological guidelines. The aim of this paper is to disseminate TD content and process learnings from a 6-month pilot project at a Dutch academic hospital. The project was commissioned by a senior human-robot interaction researcher in December 2022 after he presented a vision of transdisciplinary research integration to shape the future of work. This vision translated into an approach where roboticists, designers, psychologists, organisational scholars, and nurses strived to integrate academic, professional, and experiential knowledge. As a result, the core project activities were performed by a team of four junior researchers representing four out of five of these disciplines in collaboration with eight practising nurses. We particularly focus on the second half of the project, where, over the course of three months, the core project team engaged in a four-stage TD research process:

1. Grounding in literature and research site
2. Understanding current nursing work processes

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3. Joint exploration of preferable and plausible future work processes supported by robotics (TD workshop)
4. Sensemaking and joint reflection

This paper aims to capture our learnings about content—the lived experience of oncology nurses and potential avenues for change on the work floor from an organisational, interaction design, worker and robotics perspective—and about the process—barriers and enablers of transdisciplinary practices as reflected upon by the authors. We have come to understand this project as a meeting of two hierarchical systems of knowledge production: a TD System (an academic and innovation consortium of which the authors of this paper are part) and a Convergence System (representing the commissioning organisation: academic hospital aimed at accelerating technological innovation in health). Both systems contain academic- and non-academic actors with specific knowledge, expertise, experiences, interests, and power dynamics, providing for rich learnings and challenges within and across (sub)systems. We report on the project genesis, what content was learned from the four-phase methodology, and most importantly—what we learned about the process that can be taken into subsequent TD projects that aim to understand and shape the future of work with and for workers.

KEYWORDS: transdisciplinary research; human-robot interaction; healthcare design; nursing; human-centred design; organisational change

RSD TOPIC(S): Cases & Practice, Health & Well-Being, Methods & Methodology

Introduction

Transdisciplinarity is a research strategy and innovation approach considered necessary when addressing complex societal challenges (Renn, 2021; OECD, 2020). We see transdisciplinarity as distinct from multi-disciplinarity and interdisciplinarity, as comprising three main aspects of knowledge integration:

- value-driven interdisciplinary knowledge production
- the necessity to integrate experiential and pragmatic modes of knowledge production
- the importance of taking a complex systems perspective that embraces emergent knowledge production (van der Bijl-Brouwer, 2022).

While the case for transdisciplinarity is increasingly made cogent (e.g., Phol, 2007, 2011; Klein, 2013; Bammer et al., 2020; van der Bijl-Brouwer, 2021), there are few clear guidelines on how to deal with the various drivers, restraints, interests, and expectations of the different actors involved. Case studies in the literature do not always describe how to structure TD research projects in practice (e.g., Oyinlola et al., 2018) and are hard to generalise or translate to other domains for TD practice—TD processes are emergent and context-dependent in nature (clear discussion in Lawrence, 2015; Pohl & Hirsch-Hardon, 2008; van der Bijl-Brouwer, 2022). Relatedly, there is a lack of guidelines on how to engage with the emergent nature of TD, how to translate TD theory into practical activities, and how to organise TD collaboration to achieve knowledge integration (for meta-discussion of 41 TD studies, see Scholz and Steiner, 2015).

The authors of this paper advocate the sharing of transdisciplinary research experiences that contend with barriers, enablers, and transparent reflexive activities. When we started the 6-month TD project reported in this paper, we searched the literature for other case studies that could be relevant to us. Specific case studies from different domains (e.g., sustainable housing, see Oyinlola et al., 2018) or even the same domain (e.g. health studies, see Archibald et al., 2023) were not easily translated to our domain of interest, and general insights from a review of 41 transdisciplinary studies (Scholz & Steiner, 2015) were difficult to translate into concrete choices around—for example—which disciplinary backgrounds to involve, which research methodologies to

use, which stakeholders to engage with (and how many), and how and when to organise what activities with whom.

This paper reports on the barriers and enablers the authors experienced during a first-time engagement in TD practice. We aim to contribute to the Systems Thinking and Design community as newcomers, seeking more tangible and actionable TD guidelines, heavily drawing upon the reflexivity activities throughout the project, but especially during the writing of this paper. Our goals are to hone our practice of engagement in a wider learning ecology (see reference to FRAIM and our academic consortium below), to provide pointers to TD practitioners in and beyond the systems thinking and design community, and to integrate knowledge relevant to social learning when addressing complex social challenges.

Nursing staff shortages and the potential of robotics

The project was commissioned by FRAIM to explore how robotics might help deal with (the impact of) staff shortages in nursing. Staff shortages have a negative impact on the workload of nurses and their ability to deliver adequate care and ultimately affect retention and recruitment efforts (Adams et al., 2021; Alameddine et al., 2017). Nursing staff shortages are expected to increase due to growing healthcare demands, particularly in a rapidly ageing population. We thereby acknowledge the nursing workforce shortage as a complex problem situation or grand challenge (Renn, 2021) relating to the many different stakeholders in the healthcare ecosystem and the system's inherent complexity (Drennan & Ross, 2019). Addressing this challenge is imperative for the sustainability of the healthcare system. Technological innovations, including robotics, are put forward as potential solutions to address this challenge. These innovations can range from low-tech quick wins to high-tech future prospects and may encompass the digital (software, data), the physical (tools and machines) as well as AI-powered robots.

Despite the many projects exploring robotics for healthcare systems, e.g., see Kyrarini et al., 2021; di Lallo et al., 2021), the actual integration of robotic systems into hospital work processes is limited. Already a decade ago, Alaiad and Zhou (2014) highlighted the oversight of social challenges in implementing robotics in specialised and highly complex environments like hospitals. Such environments necessitate intensive research

on human-robot interaction and psychological barriers to acceptance (Maalouf et al., 2018). In addition, a diverse group of stakeholders (i.e., nurses, doctors, patients, relatives, and support staff) with unique perspectives, interests and priorities should be considered. Therefore, we challenge the notion that grand challenges such as nursing staff shortages can be addressed by merely 'rolling out' (robotics) solutions in the organisation, expecting this to lead to nurses' adoption. Instead, we take a TD approach and carefully consider how expectations develop, relying on learnings that can take place within this TD process that will contribute to a more informed and value-driven perspective.

History of our case study

We report our learnings from a 6-month pilot study, serving as an opportunity to put into practice an untested TD approach aimed at understanding and shaping the future of physical work. This TD approach was generated by a consortium of 35 scientists from 5 Dutch universities of varying disciplinary backgrounds and innovation partners from field lab RoboHouse at TU Delft while preparing for a large 10-year grant proposal. This paper focuses particularly on the second half of the project, aimed at understanding current and future workplace attractiveness for nurses and how robotic capabilities might contribute to that. Yet, to interpret what we did and why and to understand what we learned (both about content and process of TD research in practice), it is important to be aware of the project's history.

In November 2022, author DA presented the vision and activities of the transdisciplinary research centre FRAIM² at the Convergence³ Health Tech event. DA was subsequently commissioned by Convergence Health and Technology to perform a

² FRAIM is a TU Delft initiative led by author DA, integrating innovation knowledge (grounded in field lab RoboHouse) and interdisciplinary knowledge from the large consortium of 35 researchers at five Dutch universities. FRAIM aims to understand and shape the future of work, by engaging in mission-driven transdisciplinary research and innovation with and for workers, currently focusing on physical work processes and the potential of robotics to understand and help improve workplace attractiveness.

³ Convergence is an initiative between TU Delft (TUD), Erasmus University Rotterdam (EUR) and Erasmus Medical Centre (EMC) that aims to accelerate technology-driven innovation. We interacted with part of that initiative: Convergence Health & Technology.

six-month project at an academic hospital (Erasmus Medical Centre in Rotterdam), using funds available that required immediate spending in December. After expressing his inability to lead and supervise the project until mid-February due to the final stages of grant submission and negotiating the majority of the work could start then, he proceeded to reach out to the Dutch consortium to deliver good candidates for an interdisciplinary team of junior researchers, to be appointed within two weeks.

The aim of the TD project was to create opportunities to develop epistemic intelligence (van der Bijl-Brouwer, 2022) between and across the four disciplinary perspectives represented by the core project team by focusing on robotic capabilities to improve nursing work. During the first phase of the pilot project (December 2022 to February 2023), several challenges emerged that influenced the second phase of the TD project (March to May 2023). We highlight three challenges that the authors all experienced as influential for the process.

First, the core project team (authors AA, SM, SB, TK) experienced a lack of onboarding during the first phase and had little interaction with the FRAIM supervisors (authors EV, DF, DA). The need for a 'fast launch' resulted in the actors' roles not being clear from the outset, which made them only start to understand the interests and expectations of the different parties as the collaboration unfolded.

The lack of interaction between the core project team and FRAIM supervisors (due to FRAIM actors having limited to no time to invest in supervision, mentoring and collaboration) resulted in a second challenge: unproductive collaboration dynamics between the core project team and supervisors. The core project team learned to work cohesively but was isolated from FRAIM supervisors, with insufficient trust built up towards the supervision team. This carried over into the second phase of the project when FRAIM supervisors stepped back in. Despite shifting focus from the logistics project to nursing and the FRAIM supervisors being eager to contribute, collaboration dynamics were characterised by frequent frustration and misunderstanding. Several long reflective sessions were required to understand each other, grow trust, and re-establish constructive collaboration dynamics.

Third, the originally agreed-upon topic for the TD project of 'understanding current and future workplace attractiveness for nurses and robotic capabilities' possible role therein'

was discarded by Convergence system actors at a kick-off meeting organised by FRAIM supervisors in December 2022. Instead, Convergence actors proposed a different direction and department, providing a relevant work case: innovation for logistics in the operating theatre. As this happened after principal investigator DA left the meeting, this suggested 'power confusion: neither TD nor Convergence system actors felt authorised to speak up to defend the previously agreed-upon topic. Particularly core project team members were surprised to be working on a different topic than initially hired for.

Methodological approach

Our research stance

The overarching goal of this transdisciplinary research project was twofold: to learn about the content (the lived experience of oncology nurses and potential avenues for change on the work floor from an organisational, worker, and robotics perspective) and to learn about TD processes (gaining experience in TD practices, while identifying barriers and enablers of TD). Supporting this broad aim, we adopted a qualitative inductive approach and a process-oriented sensibility (cf, e.g., Gioia et al., 2013; Langley et al., 2013) to leave room for emergent findings, insights, and learnings.

Two knowledge production systems: the transdisciplinary system and convergence system

Based on our reflexive activities during the writing of this paper, we came to understand the transdisciplinary work we did as two distinct systems of knowledge production assembling for a pilot project: a transdisciplinary (TD) system and a convergence system (Figure 1). In an ideal setting, actors within these two systems jointly engage in knowledge production. However, in practice, actors from both systems invested considerable effort into creating an environment for joint exploration and knowledge production. Joint exploration- and reflection activities were achieved by including all tiers in certain activities while only collaborating between specific tiers in others (e.g., actors advocating for transdisciplinary collaboration in their respective systems and the two systems jointly engaging in exploration).

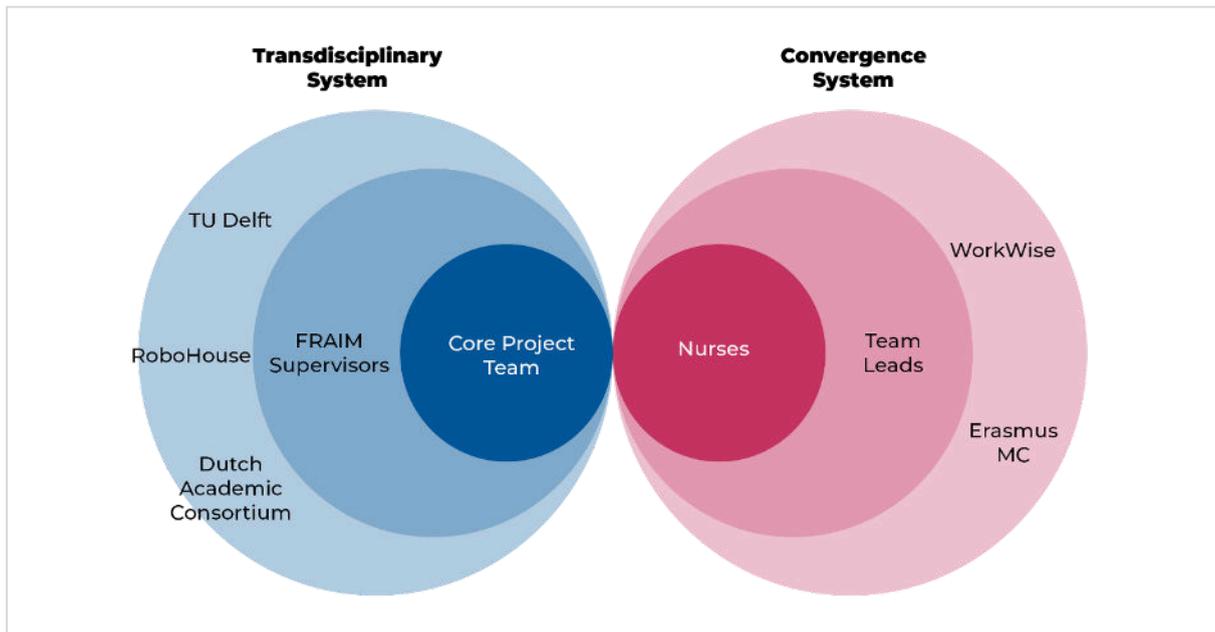


Figure 1. An Idealised structural schematic of the project representing the dynamic confrontation between two hierarchical three-tier systems of knowledge production. Learning and knowledge production happened during several key activities (see also Figure 3).

Tiers and actors in the knowledge systems

Each system consisted of three tiers involving different actors (Figure 1). For the TD system, the inner tier comprised of core team members (AA interaction design, SM organisational change, SB robotics, TK nursing science), supported by tier 2: the FRAIM supervision team (senior researchers DA and DF). The third tier represented involved organisations and consortia: RoboHouse, TU Delft, and the Dutch Academic Consortium. DA served as a representative for all three organisations in tier three. RoboHouse was represented by innovation lead EV. Several researchers from the Dutch Academic Consortium, among which author CZ, attended the TD workshop or provided feedback on the paper.

In the convergence knowledge system, the inner tier consisted of eight practising nurses at the ErasmusMC oncology department, supported by tier 2: nurses' team leads (n=4). Team leads also supported the TD system in activity scheduling and providing nurses. The third tier represented the organisation of Erasmus Medical Centre, and relevant

actors included a professor in Nursing Science, a board advisor to strategic Convergence projects, a programme manager from the nursing programme WorkWise, and a Convergence professor bridging TU Delft and Erasmus MC. These all helped advocate internally for collaborating with FRAIM, providing funding, and, at times, stepping in to streamline the organisation or speed up the scheduling of activities.

Initial project contracting

As discussed in the history of our case, the outer tiers of the TD and convergence system were involved in commissioning the project, with DA representing the TD system (TU Delft/RoboHouse/Dutch Academic Consortium) and actors from ErasmusMC representing the Convergence system. They agreed on four key approaches to organise the TD project:

1. The central position of nurses as experts in their work processes and lived experiences
2. Linking the project to a larger ecology of learning (represented by the outer tiers of both knowledge systems)
3. Taking a transdisciplinary approach through establishing a TD core research team (inner tier of the TD system). For this project, the roboticist and designer, recently graduated MSc students from TU Delft, worked 30 hours per week for six months. The organisational scholar and nursing scientists were PhD candidates, working 12 hours and 4 hours, respectively
4. Roughly organising the project in four phases: grounding, understanding, joint exploration, and sensemaking and joint reflection

TD project activities

We conducted TD activities across four phases (see, e.g., Scholz & Steiner, 2015). Actors were involved differently during each phase, visualised in Figure 3 as different streams coming together in various activities.

Phase 1: Grounding. The core project team grounded themselves and each other through academic (conducting a scoping literature search across the four disciplines) and pragmatic learning (familiarising themselves with organisation, negotiating access

to spaces and people, and establishing relations within Erasmus MC and various departments interested in innovation). This phase also characterised the increased regularity of meetings between the FRAIM supervisors and the core project team.

Phase 2: Understanding. The core project team gained a more experiential understanding of nurses' current work processes and attractiveness through a) 'shadowing' two nurses (one male (surgical oncology) and one female (internal oncology) in their daily practice applying ethnographic methods (e.g., Ball & Christensen, 2018); b) semi-structured interviews revolving around the construction of spatial maps by the nurses and c) analysing and visualising (Bresciani, 2019) the collected experiences in transition and empathy maps.

Phase 3: Joint Exploration. To bring together the two knowledge production systems, with nurses at the core as experts in their practice, we planned for a TD workshop. In preparation, we involved several experts from the Dutch Academic Consortium (tier 3) to arrive at a workshop plan that would facilitate joint knowledge production between systems, allowing both learning about content and process. Design methods (e.g., Dorst & Cross, 2001) served as a backbone and were modified to accommodate other disciplinary perspectives (see, e.g., Bowen et al., 2016). We brought together a wide range of actors across the three tiers of both systems to engage in four activities during the TD workshop: a) spatial mapping of nursing practice; b) exploring practitioners' sentiments regarding specific nursing tasks; c) engaging in parallel speculative ideations (Bleecker, 2009; Lindley & Coulton, 2016; Tanenbaum, 2014) exploring robotic capabilities and desired nursing futures (featuring a PANDA robot arm), and d) discussion and joint reflection on learnings by/for both systems.



Figure 2. An impression of activities at the TD workshop, with nurses central to exploring future nursing work using design speculation (left) and experiential confrontation with robotic capabilities (right).

Phase 4: Sensemaking & Joint Reflection. The core project team synthesised and shared insights from the previous phases at a final meeting where actors representing all tiers from both systems were present. These were discussed and jointly reflected upon, after which actors from both knowledge systems envisioned possible future collaborations and intentions.

Note that the enactment of these activities borrowed heavily from ethnographic methods and interaction design but were by no means mere execution of the prototypical methods (e.g., journey maps, speculative exploration, etc.) The interaction designer (AA) in the core project team, guided by a disciplinary mentor (third-tier TD system), provided an initial structure and approach for the workshop. Yet we noticed that design practice needed adaptations to fit with a structure and activities incorporating the other disciplines. This flexible reconfiguration of design methods, learning change to be more transdisciplinary, is advocated in recent work by one of our consortium members (van der Bijl-Brouwer, 2022). Thus confirming our inductive research stance as appropriate to fit the novelty of TD approaches.

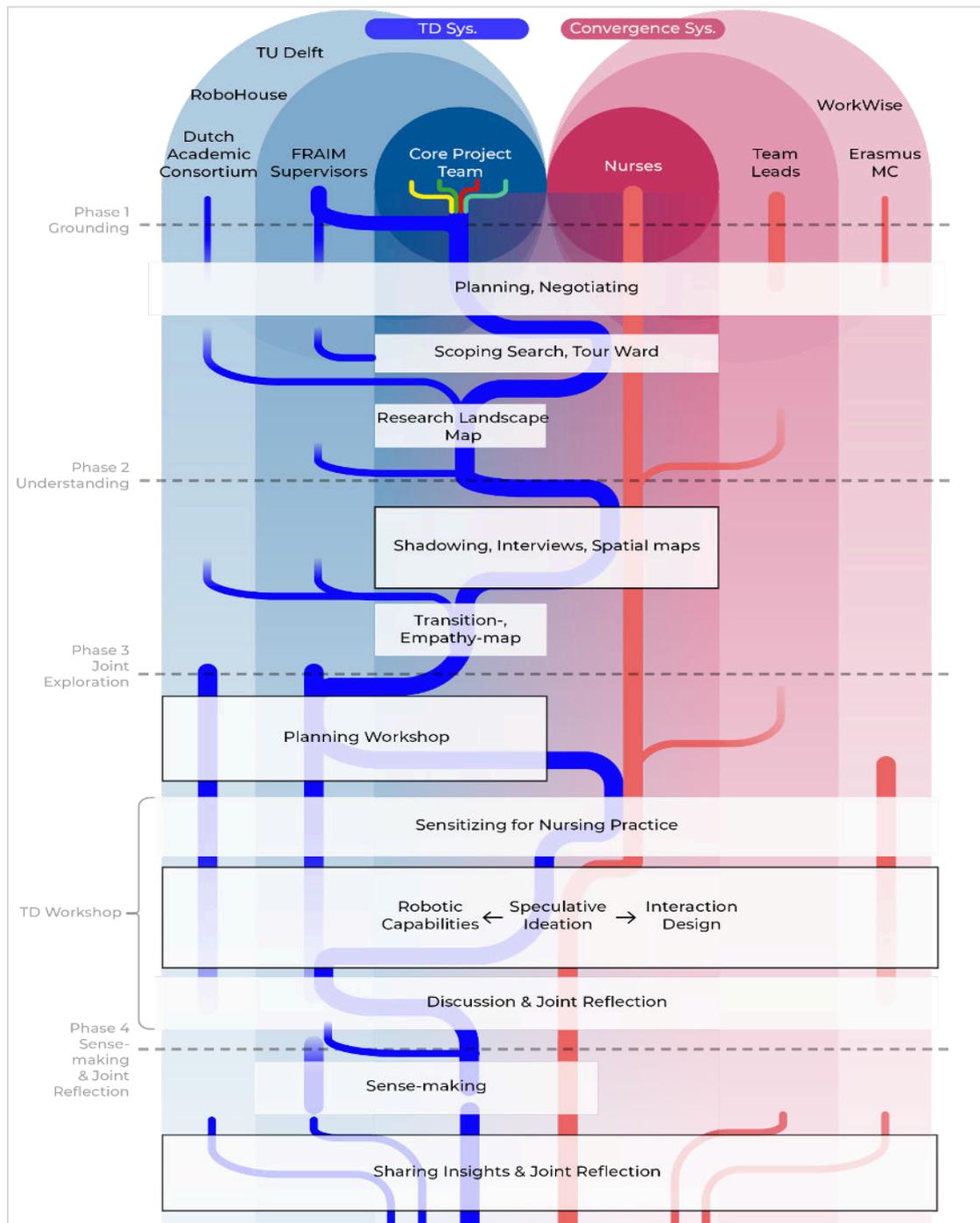


Figure 3. Activities of the two learning systems during the four phases of the 3-month project. The three tiers of the TD system (blue, left) interact with the three tiers of the Convergence system (red, right) in various activities mentioned in the text. Note: The varying line thickness indicates the perceived contribution of each tier. The thickness changes according to the different activities at any given phase.

Emergent knowledge integration

Here, we summarise what the authors considered key learnings regarding the content (see table) and the TD process (rest of the section).

Learnings about content	Related research agenda for the four disciplinary perspectives
<p>We obtained a joint experiential understanding of the complexity and diversity of nursing work processes. Hospitals are complex ecosystems with different actors (patients, patients’ relatives, nurses, surgeons, etc.) Therein, nurses experience work pressure, leading to care tasks not being performed as desired and work breaks often under pressure. Long walking distances, unstructured storages and hygiene regulations contribute to nurses’ spending less time with direct patient care.</p>	<p>Robotics: The experiential understanding of current nursing work and organisational complexity is sobering when considering what robotic capabilities are plausible for future robot-assisted work processes. Use cases for robotic assistance (such as delivery robots so nurses walk less and spend less time retrieving items or robot assistance for making beds) emerged, which can be approached through new robotic capabilities, including human-robot interaction techniques (voice-based so they can have their hands free, for example).</p> <p>Design: Nurses wish to spend more time with patients and could see robots assisting them with less desirable tasks such as walking back and forth and cleaning beds (so robots not taking over social tasks is desirable). The many different stakeholders in the hospital environment raise the challenge of finding robot behaviour acceptable to all, including those that cannot be trained.</p> <p>Organisation: Work pressures and insufficient time with patients are associated with reduced workplace attractiveness, negatively affecting retaining and recruiting personnel. Part of the solution to long walking distances may not be robotic in nature, but rather logistic (insufficient overview of where materials/medicines are stored)—and therefore better approached by other innovations (e.g., improved data systems, smartwatches).</p>
<p>Nurses are experts in creating workarounds in their physical tasks while aiming for patient care (e.g. while changing beds is not the most preferred task, nurses use it as a</p>	<p>Nursing science: More research into analysing current work processes (particularly how nurses spend their time, the amount of time spent on meaningful work, and barriers and facilitators to adoption).</p> <p>Organisation: The adaptability of nurses is key to high-quality patient care, yet the “don’t complain just solve it” attitude means</p>

Learnings about content	Related research agenda for the four disciplinary perspectives
moment to have a conversation with the patient)	<p>that ideas to improve work processes are not voiced or heard often enough. Secondly, nurses were worried that innovations allowing them more time with patients would lead to the organisation increasing patient numbers (i.e., more efficiency instead of time with patients).</p> <p>Robotics & Design: The adaptability of nurses is well beyond current robotic capabilities for the foreseeable futures—there is little risk of nurses being replaceable. However, understanding how robot-assisted work processes change the nature of work and how nurses and organisations would adapt to that requires longitudinal transdisciplinary research.</p>

The author team gained insight into the barriers that emerged in conducting a TD project. Actors from both knowledge production systems could address these barriers through several coping practices (enablers) by reflecting on them during and after the project. To illustrate the emergence of barriers and enablers, we first zoom in on the previously defined phases before zooming out to compare them analytically.

Phase 1 Grounding in literature and research site: Knowledge production mainly occurred within the boundaries of the TD System, particularly for the core project team and FRAIM supervisors. Convergence system's nurses provided insights into nursing practices to TD system actors at an ErasmusMC site visit, supporting the latter in familiarising with the research site (non-academic knowledge). The core project team also gathered academic knowledge through a literature search across the four disciplines. We identified two main barriers in this phase:

- mismatches in temporal structures (at boundary TD System—Convergence system actors) (see, e.g., Jarvenpaa & Välikangas, 2022)
- mismatches in envisioned collaboration practices (within TD system, between the core project team and FRAIM supervisors).

The first barrier originated in actors in the TD system facing time pressure to conduct the project (3 months), creating urgency to engage with nurses in sequential activities in a short time frame. However, it was virtually impossible for the Convergence system's nurses and team leads to adhere to this request since it was challenging to redistribute nurses from their daily work practices to TD activities. Actors from both systems attempted to work through this barrier by compromising on the amount of time, activities, and nurses in the project (enabler) to find a collaboration dynamic suitable for both systems.

The second barrier resulted from unproductive collaboration dynamics between the TD system core team and FRAIM supervisors in the first half of the research project. When the FRAIM supervisors attempted to reconnect in the first phase, the core team refrained from their previously established, cohesive, but isolated collaboration dynamic. Actors coped with this barrier through stimulating reflection practices (enabler), enabling actors to disclose experienced frustrations and misunderstandings.

Phase 2 Understanding current nursing work processes: Joint knowledge production started to emerge between the core project team and Convergence's nurses through observation and interviews. We identified two main barriers:

- mismatches in temporal structures resurfaced
- capturing the complexity and dynamism of nursing.

However, the first barrier soon diminished through the core project team and nurses connecting in the here and now (enabler) at scheduled activities and the core project team following the workflow of nurses (enabler). Both practices helped the system's actors to address this barrier—at least temporarily. Regarding the second barrier, the core project team soon realised how hard it was to capture nursing work's complexity, abandoning the intra-disciplinary observation protocols they initially planned to use. The core project team and nurses jointly addressed this barrier by reflecting on complexity using a boundary object (enabler). A spatial map served as a boundary object (Carlile, 2002; Hsiao et al., 2012), helping nurses gain insight into the diversity of their shifts and, through that, identify challenges and opportunities for improvement in their work processes. At the same time, the spatial map served as a tool for the core project team to understand and sensitise to the nurse's work processes, challenges, and

wishes. Reflecting on these learnings with FRAIM supervisors served as input for the TD workshop in phase 3.

Phase 3 Joint exploration: The core project team attempted to provide optimal learning conditions for joint knowledge production in both systems by facilitating a TD workshop, at which actors from all tiers of both systems were represented. In this phase, we identified three barriers:

- Mismatches in temporal structures resurfaced but were addressed through connecting in the here and now (enabler) and accommodating nurses limited availability (enabler) through providing the option of walking in/out of the workshop.
- Bridging knowledge boundaries between nurses (non-academic, experiential knowledge) and researchers (academic knowledge) for developing shared understanding as well as a shared vision for the future of nursing. TD and Convergence system actors addressed this barrier of different knowledge boundaries through experiential learning practices using a (robot) boundary object (enabler) and speculative narratives (enabler) expanding on objects or photos nurses brought from their own work practices (boundary objects). TD actors invited nurses to get a sense of and interact with the robot arm present. Subsequently, TD actors invited nurses to propose a task where robotics could possibly support them. The nurses propose 'making beds', and as roboticists and nurses think through the required robotic capabilities, the nurses start understanding the complexity of this task from a robotics perspective, while roboticists develop an understanding of tasks for which nurses would prefer robotics support. At the same time, speculative design narratives, constructed around objects familiar to the nurses, were used to envision additional functions or systems that could solve nursing-specific challenges. Nurses and researchers together envisioned a "smart wristband" and a "delivery robot" by describing what the (boundary) objects (things or photos from the nurse's practices) should/should not do.
- Capturing complexity and dynamism of nursing resurfaced (Convergence and TD system actors struggling with exploring suitable robotic capabilities), but was

also addressed through experiential learning practices using a (robotic) boundary object and shared envisioning of speculative objects.

Phase 4 Sensemaking and joint reflection: In the final phase, boundaries between the TD and Convergence systems blurred through a 4-hour insight-sharing and joint reflection session, with attendees from all tiers of both learning systems, including a closing dinner afterwards. The most important barrier was, again, bridging knowledge boundaries. What facilitated learning was for the authors to reflect their learnings to the entire joint learning system in a presentation and create the space for nurses and team leads to publicly state what they learned—which had a different effect than just telling the core project team. For example, when asked what they learned from the project, one nurse mentioned in the session how he now realised that his adaptive behaviour was not only his strength but also meant he adapted to unhelpful organisational practices without complaining, and he now realised he could discuss these with the organisation. Another nurse mentioned how this was the first time in seven years that he was included in an innovation study: this was normal for surgeons but not for nurses—and it was exciting, fun, and insightful for him. These public reflections stimulated system learning, and, as a result, those present could experience a moment where the joint system learned more than one system could achieve by itself. In the end, the authors valued this as one of the most important learnings for this TD project.

Overall, we identified barriers persisting over time between the TD and the Convergence system (mismatches in temporal structures) and within the TD system (mismatches in envisioned collaboration practices), as well as temporary barriers between the systems (capturing complexity and dynamism of nursing bridging knowledge boundaries). The persisting and temporary barriers were approached through a variety of enabling practices, where enabling reflexivity was key. Further, we highlight the possibly fruitful practice of “embodying boundaries” (Langley et al., 2019, p.717) in a transdisciplinary context. The core project team, at times absorbed tensions they encountered to enable collaboration in the first place (Yagi & Kleinberg, 2011). By acknowledging actors’ differing perspectives, they attempted to foster opportunities to articulate and negotiate differences—allowing potentially divergent actors to overcome the identified barriers. Embodying boundaries places people in a position of liminality where they function as thresholds between different groups. More generally, we draw

attention to the role of power dynamics within a transdisciplinary context. For example, to negotiate access to the research site under time pressure, the core project team could not address some barriers to the Convergence System by themselves and needed an actor with more power (DA) to negotiate access. We acknowledge that some barriers and enablers are not unique to TD projects. However, these barriers are amplified in a TD context due to the many knowledge boundaries existing across academic disciplines and between academics and practitioners. We learned that this required additional efforts from actors across systems—thus highlighting the key role of nurturing fruitful collaboration dynamics within and between these knowledge systems.

While the four research phases proved meaningful in this project, we see them as a dynamic guideline that would have to be adjusted depending on future contexts/problems, project duration, and knowledge systems involved. However, we see it as potentially meaningful to open up the space of possible solutions through a separate shared ideation activity before coming in with boundary objects such as robots. This would allow participants from all tiers to consider a broader range of future work practices before narrowing down discussions on currently feasible technology. Based on our experience, we especially advise more room (both physically and in a timely manner) to prototype and test out interactions/products/robots/etc.

Final remarks on the TD learning ecology

The rich learnings experienced during the projects and the writing of this paper cannot be captured in their entirety here. Yet, we would like to highlight key enablers that the authors will take with them to further projects that may be useful to others engaging in transdisciplinary research.

First, TD work takes time, patience, and effort from all actors involved, and already, this short project was a major source of learning. However, three months is too short for a TD project to go sufficiently deep into content. For example, no plausible robot-assisted work process was realised for nurses to experience during the TD workshop as originally intended, nor could we realise any substantial disciplinary research, and the authors needed at least a month more after the project ended to digest and capture learnings during the paper writing process. We also learned that a physical space where the core team could meet at least one or two days a week would have been beneficial,

which we advise for future TD projects. Still, even with the hard start and the corresponding 'repair work' in the TD system, the actors in the Convergence System spoke about the project as a success.

At the end of the final phase, we asked each actor, starting with the nurses: Now that you've experienced how we work together, would you like to continue this work if possible? All participants in the Convergence system said yes, and we noticed a shift from technology-driven efficiency aspirations to workplace attractiveness. Concrete plans were made to arrange a collaboration space and further funding to deepen the collaboration with five postdocs for two years. The team leads wanted to ensure it happened on their wards, and the involved nurses wanted to stay involved. The authors see this as the seeds of change. In short, future TD projects that aim to create trust and seeds of change should cover a time span of at least six months while ensuring sufficient follow-up during and after the process to prevent disappointment and distrust in workers and team leads. Therefore, we advocate for longitudinal programmes (in the order of 5–10 years) aimed at creating change in practice and academics through joint knowledge production and technology innovation.

Second, the regular joint reflexivity that happened during the process (including paper writing and beyond) was perceived as key to TD quality and collaborative practices. Ensuring sufficient time to reflect honestly about barriers and enablers of learning—both within the TD system and at joint events with the Convergence system—is something we will continue exploring in future TD projects in terms of frequency, depth and actors involved.

Reflections continued even during the writing of this paper when self-reflection gave rise to reflecting on actors in the same tier of the other counterpart system, which deepened insights into analogies and differences in experiences (e.g., around power dynamics). For example, since team leads in both systems are the mediating interface between the routine work and the larger system—they are also the most likely to provide continuity between projects. For short-term projects like this, the permeation of the produced knowledge (including towards following projects) depends heavily on the team leads. Key learnings from this project have already impacted planning and negotiations for the next TD project, coming on the heels of the nursing project, negotiated with a very different entity in a very different sector. For example, a 2-month

lag between the official project start date and core project team kick-off allows the TD System to prepare—so that the hiring process and onboarding of the core project team are more intentional and well-planned to accommodate the specific context, epistemic intelligence, and relationship building. Also, in terms of planning and expectation management, we negotiated up-front access to the counterpart site, regular moments of reflection and setting rough dates for joint-system events.

Finally, we see two events (the TD workshop in phase 3 and the reflective session in phase 4) as key for joint system learning. Because actors from all tiers in both knowledge systems were present, and because all the preparations in phases 1 and 2 accommodated relationship and trust building, we could learn from each other and, in doing so, learn together something larger than each system could do on their own.

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Reflexivity/Positionality

We want to explicitly acknowledge that the perspectives in this paper are limited to the interpretation of the authors: a select group of researchers and practitioners directly involved in the project execution. Consequently, much of the knowledge and expectations from actors not in the author list are taken from explicit statements or inferred from implicit statements and interactions during the project. Core project team members (AA, SM, SB, TK) are junior researchers who have been most engaged in daily knowledge integration across disciplinary boundaries. Note that author CZ was part of

the large Dutch academic consortium that advised us both during preparatory meetings and the writing of this paper. The last three authors formed the FRAIM supervisory team that participated directly in some phases, supervised and collaborated with the core project team, and facilitated processes (including learning) with the other tiers in the TD and Convergence systems.

Note that although all authors had received academic training in their lives, they come from different professional, disciplinary, and cultural backgrounds, bringing together a variety of expertise, epistemologies, interests, biases, value frameworks and amount of experience in engaging in research and innovation. This variety highlights the significance of disclosing our positionality, influenced, for example, by qualitative epistemologies (Bourke, 2014), by feminist standpoint theory (Bardzell, 2010; England, 1994) and by educational research (Milner, 2007). Our research was informed by the confrontation between different epistemologies like pragmatism, speculation, designerly ways of knowing, social constructivism, and positivism (an engineering mindset), with respect for utilising intuition, feelings and other ways of knowing. Our methodologies were strongly grounded in ethnographic methods, interaction design and participatory design while bringing in expertise from the larger consortium in showcasing robotics capabilities. During the second half of the project, the core team and FRAIM supervisors engaged in various reflexivity activities to reflect on barriers and facilitators in collaboration and knowledge integration, as well as on power dynamics in our own TD system and in the Convergence system, which influenced and challenged research decisions. We iteratively discussed with the authors how to deal with our positionality in a spirit of co-sense making—which has influenced our meta-analytical lens and our writing style.