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An Exploration of Experiences of Transdisciplinary Research in Aging and Technology

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Key words: transdisciplinarity; team science; semi-structured interviews; thematic analysis; aging and technology; communication; barriers; promising practices

Abstract: Transdisciplinary research (TDR) involves academics/scientists collaborating with stakeholders from diverse disciplinary and sectoral backgrounds. While TDR has been recognized as beneficial in generating innovative solutions to complex social problems, knowledge is limited about researchers' perceptions and experiences of TDR in the aging and technology field. We conducted a qualitative study to address this knowledge gap by exploring how members of a pan-Canadian research network on aging and technology perceived and experienced TDR. Thirty members participated in semi-structured interviews. Interview data were analyzed thematically. Participants identified benefits that can be gained from implementing TDR, including mutual learning, improved capacity to understand and solve problems, and community engagement and empowerment. Participants also identified challenges to implementing TDR: communication issues and conflicting priorities among team members; tensions between traditional and TDR approaches; and difficulties identifying partners and developing partnerships. In addition, contradictions between TDR principles and participants' understanding of them became apparent. Nevertheless, some participants described successful strategies for implementing transdisciplinary principles in their projects: stakeholder engagement; language and goal sharing; and open, respectful communication. We offer recommendations to support TDR in aging and technology that focus on education and reform of the culture and values that can constrain efforts to practice TDR.

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1. Introduction

Developing usable technologies that can have positive impacts on older adults' daily lives is a complex endeavor because the problems that technologies aim to address are typically multifaceted—that is, they comprise physical, cultural, and systemic factors. Understanding and solving a complex social issue that currently has neither conclusive nor objective answers, generally referred to as a "wicked problem" (RITTEL & WEBBER, 1973, p.160), requires a multifaceted approach that encapsulates cross-disciplinary and cross-sectoral collaboration and input. Engaging older adults as research partners is essential when developing technologies to enhance their everyday lives. This is because such engagement can facilitate the co-development of project goals and the co-design of solutions that are meaningful to older adults. In addition to working with older adults, it is imperative to involve academics with expertise in aging-related challenges. Such individuals include: health professionals or scientists who are knowledgeable about how age-related physical and cognitive decline shapes older adults' use of technologies; computer scientists who can develop programs and applications for enhanced communication and interaction; and engineers who are able to create more intuitive user interfaces that can guide older adults and improve their experiences of technology use. Industry-related expertise is also essential in order to both produce marketable products and then effectively commercialize them. In short, if a technology is to be developed and then, in this specific example, adopted by older adults, the project partners should bring expertise from a variety of disciplines and professional and experiential backgrounds, and work together so that all aspects of the development and commercialization process are effectively integrated. The requisite integration is unlikely to happen if the project partners are working in isolation within their own areas of expertise rather than as part of a team comprised of individuals from multidisciplinary and multi-sectoral backgrounds. [1]

Multidisciplinary, interdisciplinary, and transdisciplinary approaches are the three discrete forms of a team-science approach to research. These three terms are frequently used interchangeably, and this apparent lack of understanding of their differences could in itself be considered a barrier to taking a team approach to a problem. The three approaches are similar in that they all involve cross-disciplinary collaboration, but they differ in how knowledge is exchanged and leveraged. In a multidisciplinary research approach, everyone works on the same problem, but they do so within the siloed boundaries of their own disciplines, using their own disciplinary assumptions, methods, and frames of reference. In interdisciplinary approaches there is some overlap of disciplinary boundaries, with some blending of common assumptions, restrictions, and philosophies. In a transdisciplinary research approach, there is greater integration and collaboration, as well as an explicit focus on the integration of academic and non-academic knowledge, which leads to a co-production of knowledge that transcends disciplinary and sectoral boundaries. This transcendence of diverse knowledge occurs through greater participatory collaboration between diverse academic and experiential stakeholders (e.g., individuals who have lay knowledge or "lived" knowledge), and engagement in mutual learning, sharing, and crossing

disciplinary/sectoral boundaries in the design, development, prototyping, and commercialization of technologies (BOGER et al., 2017; CHOI & PAK, 2006; GRIGOROVICH, FANG, SIXSMITH & KONTOS, 2019). [2]

In the field of aging and technology, this has meant in practice that researchers from different disciplinary backgrounds collaborate as equals with key experiential and sectoral stakeholders (e.g., older adults, carers, community organizations) to identify a real-world problem, develop the objectives of a project, and then design the project in order to create solutions to the problem. The problems identified to date in this way vary from older adults' mobility issues to social isolation, to cognitive decline, to caregivers' health issues. The research team investigates the problem and needs of those affected by it and designs a technology that can (potentially) solve the problem (e.g., assistive technology, a communication platform software program [AGE-WELL NCE, n.d.]), develops and tests a prototype of the technology, and refines the design and functionality based on the test results. A key characteristic of this process is collaboration with industry partners who have equal status to the researchers. This is a critical component of TDR and is intended to ensure the marketability of technological products that can solve the problem. [3]

While it is not yet known which research approach is the *most* useful/productive, there is evidence to support the merits of TDR for facilitating holistic understandings of a problem area and generating more effective solutions through cross-boundary knowledge exchange and integration (KLEIN, 2008; POHL & HADORN, 2007; STOKOLS, MISRA, MOSER, HALL & TAYLOR, 2008). There is also evidence that adopting a transdisciplinary research approach has multiple benefits, including: acquiring a fuller understanding of a problem (BENARD & DE COCK-BUNING, 2014; HALL, STOKOLS et al., 2012; JORDAN, 2006); increased research productivity (HALL, STOKOLS et al., 2012; VANASUPA et al., 2014); effective knowledge translation through broader dissemination of research findings (STIPLEMAN et al., 2014); and improved learning and training outcomes for students (BALSIGER, 2015; BENARD & DE COCK-BUNING, 2014; POHL & HADORN, 2007; STOKOLS et al., 2008). [4]

A growing international body of literature argues for the need to adopt TDR in aging and technology (SIXSMITH & GUTMAN, 2013). This approach is also encouraged internationally at the public policy level, as reflected in the multi-million dollar public research investment in TDR initiatives (e.g., Canada's Aging Gracefully across Environments using Technology to Support Wellness, Engagement and Long Life [AGE-WELL] NCE Inc., the U.S.'s Transdisciplinary Collaborative Centers for Health Disparities Research Program, and Ambient Assistive Living Technologies for Wellness, Engagement, and Long Life, which is jointly funded by Canada, the UK, and Sweden). However, because transdisciplinarity is a relatively new approach in this field, there is limited knowledge regarding researchers' perceptions of TDR and their experiences with this approach (GRIGOROVICH et al., 2019). Such knowledge is integral to further developing transdisciplinary approaches in this field so their benefits for promoting holistic, relevant research, and for societal problem-solving can be fully

realized. Therefore, we conducted a study to expand the current knowledge base by exploring the perceptions and experiences of TDR in AGE-WELL, the Canadian Network of Centres of Excellence on aging and technology. The AGE-WELL network offered a unique and timely opportunity for this study, as it not only represents a national-scale research network, but it is also the largest pan-Canadian initiative for collaborative team-based research focusing on aging and technology research and development. AGE-WELL explicitly advocates the implementation of TDR not just within individual projects, but also more generally across the research network. Our study therefore constitutes both a unique and important opportunity to discover more about perceptions and experiences of TDR in the context of aging and technology projects in order to both identify barriers and challenges to the implementation of TDR, and also suggest how the AGE-WELL network may be able to address them. As the aging population rapidly increases across the world, many countries are experiencing unprecedented complex, interrelated social issues—such as new and more challenging health care demands and associated increasing financial costs—which require collaboration across disciplines and sectors in order to develop innovative solutions. Given the dearth of national-level research networks across the globe that also focus on aging and technology development using TDR, the research in this article can uniquely contribute both nationally and internationally towards advancing an understanding of TDR in this field. [5]

This article comprises methods (Section 2), findings (Section 3), discussion (Section 4), and conclusions (Section 5). In the methods section, we describe the strategies that we used for sampling, recruitment, and data collection and analysis, and summarize participants' disciplinary and professional backgrounds and roles in the AGE-WELL network. In the findings section, we highlight four key themes that illustrate participants' perspectives and experiences of TDR, and in the discussion, we delineate four implications for supporting the implementation of TDR in the field of aging and technology. We summarize the findings and emphasize the importance of future efforts to foster TDR in the conclusions section. [6]

2. Methods

This was a qualitative research study in which we used semi-structured individual interviews in order to facilitate an in-depth exploration of participants' perspectives and experiences of TDR. All data were analyzed thematically drawing on BRAUN and CLARKE's (2006) analysis techniques. [7]

2.1 Participants

All members of the network were eligible to participate in this study, including administration and management, researchers and trainees (e.g., students and postdoctoral fellows), advisory group members, and partners. We used purposeful sampling (PATTON, 2002) for recruitment to maximize participant diversity in terms of: 1. their role in the network (e.g., investigators, trainees, administration and research management, advisory group members, affiliates,

partners); 2. the environment they work in (e.g., science/academia, industry, policy, community); 3. their knowledge and training (e.g., discipline, sector); and 4. their career stage (e.g., professor, executive/director, research coordinator, trainee, retired professional). The network's managing director facilitated recruitment by sending a network wide e-mail invitation on our behalf to participate in the study to members (including more than 200 researchers, 250 partners, and 480 trainees). This e-mail described the study objectives and protocol, and provided contact information for the principal investigators. Our aim was to recruit 30 participants into the study in order to generate rich information which could be analyzed for commonalities, uniqueness, and context specific nuances. [8]

Thirty members were recruited into the study. Twenty-three percent of participants were from health and rehabilitation sciences, and 13% reported that their backgrounds were technology-related (e.g., educational technology, engineering) (Table 1). Most participants were from the scientific/academic sector with network investigators and trainees accounting for 40% and 30% of participants respectively. The project was approved by the University Health Network Research Ethics Board and the Office of Research Ethics at Simon Fraser University.

Discipline	**n**	**%**[1]
Health and rehabilitation	7	23.3
Technology (educational technology, technology, engineering)	4	13.3
Public health	3	10.0
Computer science	2	6.7
Education	2	6.7
Management	2	6.7
Psychology	2	6.7
Other (e.g., neuroscience, immunology, geriatrics, gerontology, business, literature, social work, law)	8	26.7

Table 1: Participants' disciplinary and professional backgrounds

1 Percentages sum to 100.1% due to rounding.

Primary network role	**n**	**%**
Investigators	12	40.0
Trainees	9	30.0
Network leadership	2	6.7
Partners	2	6.7
Undisclosed	1	3.3
Other	4	13.3

Table 2: Participants' primary network roles [9]

2.2 Data collection

We used semi-structured in-depth interviews to collect data because they are an effective way of accessing complex human experiences without imposing a priori ideas that may limit the scope of our understanding of people's subjective lived realities (FONTANA & FREY, 2005). In our study, each participant was invited to participate in a 60- to 90-minute interview. All interviews were conducted by author AG in person (n=8) or by phone (n=22), at the convenience of each participant. The interviews covered: 1. how network members understood TDR; 2. how network members experienced working in large team-science initiatives with diverse stakeholders; and 3. perceived facilitators and barriers regarding the practice of TDR in aging and technology projects. The interviewer used a semi-structured interview guide which included open-ended questions to allow for more of a discussion with the interviewees, and to thereby facilitate sharing of their perspectives and experiences of transdisciplinary working within the network. To enhance the ability of non-native English speakers to participate in the study, we offered participants the option of being interviewed in the language of their choice with an interpreter present. Two participants accepted this offer and were interviewed in French. [10]

2.3 Data analysis

Interviews were digitally recorded, translated where necessary, professionally transcribed verbatim, de-identified to ensure anonymity, and analyzed using thematic analysis techniques (BRAUN & CLARKE, 2006). This process began by author MW reading and re-reading the transcripts, and then subsequently leading the development of the initial set of descriptive codes using the qualitative data analysis software NVivo 11. We independently read the transcripts and contributed to the development of codes. Initial codes were then collated into categories that captured the semantic content of the data, and were subsequently clustered into categories to create overarching themes that encapsulated participants' perceptions and experiences of TDR across role, research environment, discipline/sector, and career stage. Patterns were generated across the categories which were organized into provisional themes and sub-themes by

author MW but with input from all of us. Full team discussions were held to negotiate and agree on the themes and the overall interpretation of the data. In this way a more nuanced understanding of the data was developed. In addition to our inductive approach to generating codes that captured participants' perceptions and experiences, we adopted a deductive approach by examining points of intersection and disconnect between the data and existing TDR principles for the field of aging and technology developed by BOGER et al. (2017). [11]

3. Findings

Our analysis generated four key themes (Table 3): 1. perceived benefits of a transdisciplinary approach; 2. challenges to implementing TDR; 3. contradictions between key TDR principles and participants' understanding of them; and 4. promising practices for TDR. All the key themes, with the exception of "contradictions between TDR principles and participants' understanding," have three sub-themes. In the direct quotes below, participants are identified by "P" to indicate "participant" followed by their identification numbers.

Theme	**Sub-theme**	**Example codes**
Perceived benefits of TDR	Mutual learning and growth Improved capacity to understand and solve issues Community engagement and empowerment for older adults	Broadened perspectives Better outcomes Meaningful participation
Challenges to implementing TDR	Communication and conflicting priorities among team members Systemic and cultural barriers: Academic and organizational expectations Identifying partners and developing partnerships	Technology literacy Shared interests and values Lack of interest in collaboration
Contradictions between TDR principles and participants' understanding	n/a	Partnerships with stakeholders Knowledge integration
Promising practices for TDR	Involving experiential stakeholders as research partners Developing shared language, values, and research objectives Conducting open, ongoing, and respectful communication	Accessible language Relationship building Team formation

Table 3: Themes, sub-themes, and example codes regarding participants' perceptions and experiences of TDR [12]

3.1 Perceived benefits of a transdisciplinary approach

Participants described a number of perceived benefits of TDR: mutual learning and growth; improved capacity to understand and solve issues; and community engagement and empowerment for older adults. [13]

3.1.1 Mutual learning and growth

TDR was viewed as creating opportunities for investigators and trainees to learn from each other and to enhance their academic knowledge, perspectives, and skills to solve a particular problem. For example, P16, an investigator, explained:

> "[T]here's actually something beautiful and satisfying when you hear somebody describe something you were thinking about with one perspective, one lens that you're using, and to hear people describe it in another way is sometimes completely different ... [and this] expands your understanding of different ... way[s] of looking at phenomena." [14]

By encouraging academics/scientists to collaborate with stakeholders from diverse disciplinary and sectoral backgrounds, TDR offers opportunities for academics/scientists to be exposed to new perspectives; exposure, in turn, alerts them to the limitations of their own disciplinary "lens" and extends the horizon of their knowledge of various topics and experiences. TDR was also perceived to expand knowledge of diverse research methods. For example, P6, an investigator, stated: "[Y]ou'll be able to apply different methodologies that say one person might not know or be familiar with ... and it just means that you learn a lot more from the research." Trainees recognized that their exposure to multiple perspectives, concepts, and methods from diverse disciplines and sectors in the context of training in TDR helped them understand real-world problems more holistically, which in turn increases their capacity to develop better solutions to those problems. [15]

Sharing and integrating different disciplinary knowledge and perspectives within a team comprised of individuals from multidisciplinary backgrounds was perceived as leading scientists/academics and trainees to reflect on, and become aware of, not only their own knowledge about their field(s) of interests, but also the application and "value" of their disciplinary knowledge and skills in the pursuit of shared team goals. As an example, P11, a trainee, noted: "[T]he benefit of working in a large team is that ... you learn sort of where your place is, how you can add value relative to everybody else and how they're adding value." [16]

3.1.2 Improved capacity to understand and solve issues: "Collective expertise"

In addition to being viewed as increasing a team's ability to understand issues of interest, TDR was also experienced as expanding the capacity of a team to design research and tackle complex issues, which was thought to lead to "better" research outcomes. Participants emphasized the importance of understanding

the perspectives of individuals directly affected by the problem that they were trying to solve with technology. For example, P16, an investigator, noted:

> "[W]e construct a lot of our own reality and ... unless you understand that from the perspective of people who are providing care, it's very difficult to be able to do things, like introduce change or to look at sustainable adoption of new technologies, unless you understand the perspective you can't design process but again, have a higher likelihood of being adopted and sustained." [17]

Collaborating with older adults directly was valued not only for enabling researchers to learn about first-hand experiences of a problem in context, but also for generating a holistic understanding of how to develop innovative solutions for it. Participants explained that because TDR supports a "more informed" (P20, investigator) or "a more holistic view of the problem" (P4, trainee), it enhances the likelihood of producing "better quality," "more acceptable," and "better adapted" technological solutions. A particularly noteworthy illustration of this was provided by P4, a trainee:

> "[Y]ou get a more holistic view of the problem. And it does cause people to think differently whether they like it or not. ... the basis of ingenuity and creativity is to be challenged to think in ways that are different. And that's when you come up with some really neat ideas on how to problem-solve that, you know, haven't been done before. You have to think differently than what's been done before. ... to really properly look at and address large problems you do need transdisciplinary work because you do need innovative thinking and you need thinkers for many different viewpoints." [18]

Different ideas and perspectives exchanged and consolidated through transdisciplinary collaboration was perceived as leveraging a team's collective expertise to co-produce new knowledge and stimulate innovation that could better solve a problem. As another participant noted: "[A]t the end of the day we have developed better technologies ... being commercialized faster" (P5, network leader); this is because the integration of different knowledge and perspectives from relevant stakeholders, such as older adults, clinicians, policymakers, and industry partners, helps keep research grounded in real problems and have an impact on the real lives of the older adults and carers who will use them. [19]

3.1.3 Community engagement and empowerment for older adults

Participants commented that older adults can be a vulnerable population in the context of using technology given that many of them have low technological literacy. Thus, a notable perceived benefit of TDR was the empowerment of older adults through facilitation of their comfort/familiarity with technologies in the process of participation in the research and development of technologies. For example, P18, an investigator, commented:

> "[V]ery often older adults feel under-empowered, and particularly when it comes to technology because very often they don't feel comfortable with technology, or they

> feel anxious about technology. And there's really a barrier there that needs overcome. ... we spend a lot of time so that our older adults do feel comfortable and feel empowered to be able to be a part of the research team. ... basically, it's creating a safe and comfortable environment." [20]

Furthermore, TDR in aging and technology was thought to expand the opportunities for older adults to learn about potential technological solutions to aging-related problems that resonated with their experiences, to socially engage with others, and to empower older adults to share their learnings with others in the community. As P15, a trainee, noted in relation to a project that involved partnering with members of a local community center:

> "If people want to be involved [in research] then they should have a platform to be able to do that. ... the impact it also has on people who are participating ... they feel more informed about issues around health and aging because they've been involved more as collaborators and partners. And ... we talk about social isolation and aging and I never thought that this group would be a platform for decreasing that, but people have told us that they like to be involved, if there's just simply a way to be involved in their community. So, they feel like they belong to a group and around a topic that they're interested in ... they can pass along learnings that they've helped to co-create or that they've learned from the group and they can share those with other people in the community." [21]

A transdisciplinary approach was perceived as enabling older adults not only to engage as active team members in research that explores and addresses problems in their everyday lives, but also to develop meaningful social connections with their communities. [22]

3.2 Challenges to implementing TDR

Participants identified several challenges and barriers regarding the implementation of TDR in terms of: communication and conflicting priorities among team members; systemic and cultural barriers; and identifying partners and developing partnerships. [23]

3.2.1 Communication and conflicting priorities among team members

Participants identified communication as the primary challenge for engaging in TDR, as it involves working within a large team with multiple academic and non-academic stakeholders. Geographical distance and associated different time zones, as well as the reliance on technology for communication, were identified as barriers to effective communication in a large team. P23, an investigator, commented that direct, face-to-face communication can aid and improve productivity when people from different disciplines are collaborating:

> "I find there's no substitute for face-to-face ... because some of the stuff when you get people together who don't know each other well and give up on the first day, it's the

> second day where you start getting a sense of things. Maybe the third day when you actually get some work done." [24]

Compared to technology-based methods of communication, face-to-face communication was experienced as being more effective in that it helped research team members, who may not have collaborated previously, to communicate spontaneously and directly, which they felt was more likely to help them build a trusting relationship and subsequently foster knowledge exchange and strengthen the integration of their shared knowledge. Another drawback of using technology rather than face-to-face interactions for communication is that it makes it challenging to read non-verbal cues that indicate, for example, appropriate moments for interjecting to share ideas in a team meeting. [25]

Being able to understand knowledge shared across different disciplines and sectors was perceived as particularly complex because the same terms may be used in multiple disciplines but with different meanings, which can easily result in miscommunication among research members. As P1, an investigator, said:

> "Sometimes people will come up with terminology or goals that are not familiar [to] another person. ... I used the word 'hack' ... Outside of computer science it means someone is stealing your bank account information. And to me it means something completely different. ... there's some conflict and some ruffled feathers because the kind of terms are coming out of one person's perspective and they didn't bother to clarify things or to think that maybe they had to change how they say these things to suit people who aren't used to hearing about commercialization. So that put off this individual." [26]

The challenges associated with understanding discipline/sector specific "jargon" within TDR projects resulted from team members using their discipline- or sector-specific language without considering that it might be misunderstood by other team members. [27]

Another challenge identified concerned the multiple and at times conflicting priorities among different team members involved in TDR projects. Several participants noted that conflicts often arise when business-oriented goals and the imperatives of industry partners are at odds with other priorities of academics/scientists and those from other sectors. For example, when considering technology development, members from a business culture posed the question "What is your market? How are you going to make money?" (P1, investigator), whereas members from an academic culture were more inclined to take the position of, "We don't care about the number of users" (P10, affiliated researcher). Others highlighted the tension that can result from the push to commercialize a product at the cost of not knowing enough about the older adults who will be using the product. The following comments by P11, a trainee, are particularly noteworthy:

> "I think it actually creates relationships that are too superficial to be progressive or productive. ... there were these really memorable moments where ... on [one] side of

> the argument it would be, 'Well we know enough about our user. Now we just need to build stuff,' and then the 'user' researchers would say, 'Well we don't know our users that well, otherwise we would've built stuff that they're willing to accept and adopt and buy.' You know so you have these kinds of tensions at the table. ... I felt like we could've been more cohesive as a team." [28]

As P11 notes, in a TDR team, members from diverse disciplines and sectors may prioritize discipline-specific values when negotiating project goals and directions with other members. Different values across disciplines and sectors can create territorial conflicts and impede the team from finding a middle ground that requires openness, respect, and consideration for different values across disciplines and sectors. [29]

3.2.2 Systemic and cultural barriers: Academic and organizational expectations

Many participants identified systemic and cultural barriers to implementing TDR. For example, several of them found it difficult to collaborate with researchers who value a more traditional, particularly single disciplinary approach to research. Such an approach to research typically involves a hierarchical decision-making structure and often stands in opposition to the collaborative team approach involved in TDR. As P21, an investigator, described, this was not only driven by individual researchers' preferences, but is also an approach that continues to be championed within the academic sector more broadly:

> "[I]n some cases it [TDR] is not always appreciated or adequately reinforced or rewarded, so I have colleagues in some academic areas where that's a challenge for them, they're ... discouraged from the more transdisciplinary research in favor of more disciplinary ... for purposes [of] promotion and tenure." [30]

As an example of this cultural barrier to TDR, individual academic researchers' productivity is normally evaluated in terms of the number of their publications in peer-reviewed journals in their own disciplines. Further, solo-author, first-author, or senior-author publications are valued higher than other kinds of knowledge outputs that they produce. P19, a partner, explained:

> "[W]hen you're on that tenure panel and you're reviewing somebody's application, if they're on a multi-authored paper or a multi-applicant grant, it's really hard to assess what people's involvement actually is. So figuring out ways to convey that information, and then ... I'd like to think with some of the disciplines out there that don't really acknowledge a team base at all, if they want only a sole author, how do we get some of those disciplines to recognize that work?" [31]

Such evaluation metrics, and the research values that they reflect, dissuade many participants from conducting TDR because the cross-disciplinary and cross-sectoral collaboration involved encourages researchers to publish with multiple authors in journals of disciplines that are different from their own. [32]

A key systemic barrier that was highlighted by participants was the lack of time to accommodate the needs and interests of stakeholders, and the iterative nature of the research, within expected timelines by funding agencies. As P8, an investigator, commented:

> "The reality is the funding announcement is tomorrow, you have four weeks to write your proposal. So things you've been sort of thinking about in the back of your mind, you throw down on a piece of paper, you submit it and this sort of cycle repeats itself again and again. So ... we haven't had the bandwidth to sort of consistently include a user at the front end. It's an excuse. ... it's so busy that ... it's hard to figure out." [33]

3.2.3 Identifying partners and developing partnerships

Although all relevant stakeholders in aging and technology TDR are expected to be engaged from the outset of a project to co-produce products that are not only effective but commercializable, this did not always happen. Consequently, several participants reported challenges with recruiting industry partners. Participants identified several potential reasons for the difficulty in attracting industry partners, including incompatible priorities regarding research, as well the lack of a forum that could help both industry and researchers find partners with mutual interests and a shared focus. A comment from P15, a trainee, for example, highlights challenges in engaging partners:

> "I had reached out to some industry and policy-making types of folks to be more involved and the response was not as positive. Not because they're not interested in the project, but because of the time issue for them or perceived lack of time. So, I don't know if that's because of prioritization or my communication in terms of the benefits to them and maybe just not knowing exactly how to catch their attention, and I don't want to use the word ‘sell,' but get them motivated to want to spend their time on this project." [34]

The researchers and stakeholders may have conflicting or incompatible interests, and researchers may be unaware of the stakeholders' priorities and interests or how to effectively communicate a project's values and benefits to them. Other participants discussed conflicting time frames regarding the research and technology development process, a challenge identified earlier with communication and conflicting priorities. A comment from P5, a network leader, is illustrative of this tension:

> "[F]rom a design perspective, [involving older adults or caregivers in research] could slow down the process. It could require more investment upfront to get things done. But at the end of the day hopefully the payoff is greater than those factors. But those things are why it's sometimes difficult to get industry to kind of buy into that philosophy as well 'cause while they need to get a product out very quickly and they're expecting to involve seniors and kind of go through this slower process then obviously, they're not going to hit their targets." [35]

TDR in the context of aging and technology was viewed as more challenging and time-consuming in this regard because it requires greater collaboration with industry and other non-academic stakeholders than does a traditional research approach. [36]

3.3 Contradictions between TDR principles and participants' understanding

Our analysis revealed contradictions between the principles highlighted as characteristics of TDR in extant literature (Table 4) (BOGER et al., 2017) and participants' understanding of them. The first contradiction concerned non-academic stakeholders' roles and levels of participation or engagement in the research process itself. Participants reported that they engaged with non-academic stakeholders such as older adults, carers, and industry partners, mainly for soliciting feedback during the data-collection phase of their project. For example, when directly asked how they were engaging older adults and carers in research, P20, an investigator, replied:

> "[We are] doing direct testing with older adults living in a nursing home and their caregivers ... it's basically ... testing the technology to see their feedback and how they experience it. And so that's directly related to engaging the users and taking that feedback into building a better design and trying to work out processes for implementation." [37]

Participants described that when older adults were involved in their research, their roles were restricted to providing their perspectives, knowledge, and ideas as a potential user of technology through participation in interviews, focus groups or surveys. Older adults were rarely co-researchers or active decision-makers in the research process.

Domain	**Principle**
Complexity and holism	Address wicked, needs-driven, real world problems Have an attentiveness and appreciation of complexity Cross ideational borders Have a common understanding of problems Share goal creation
Relationship	Engage in ongoing inter-sectoral and technology-user involvement Challenge accepted ways of researching and working Foster trust and respect Maintain high-levels of tolerance, commitment, and resilience
Communication	Engage in clear, transparent, ongoing communication Agree on a shared vocabulary Use frameworks and methodologies as appropriate

Domain	**Principle**
Transformation	Critically identify and challenge assumptions, at both personal and project level
	Achieve outcomes that have a transformative, real-world impact
	Push beyond common ground to establish a deeper level of understanding
	Practice accessible knowledge translation
	Work in an iterative fashion to allow for transformational processes
	Maximize impact

Table 4: Domains and principles of TDR (BOGER et al., 2017) [38]

Similarly, when policymakers or industry partners were involved in the research, their role was limited to being funders or research participants who provided feedback on the usability and application of the developed technology in the context of policies and business interests. Rarely were they involved in developing the new technology itself. Furthermore, policymakers and industry partners were more likely to be involved in later stages of the research, particularly as the technological products began to take shape, and only when researchers felt their feedback was necessary. As P8, an investigator, explains:

> "This is very, very experimental. Like we didn't even know what, if anything, we could find. ... I mean industry was involved in ... we approached the company and said, 'Can you make us a deal on one of these cameras? Here's what we're planning to do.' ... they gave us a discount because we were using it for research and not for industrial purposes. But they weren't involved in the study design or anything like that." [39]

Participants' comments suggest that TDR was understood as an approach that primarily involved scientists/academics from various disciplines who make critical decisions about the research process without consulting with non-academic stakeholders. This contradicts a key tenet of TDR that scientists and non-academic stakeholders form an integrated team, collaborating to co-create new knowledge and technology. A key characteristic of TDR is not only cross-disciplinary, but also cross-sectoral knowledge exchange and integration (GRIGOROVICH et al., 2019). [40]

The lack of cross-sectoral knowledge integration presented a second contradiction between what participants understood about TDR and its actual principles. Although knowledge exchange, and sometimes also integration across various disciplines was identified as an important element of TDR, the co-creation of knowledge that both integrates and transcends disciplinary and sectoral boundaries was rarely mentioned. Our analysis suggests that some participants predominantly understood TDR as "just about trying to work across disciplinary

boundaries" (P19, partner), or as "look[ing] at our topics from a bit of a different perspective" (P15, trainee) rather than the co-production of new, transformative knowledge and innovation that transcends traditional sectoral boundaries through iterative process of synthesizing and extending different sector- and discipline-specific knowledge (BOGER et al., 2017). The understanding that TDR entails crossing one's own disciplinary boundaries to develop skills and knowledge in areas outside of one's own expertise is evident in the following comment: "[Y]ou specialize in a certain field but ... you are actually using different types of abilities to do different types of work in different fields, not just working with people who are from different fields" (P9, trainee). For this participant, TDR meant expanding their capacity to solve problems by learning new skills and applying expertise themselves, instead of by being part of a research team with a range of different disciplinary and sectoral expertise who collectively integrate knowledge and develop solutions that transcend individual disciplinary and sectoral boundaries. Another participant similarly interpreted TDR as enabling individual perceptual adaptation and integration, rather than collective integration and co-creation of new conceptual knowledge and expertise within a team (i.e., thinking like each other rather than both developing new ways of thinking): "[In TDR] the boundaries are not as clear, so it means that the engineer has to think like the OT [occupational therapist], the OT has to think a bit like the engineer ... you have to adopt different perspectives" (P24, undisclosed role). [41]

3.4 Promising practices for TDR

While many participants identified barriers to implementing TDR, our analysis also demonstrates that a few participants were successful in implementing TDR principles in some of their aging and technology projects. These principles included: involving experiential stakeholders as research partners; developing shared language, values, and research objectives; and conducting open, ongoing, and respectful communication. [42]

3.4.1 Involving experiential stakeholders as research partners

Several participants reported engaging experiential stakeholders as research partners throughout their research process and felt that this was critical to successful research in aging and technology.

> "We see their [older adults'] role as an active member of the research team. ... we really want to involve them all the way through the process ... not just as asking for their advice, but also having them be part of the decision-making process. ... We really believe that it's the way in which you can maximize the benefits of the work that you do and make it relevant to the audience that you're trying to deliver to" (P18, investigator). [43]

Other participants, albeit only a few, reported that policymakers and business and industry partners were also involved as partners by participating in decision-making regarding the direction of the project:

> "[W]e're already heavily connected to industry. ... they like to help give projects direction. ... It obviously works well and there's a grant that requires industry involvement and where they have vested interest in the outcome, they're involved from the beginning to help design how the thing goes" (P8, investigator). [44]

In such cases, the benefit of this kind of engagement of stakeholders was recognized; that is, stakeholders' perspectives and knowledge were appreciated and viewed as having positive impacts on the research outcomes. [45]

3.4.2 Developing shared language, values, and research objectives

The development of a shared understanding of the research goals and language used for communication with researchers and community stakeholders was another principle of TDR that some participants reported as adopting in their research projects. For example, the following quote describes how one project team approached a key communication challenge of making research language accessible:

> "[I]n academia we have the tendency of speaking our own language in such a way that other people outside of academia don't understand us. And this is a huge problem ... so I was telling the team what were my experiences and how I would like to change it, but I was speaking a very kind of accessible language that was based on my research, but also based on my personal experiences ... There was ... [also] a marketing specialist who was speaking in a very accessible language ... and [a clinician] ... was also advising us on what she knows from her experience. ... in my view this is how [all] scholarship should work" (P17, trainee). [46]

Other participants similarly reported that their team explicitly developed a shared, accessible language for meaningful knowledge exchange and co-creation by dedicating time for establishing a mutual understanding of language to circumvent disciplinary jargon. [47]

While reaching consensus on what the research objectives should be was a challenge for many participants, they nonetheless felt that achieving such consensus was important for the research process. For example, consider the example of P15, a trainee, who recounted the experience of facilitating discussion with team members to reach consensus about a research question:

> "[M]y supervisor and I ... brainstormed what we thought would be a really good [research] question, ... some in the group thought that there needed to be some changes and some thought other changes. And so, something that you think is a simple sentence, it was literally one line, took about an hour of discussion to kind of massage it out and make sure that people understood what the phrase meant." [48]

As exemplified by P15's experience, initiating meaningful and open discussion was key to reaching consensus on the research question, and this demonstrates how each stakeholder's sector- or discipline-related values and perspectives are respected and integrated into the decision-making process. [49]

3.4.3 Conducting open, ongoing, and respectful communication

Many participants consistently emphasized that open, ongoing, regular communication with research team members was key to practicing TDR, particularly for building relationships and sharing research objectives and an understanding of discipline-specific language and perspectives in a research team. P2, an investigator, summed this up as follows:

> "[T]here's a lot of negotiation at the beginning when you develop a team and understanding who's doing what. ... As you sort of go through, it becomes less and less obvious whose role is what because you start understanding the language and start understanding the process of how people address particular questions and it's just a lot easier to work together because you already have established that communication and on many things, you have shared meaning. ... if that negotiation and open communication is established early on, then moving through the project is a lot easier." [50]

The early stages of a project in particular require honest, frequent, intensive, and meaningful communication due to the necessity of understanding shared objectives and language in a team, as well as identifying members' roles and responsibilities. As P2 noted, negotiating roles, which may result in the loss of role identity, may be necessary to foster respect and trust among team members. [51]

A sense of respect, connection, and comfort were viewed as essential to building a strong foundation for teamwork. Many participants acknowledged that fostering open, ongoing, and respectful communication in the early stages of projects typically achieves this, and identified in-person interactions as particularly effective. The following comment illustrates how creating space for openness and respect changed the way in which members communicated:

> "Everybody is coming from their own perspective but we're all looking to have the same outcome. So, it's really important to be able to share your ideas openly and feel like you're not going to be judged or not listened to. So, I find that having a personal touch and having mutual respect and knowing a little bit more about each other and where we are all coming from, it makes it a lot easier for people to communicate during meetings. And it makes it a lot more enjoyable when you have a meeting where people are laughing and joking here and there, instead of just having a meeting that's very cold and serious" (P9, trainee). [52]

Fostering open, ongoing, and respectful communication among team members was perceived as creating comfort and building trust, which may in turn expedite progress in nurturing collaborative work environments. [53]

4. Discussion

This study explored how members of a Canadian research network perceived and experienced TDR in the field of aging and technology. Participants identified benefits that can be gained from integrating transdisciplinarity into research, including mutual learning, improved capacity to holistically understand and solve complex problems, and for enhancing community engagement and empowerment of older adults. Yet, participants also identified significant challenges to implementing TDR (e.g., communication issues and conflicting priorities among team members, tensions between traditional and transdisciplinary approaches to research). Our analysis revealed contradictions between principles of TDR and participants' understanding of them. Despite these barriers, there were a few participants who described examples of successful implementation of TDR (e.g., engaging stakeholders as research partners, sharing language, values, and research objectives, establishing collaborative relationships). [54]

Importantly, our analysis identified challenges that need to be addressed in order to support researchers to effectively incorporate TDR into the field of aging and technology research and development. At the individual level, the lack of in-person interactions were perceived as affecting the quality of the exchange of knowledge and the establishment of a common understanding of language and project goals; this hampered effective collaboration at the team level (SCHENSUL, NASTASI & VERMA, 2006; STOKOLS, HARVEY, GRESS, FUQUA & PHILLIPS, 2005). Developing a communication plan at the outset of a project to specify what modes of communication will be used, and how best to use them, would mitigate those challenges and play a vital role in meeting the varying, and sometimes conflicting needs of team members and non-academic stakeholders (e.g., older adults and caregivers) throughout the research process (GUTMAN, BARKER, SAMPLES-SMART & MORLEY, 2009; SCHENSUL et al., 2006). However, the lack of non-verbal cues in remote collaboration hinders effective communication, as well as interpersonal connection and trust at a personal level. Relationship building is more effective in person than through technology; reliance on technology has been identified as constraining transdisciplinary collaboration and outcomes (STOKOLS et al., 2008). Thus, more frequent, in-person meetings may be required to first establish and subsequently foster not only relationships among team members but also a mutual understanding of language and project objectives. [55]

At the systemic level, we found that the lack of resources as well as traditional academic culture manifested in academic and organizational expectations, requirements for funding applications, and evaluations of productivity were key barriers to conducting TDR, which is consistent with previous studies (BLASSNIGG & PUNT, 2013; GUTMAN et al., 2009; POLK, 2015; SCHENSUL et al., 2006; STOKOLS et al., 2005). The extant literature suggests that providing adequate institutional resources and developing a research infrastructure (e.g., advisory groups for quality assurance and coordination centers that facilitate communication between stakeholders) is key to facilitating TDR (HALL et al.,

2008; HALL, STOKOLS et al., 2012; HARPER, NEUBAUER, BANGI & FRANCISCO, 2008; LOISEL et al., 2009; SCHENSUL et al., 2006; SNOW, SALMON & YOUNG, 2010; STOKOLS et al., 2005). GEHLERT et al. (2010) suggest the need to promote TDR for publication in professional journals and develop manuscript review guidelines that encourage and foster researchers' efforts to co-develop manuscripts in a team comprised of people from multi-disciplinary and multi-sectoral backgrounds. [56]

We also identified a gap in participants' understanding of two key TDR principles. In many cases, stakeholders were involved as research participants rather than research partners, and while knowledge exchange seemed to occur across disciplines, our findings suggest that there was limited integration of knowledge from across various disciplines and sectors. Further, for the most part, participants reported relying on a traditional research model rather than adopting a TDR approach, thereby creating a hierarchical and competitive environment that impeded a holistic understanding of an issue of interest and hindered the co-creation of outcomes that could have a transformative impact in real-world contexts. As STOKOLS et al. (2008) argue, if team members do not have a collaborative attitude and dedication to practice TDR, the effectiveness of their research will be compromised. [57]

Our findings offer a novel contribution to research on TDR given our identification of challenges of "doing transdisciplinarity" that are unique to the field of aging and technology. These challenges include conflicting priorities, values, and interests between academic researchers and industry partners, which make collaboration difficult. For example, rigor of research and a user-centered approach to designing technology are seen as core values and priorities for researchers, whereas market value and getting the products of research to the market in an efficient manner are perceived as core values and priorities for industry and business partners. In order for researchers to collaboratively develop knowledge and innovation with such stakeholders, it is essential for researchers to master strategies for effectively communicating conflicting interests and priorities and negotiating time frames and goals with them. [58]

Success stories in implementing principles of TDR in projects were identified (e.g., engaging stakeholders as research partners, sharing language, values, and research objectives, and conducting open, ongoing, and respectful communication). The participants who described that principles of TDR had been integrated into their projects tended to be researchers who had a developed understanding of TDR or had already well-established collaborative relationships with stakeholders, which allowed them to communicate openly and directly with those stakeholders and thus create a shared understanding of language, values, and objectives. It is important to note, however, that the principles described as having been successfully implemented in this study were primarily those relating to relationships and communication, as identified by BOGER et al. (2017), and that other principles, particularly those that facilitate transformative impacts on real-world problems, have yet to be implemented. [59]

There were also benefits identified by the participants of implementing a TDR approach in aging and technology research, which echo findings from earlier studies in other fields. Among research team members, mutual learning about theories and perspectives occurs via the exchange of knowledge and perspectives from various disciplines and sectors, which can help members understand real-world problems (HALL, VOGEL et al., 2012; LAMBERT & MONNIER-BARBARINO, 2005; OROZCO & COLE, 2008) and address them synergistically (GEHLERT et al., 2010; PROVAN, CLARK & HUERTA, 2008). However, it appeared that non-academic stakeholders were often involved as passive research participants rather than as active research partners, which suggests that researchers implemented multi- and inter-disciplinary research rather than TDR. Community-building and empowerment have consistently been reported as a positive outcome of participatory research methodologies (BAUM, MacDOUGALL & SMITH, 2006; NELSON, OCHOCKA, GRIFFIN & LORD, 1998), although to date they have not been widely discussed or demonstrated in the literature on TDR. By involving people from different disciplinary and sectoral backgrounds who have a mutual interest in addressing a specific social problem, TDR expands and diversifies its network of team members (LOISEL et al., 2009). This, in turn, can benefit those facing the problem in the real world (e.g., carers of people with dementia) since the research team will be better informed and thus better equipped to understand and address the complex social problems, as has been noted by GEHLERT et al. (2010). [60]

Finally, our findings have four implications for future efforts to support TDR in the field of aging and technology, and may additionally have resonance in other fields where TDR is advocated. First, educational resources (e.g., workshops, written materials) need to be developed for researchers to increase their understanding of TDR (e.g., key principles and *how to* integrate them into projects) (see, for example, GRIGOROVICH, FANG, WADA, SIXSMITH & KONTOS, 2017). Particular emphasis needs to be placed on the importance of engaging non-academic stakeholders (e.g., older adults, informal caregivers, clinicians, industry) as research partners from the outset of a project. It is also important to teach researchers that knowledge exchange and integration across disciplines and sectors is critical to developing a holistic understanding of a complex social problem and generating transformative ideas and products that can address it. To help researchers lead the process, on-going guidance and consultation may also be necessary. [61]

Second, to facilitate effective communication and meaningful relationship-building among team members, especially when they are dispersed geographically, researchers need to be informed about and equipped with multiple, reliable multi-channel communication methods that meet various needs of members (e.g., Skype, teleconference, age-friendly and multisensory computer programs). As noted earlier, effective and mutually acceptable forms of communication could be integrated into a communication plan developed in the initial stages of the partnership-building process. In-person meetings should be recognized as a particularly effective medium for building collaborative relationships and a shared understanding of language and project goals within a team (GEHLERT et al.,

2014), and the time required for and costs of the meetings (e.g., travel) should be provided. Additionally, researchers need to be trained in group process and conflict resolution in order to co-create and lead a transdisciplinary team effectively (GEHLERT et al., 2010). It is especially important that they learn how to negotiate and navigate through an environment of diverse and often conflicting values and priorities, all from different disciplines and sectors, and to work with group members in building respect and trust in a team. [62]

Third, TDR needs to be advocated by highlighting its benefits to community members facing a complex social problem, researchers, research trainees and students, research institutions, and research funding agencies in order to change the research culture and values. It is particularly important for academic/research institutions to shift the values and culture to support, guide, and reward TDR (BLASSNIGG & PUNT, 2013; GEHLERT et al., 2010). This would require high-level members of academic institutions to lead by example. [63]

Fourth, it is critical to develop a project or network-level advisory group to aid researchers in identifying and recruiting key non-academic stakeholders, and to educate researchers about strategies for effectively communicating and negotiating project goals and time frames with these diverse experts (particularly business and industry partners). This extends beyond addressing the complexities of working in transdisciplinary ways at a project level to the promotion of systemic changes in expectations at an institutional (educational, research, and funding) level. [64]

The findings and implications of this study should be interpreted with some caution as the work was conducted in only one, albeit very large, research and development network with a specific focus on aging and technology within the Canadian context. While suggestions are made regarding the translation of findings into other networks, more research is necessary to establish exactly how TDR can be achieved in different sociocultural and institutional environments. In particular, our participant recruitment pool reflected members who joined a network that explicitly promoted TDR, and thus the experiences we captured regarding this approach (including barriers) are limited to these stakeholders' perspectives. The recruitment strategy yielded 30 participants from a large pool of eligible network members, and most of the participants shared a homogeneous sectoral background (70% were from scientific/academic sector), which facilitated an in-depth exploration and identification of common experiences within this particular sector. However, it also limited our understanding of the experiences of members from other sectors (e.g., industry, policy, community). In particular, while older adults and caregivers were included in our recruitment strategy, none chose to participate in the study, which may have influenced the range of barriers, challenges, and benefits regarding TDR that were identified. Future research should involve experiential stakeholders from these and other sectors and from different disciplines to broaden and enrich our understanding of TDR. Given that there is already evidence that hierarchies between disciplines may influence cross-disciplinary collaborations (KONTOS & GRIGOROVICH, 2018), this will be particularly important to explore as a potential challenge to TDR.

Additionally, it will be important in future research to follow up with network members and alumni to explore how time in the field influences understanding and implementation of TDR. AGE-WELL was a new TDR network at the time of data collection (i.e., established less than two years prior to the initiation of our study). Such an extension of the research we conducted would yield valuable insights regarding how members' TDR practices have changed over time, as well as any structural changes within the network that might enable and/or constrain TDR. [65]

5. Conclusions

This paper explored how members of a Canadian research network on aging and technology perceived and experienced TDR. The findings demonstrate that several principles of TDR were successfully integrated into some of the network projects and that TDR was viewed as useful for facilitating mutual learning and understanding, and efforts to solve complex problems in this field. However, various barriers and challenges to the implementation of TDR were also identified at individual and systemic levels. Developing ongoing supports and educational resources that help researchers understand TDR and learn effective communication and relationship-building techniques—and making such support and resources readily available to researchers—is essential to encourage and support engagement in TDR. For example, developing online resources on TDR, offering regular workshops, as well as one-on-one consultation services may help researchers develop their knowledge and thus feel more confident about engaging in TDR. Such initiatives to support TDR may also contribute to broadening its reach and bolstering its adoption as a robust research approach worldwide, thus challenging the traditional approach to research which still appears to dominate across different national and sectoral contexts. [66]

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We declare no conflicting interests.

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