Defining and evaluating transdisciplinary research

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Defining and evaluating transdisciplinary research: Implications for aging and technology

Purpose: Transdisciplinary research has the potential to enhance the real-world impact of the field of aging and technology. This is a context-driven and problem-focused approach to knowledge production that involves collaboration across scientific disciplines and academic and non-academic sectors**.** To sustain broader implementation of this approach, a scoping review was conducted on the impact of this approach on research processes, outcomes, and uptake.
Materials and Methods: A systematic search was conducted of aging, health/medicine, and technology literatures indexed in three electronic data bases (Medline/OVID, EBSCO, ProQuest) from Jan 1, 2005 to Dec 31, 2015. Search terms included 3 themes: (1) transdisciplinarity; (2) research outcomes; and (3) social change.
Results: Twenty articles met the inclusion criteria. We found that a transdisciplinary approach to research enhances integration of diverse knowledges, scientific and extra-scientific outcomes, capacity to engage in translational research, and the uptake of research knowledge. We also identified a number of facilitators and barriers to successful implementation of this approach. No articles evaluating transdisciplinary research specifically in the context of aging and technology were found.
Conclusions: Adoption of transdisciplinary research in aging and technology may foster greater uptake of technological innovation in the real-world by supporting integration of diverse knowledges and enhancing engagement of experiential and non-academic stakeholders in the research and development process. However, supporting successful implementation of this approach requires investment of personal and structural resources. More research is also needed to better understand the evidence base on the adoption of this approach in aging and technology projects.

Keywords: Transdisciplinarity; research evaluation and impact; scoping review; aging and technology

Introduction

Aging and technology is an applied research field that seeks to develop ‘real-world’ technological solutions that can support older adults and carers to live well for as long as possible [1, 2]. Research in this field sugggests that innovative technologies may be a cost-effective approach to enahncing healthy aging by enabling aging-in-place, self- care and self-management, facilitating cognitive stimulation and social interaction, and improving access and efficiency regarding health and social services. However, despite considerable public and private financial investment in aging and technology research and development, this field has had limited success in fostering uptake of knowldge in the real-world (e.g. developing market-ready products and creating sustainable improvements in health services) [3, 4, 5]. Two significant non-technological challenges (e.g. research-based, social) have been identified as barriers to the realization of the potential of new technologies to impact individuals and health care systems. First, the development of technologies that are useful and readily accessible to potential users of technologies, such as older adults and carers, requires input from multiple and diverse stakeholders across academic/scientific, industry, government and citizenry. Supporting sustained and meaningful collaboration between these stakeholders would ensure that the development and commercialization of new technologies is driven by the necessary experiential and professional expertise [1, 2, 6]. However, the immense scale of such collaborations (e.g. number of disciciplines, sectors, partners, governments) makes it challenging to achieve integration and requires a more interactive and flexible research approach [1, 7]. A second and related challenge is that many academics and researchers in aging and technology may lack the necessary skillset and expertise in commercialization and knowledge mobilization. In part, this is because technological research and development has traditionally been driven by technocratic agendas (e.g. creation of ‘new’

technologies and products), neglecting to consider the ‘fit’ between developed technologies and their social and economic context (e.g. needs, practices, and priorities of expereintial and non-academic stakeholders (e.g. social, political).

A transdisciplinary approach to research (TDR) [8, 9, 10, 11] has the potential to address these challenges TDR is context-driven and problem-focused and involves collaboration across scientific disciplines and academic and non-academic sectors. While there remains confusion about the specific principles and practices that define and distinguish this approach [8], three key characteristics are consistently highlighted across the literature [9, 12, 13, 14, 15]. First, this approach is most appropriate when seeking to solve complex and seemingly intransigent social problems, what some have termed as ‘wicked’ problems [6] These types of problems cannot be solved by refining or adapting existing disciplinary or sector-specific knowledge, and requires innovative and holistic solutions. Second, TDR initiatives emphasize the importance of integrating knowledge across academic and non-academic sectors (e.g. citizens, industry, policymakers), with the aim of ultimately transcending individual perspectives to achieve a synthesis that represents a cooperative consensus. Finally, given the interest in problem-solving, a key prinicple of this approach is acheiving ‘societal or extra-scientific’ impact (e.g. changes in health outcomes, market adoption of technologies, changes in policy and/or practice).

Despite the potential of this approach to mitigate challenges the field of aging and technology faces, no systematic evaluation of the effectiveness of TDR has been conducted in any field to date, including aging and technology. Little is thus known about its impact on research processes, outcomes (e.g. products, tools, technologies, guidelines, etc.), and uptake of knowledge (e.g. evidence of social impact of research such as the adoption of evidence/outcomes/products) in the real world. Given the growing public policy

interest in TDR as a mechanism for supporting technological innovation in Canada and internationally, as reflected by public research funding of multi-million TDR initiatives (e.g. Canada's Aging Gracefully across Environments using Technology to Support Wellness, Engagement and Long Life NCE Inc., U.S.A.'s Transdisciplinary Collaborative Centers for Health Disparities Research Program, and the Ambient Assistive Living Technologies for Wellness, Engagement, and Long Life, which is jointly funded by Canada, the UK and Sweden), and its time and resource intensive nature, there is a need to gain a better understanding of the current evidence base of this approach. Addressing this knowledge gap is crucial for guiding future research and evaluation efforts, and could also enable broader and more systematic implementation of TDR across aging and technology. To that end, we conducted a scoping review with an interest in capturing the current state of empirical evidence regarding the evaluation of TDR initiatives in the field of aging and technology.

Materials and Methods

This review followed the five stage scoping review approach set out by Arksey and O'Malley [16]. The guiding question for this review was: How have transdisciplinary research processes, outcomes, and impacts been evaluated to date? To address this question we set the following three objectives:

1) Develop a comprehensive understanding of how TDR is defined across the literature, and its key principles;
2) Determine the benefits of this approach for enhancing research processes, outcomes and impacts; and
3) Identify the facilitators and barriers regarding successful implementation of this approach.

Search Strategy

The search strategy and set of search terms (see table 1) were developed in consultation with a research librarian and were informed by a preliminary literature search to identify a set of relevant articles on TDR (and its evaluation) across academic databases and Google Scholar. Using a series of scoping trials, we tested and refined our set of search terms across academic databases (e.g. Scopus, Medline). We also used these trials to identify and test our search strings to determine the optimal strategy to yield the most relevant articles without excessive irrelevant results. Given our interest in capturing a breadth of literatures on TDR across aging, health/medicine, and technology literatures, and in identifying articles that reported on the evaluation of TDR, our refinement of the search terms (table 1) was a very time-intensive and iterative process. In particular, we found it challenging to operationalize our interest in capturing the influence of TDR on processes and outcomes, and to identify articles that exclusively focused on TDR, rather than treat it as a family of related approaches (e.g. many articles interchangeably used TDR with inter-disciplinarity and multi-disciplinarity). Given that there is no accepted definition for TDR, and that our aim was not only to assess the effectiveness of this approach, but also to explore how the term TDR is applied across the literature, we decided to restrict this review to articles that explicitly characterized their research as 'transdisciplinary.'

Insert table 1 here

Database Searches

The search strategy was restricted to English-language sources indexed in 3 databases (Medline/OVID, EBSCO, and ProQuest); peer-reviewed journal articles published between January 1, 2005 to December 31, 2015; and both empirical studies (all data types) and reviews. Based on the initial scoping trials, the focus was streamlined to include only articles that reported on TDR in three research fields: aging, health/medicine, and technology. We included literature from the field of health/medicine since the call for the adoption of TDR in aging and technology originated with researchers and academics working in this sector, and as recent multi-million investments in TDR suggest, it remains a key governmental priority for technological innovation. Given that a key element of TDR is *an awareness of the problem context* (i.e. broad social or environmental structures that create and sustain the problem) [10], focusing our search on these fields ensured that we would review literature most relevant to understanding and enhancing implementation of TDR in the context of aging and technology.

We intended to have three rounds of screening for the inclusion of articles in the scoping review (title, abstract, full article), however title-screening did not provide sufficient information to determine accurate inclusion/exclusion. Thus, the screening process proceeded by applying two rounds of review (abstract and full article). Review of abstracts/full articles was undertaken by at least two team members independently and concurrently using the following inclusion/exclusion criteria:

1) Is the article located in one of these 3 fields: health/medicine, aging, technology? If not, exclude; and
2) Does the article describe how TDR influenced research processes, outcomes or impact?

In cases of uncertainty, articles were included in the next round of review. Full article screening was similarly completed by at least two team members independently and concurrently. Final decisions on inclusion of contested articles were made by consensus among the four researchers. Using a written audit trail we tracked and resolved any disagreements and reached consensus through discussion among the four team members. Inter-reviewer agreement of >70% was achieved. Screening identified 996 articles, of which 23 met the criteria for inclusion. The breakdown of our search results is summarized below in Figure 1. An Excel spreadsheet was created with conceptual categories to guide data extraction of selected articles. These included the following: full article citation; geographic area; topic field (health, aging, or technology); research question; definition of TDR provided; how TDR was evaluated; and the results of the evaluation (for process, outcomes or impact, barriers and facilitators noted). Data from the articles were extracted manually by two team members into the Excel spreadsheet. A thematic approach [17] was used to sort, identify patterns, and synthesize information within and across categories. Given the substantial heterogeneity of the articles, we opted to summarize our data descriptively to characterize different aspects of the existing literature.

Ensuring rigor

Traditionally, scoping reviews rely on a number of strategies to ensure rigor, including having two reviewers for every step of the review process, developing a systematic search strategy based on a series of scoping trials, and searching for sources across multiple academic databases. We have used all of these in this review. However, the lack of a universally accepted definition and criteria for defining and evaluating TDR (as well guidelines for how to distinguish it from other related cross-, multi- or inter-disciplinary

approaches in the context of a literature review) required that we develop and adopt additional rigour enhancing strategies to assess the quality of the articles included in this review. This was done through consensus-building, multiple rounds of discussion, and applied trial and error. For example, in our examination of articles identified by our initial scoping trials we found that articles varied widely in how they approached "evaluation" of TDR and its successes (or failures), and rarely explicitly assessed how TDR influenced research processes, outcomes, or impact directly. As such, we chose to adopt a broader understanding of evaluation that was not specific to a type of method or design. Further, while we restricted our search to articles that explicitly reported on transdisciplinary research (e.g. used this term to characterize the research or research initiative), we wanted to additionally to evaluate the quality of TDR of the included studies based on how TDR is conceptualized within existing theoretical models or frameworks in aging and technology. While it is recommended that scoping reviews do not exclude articles based on their quality, it is recommended that some form of quality assessment is conducted on all included studies to identify areas where additional research may be needed to bolster the evidence base [18] To that end, as a first step, we attempted to apply the eighteen principles of TDR identified by Boger et al [6] to a subset of articles to evaluate their quality. This exercise was helpful for grounding our discussions of how to define and evaluate TDR and to develop a template to guide extraction and analysis of data. Following this, we piloted our template (and its categories) with all four researchers independently extracting information from four articles into the categories and then meeting to discuss our results and discrepancies, and to further refine definitions of the three principles further to ensure consistency.

While we considered using Boger et al' [6] principles as an additional inclusion/exclusion criterion by evaluating how many of the eighteen principles the article authors endorsed, ultimately this proved to be too challenging to assess. In particular, we found that

articles rarely provided sufficient information about the initiative that would allow us to conclusively apply the eighteen principles, or use this process to further decide on inclusion/exclusion. While reporting this type of methodological information is not standard practice in published research, we nonetheless felt that we needed to include some form of assessment of the quality of TDR of all included studies. As a result, we chose to distill the eighteen principles into three key ones (e.g. complexity, inter-sectoral collaboration, and transformation) and use these to evaluate the included articles by posing the following three questions (see results in Table 3):

1. Was there attention to complexity and holism?
    a. Did the initiative seek to address wicked, needs-driven, real-world problem? OR
    b. Does the design/analysis demonstrate an attentiveness and appreciation of complexity (e.g. use of multiple methods, cross-disciplinary theoretical framing)?
2. Did the initiative involve inter-sectoral collaboration between academics/researchers and another stakeholder sector (e.g. citizens, industry, policymakers)?
3. Was transformation achieved (e.g. did the TDR initiative lead to a real-world impact)?

To ensure that we were consistent in our evaluation, we created a working definition for each principle, and trialed the application of these on a subset of articles. For example, inter-sectoral collaboration was defined as an initiative that had a research team made up from stakeholders from two or more sectors (e.g. academia/science, experiential, industry, government). An article that did not report

on the make-up of the research team, or only included non-academics as test subjects was deemed to not reflect the application of the principle of inter-sectoral collaboration. These additional strategies ensured that we were as rigorous and systematic as possible in identifying the articles included in this review and analyzing evidence of the effectiveness of TDR.

Insert figure 1 here

Results

Overview of the selected articles

Our final subset of selected articles for inclusion in the scoping review includes 20 articles (see Table 2 for description); 3 articles were removed at the extraction stage, one on the basis of not reporting on an evaluation of a TDR [19], and two for not reporting on a TDR initiative [20, 21]. Any articles that were identified for potential exclusion during the process of extracting the data were reviewed by one of the study co-leads (JS, PK) who made the final decision.

Although the subset of articles included in the review represents a diversity of disciplines, all were from the fields of health/medicine with the majority focused on evaluating TDR in the United States (n=16) or Canada (n=6). No articles on TDR in the context of technology, or technology and aging were found which met our inclusion criteria. A large proportion of articles were descriptive program evaluations or quasi-experimental in design (n=7) rather than empirical analyses.

In the final subset of articles, a variety of methods was utilized to evaluate TDR: qualitative methods (e.g. interviews, focus groups, document review) to explore stakeholders' perspectives on their experiences (typically these were students or trainees of a university-based research and training program, or scientists collaborating on a TDR initiative), and quantitative methods (e.g. survey, bibliometrics, network analysis) to assess outcomes and interactions between stakeholders in terms of number and diversity (e.g. within and across sectors or disciplines). Nearly all included studies were restricted to a single phase of the research process and assessed TDR in the context of one research study/institute/program using traditional criteria for evaluating 'scientific excellence' (e.g. number of academic publications, number of trainees graduated, number grants received). Few articles formally evaluated the process of 'doing' TDR as part of a research study, and even fewer evaluated the societal and 'real-life' impacts of knowledge produced *specifically* as a result of TDR.

Insert table 2 here

Definitions of TDR

The majority of articles defined TDR with direct citations or adaptations of Rosenfeld's [12] original definition [22, 23, 24, 25, 26]. For example, some articles described TDR as research that involves collaboration between scientists from 2 or more academic disciplines [27, 28, 29, 30, 31]. Others described TDR as an approach that aims to integrate and transcend disciplinary knowledge or perspectives through the development of a shared conceptual framework, and the use of methods or methodological approaches from multiple disciplines [28, 30, 31, 32, 33, 34, 35]. Several articles also specified that a TDR approach is particularly useful to adopt in

the context of developing solutions to complex social problems, or when seeking to develop a more holistic understanding of the research problem [29, 33, 35, 36]. Only five articles explicitly defined TDR as research that either involves non-academic actors in the research process or includes them in some way in knowledge production and exchange [32, 36, 37, 38, 39]. Two articles [40, 41] offered no definition or description of TDR.

The impact on TDR on integration of diverse knowledges

TDR was reported to support the research process by enhancing integration of diverse knowledges from across disciplines and sectors. For example, Lambert and Monnier-Barbarino [29] found that this approach supported translation of uni-disciplinary knowledge into information that was readily accessible to others from different disciplines. More specifically, it allowed for 'frank dialogue' between individuals from different disciplines [29], and supported sustained curiosity [29] or inquisitive interest in the points of view, perspectives, and concerns of others as reflected in the number and relevance of questions addressed to participants from other disciplines. Gutman et al [27] suggest that TDR facilitates public involvement by encouraging researchers to create opportunities to engage with public stakeholders and to seek their perspectives and feedback. TDR also enriched researchers' understanding of 'real-world' or complex issues [36], supported overcoming of disciplinary barriers [23, 29] and their detachment from personal disciplinary points of view [23]. Consequently, adopting TDR enabled the generation of new ideas [28] and

development of shared conceptual models that could guide future research [22, 35], or identify new directions for collaborations across research projects [25].

However, it was also reported that partial attempts at TDR can negatively impact processes as this can result in asymmetries in knowledge and authority between decision-makers and community stakeholders [32, 41]. Such asymmetries may lead to tensions between community stakeholders and scientists that negatively affect the potential for integration of knowledge and missed opportunities to achieve real world application of research [32, 41].

The influence of TD on outcomes

Successful implementation of TDR enhanced researchers' scientific productivity and capacity [25, 28, 30, 31, 37, 38, 40]. For example, it augmented their cultural and social preparedness to conduct research, their existing understanding of health disparities, and their research skills or capacity. It was also reported to have increased academic outputs (e.g. number of peer-reviewed publications, scientific presentations, proposals submitted, and funded grants received) [30], joint-collaborations when writing articles [28], diversity of research disciplines represented by investigators on awarded grants [27], and the number of new investigators [28]. Further, engagement in TDR facilitated cross-disciplinary [31] and cross-institutional collaborations [27, 31], which supported international competitiveness [28]. It was also found to have benefited trainees and early career researchers as it increased mentorship opportunities [29], and advanced career trajectories [27].

The influence of TD on capacity to engage in translational research

Three articles evaluated the contribution of TDR to knowledge and society beyond that of measuring traditional markers of 'scientific excellence' (e.g. number of publications, number of trainees graduated, number grants received). For example, Snow et al [34] and Orozco & Cole [36] evaluated the added value of a post-graduate program in TDR for enhancing the research preparedness and critical thinking skills of trainees. In particular, these two articles note that TDR enabled trainees' exposure to diverse methods and concepts not covered in their disciplinary training, and led to greater understanding of the research problem, including awareness of the "real-life" context. They also noted that TDR increased their tolerance for, and appreciation of, diverse forms of knowledge and led to expressed personal commitment to conducting applied or translational forms of research. Harper et al [33] also noted that adoption of TDR led to positive changes in structure and functioning within research organizations that improved the quality of work life, including enhancing communication, professional development, and promoting supportive interpersonal relationships.

The impact of TDR on uptake of knowledge

Three articles described how TDR enhanced social impact through facilitation of public involvement in the research [27, 32, 41]. Specifically noted was how TDR enabled the development of stimulating and supportive partnerships between researchers and experiential stakeholders [27, 34], and led to community-driven policy changes [41]. Ottoson et al [41] add to this by proposing that TDR can raise public and policymakers' awareness of relevant research that requires public action through community demonstrations and networking. Finally, Daudelin et al's [32] argue that the uptake of research knowledge is dependent on enabling meaningful

involvement of experiential researchers in the research process through "deliberate, sustained efforts from all participants and institutions" (p.263). In particular, they suggest that it is important to involve these stakeholders early on and invest in increasing their research skills and capacity, as well as, modifying established research practices to fit experiential stakeholders' participation needs.

Finally, it was also noted that the 'social impact' of TDR may be difficult to assess in practice because this often exceeds the primary objectives of individual studies and also requires a longitudinal research design which necessitates additional time and resources [41]. Another challenge to measuring social impact may be related to the tradition of evaluating contribution/impact of the research on policy by 'counting' or assessing policy outcomes (e.g. creation/change in legislation). This assumes that the relationship between research and policy is linear and ignores other types of research-related contributions to social knowledge that may be more difficult to capture numerically, such as lobbying efforts that inform policy [41]. In particular, a focus on policy 'events' (e.g. counting number of bills drafted/acts enacted) ignores how policymaking is a process, and how TDR research contributes to policy pre- and post-enactment (e.g. through framing the issue, mobilizing partners, evaluation of implementation).

Facilitators and barriers to successful implementation of TDR

Within the selected articles for this scoping review, several facilitators to TDR were identified. First, we found that TDR is facilitated by significant and unique investment in resources and research infrastructure, including: administrative 'coordination centers' and other institutional management mechanisms (e.g. project team/working group) to facilitate/broker communication between dispersed stakeholders; organization and the sharing of data; and other forms of support such as quality monitoring and

targeted feedback, and facilitating discussion forums or advisory groups [22, 25, 28, 30, 31, 33, 34]. Given the time intensive nature of TDR, multi-year funding for research is particularly important [22, 34].

Second, many articles cited the importance of using multiple methods for communication (meetings, advisory panels), and communication platforms (face-to-face, virtual) to engage stakeholders, and to ensure that engagement is tailored to support different stakeholders' expectations/working styles/personalities and needs [22, 27, 28, 29, 30, 32, 33, 40]. In particular, it was noted that as different stakeholders have varying levels of knowledge and use different and often discipline-specific languages to communicate (academic/lay, biomedical/social), it is important to ensure that a variety of communication mediums and strategies are used. These can include the creation of targeted documents that distill and translate scientific results for community-based stakeholders (e.g. research brief), use of multiple knowledge exchange forums (e.g. large stakeholder forum, small discussion group, one-one session), and the establishment of a central 'program office' that oversees knowledge translation and exchange [27, 33].

Third, given the imperative to integrate and synthesize knowledge in TDR, it is important to engage stakeholders in collective planning/visioning around goal setting, development of a shared language, selection of research questions and methods, and at later stages, decision-making related to publication [30, 33, 34, 37]. Diffusing power differentials by addressing asymmetries in knowledge (e.g. making knowledge accessible to all stakeholders) and by facilitating and validating different stakeholders' contributions in a careful, deliberate, and democratic manner (e.g. at the start, participatory or bi-directional integration that allows for direct influence on research/plans). This ensures that non-academic stakeholders are able to participate effectively and feel that their perspective is valuable [27, 32]. This is particularly important as engagement with non-academic stakeholders in the research enhances scientific

stakeholders' ability to 'see' the applicability of their research in real-life [36]. Examples of successful strategies applied have included hosting of knowledge exchange forums [27, 33, 34, 41], and the use of internships or other forms of applied or 'field-work' opportunities for trainees [36].

Finally, personal and team characteristics were cited as important. For example, having and/or developing close inter-personal relationships (e.g. built on mutual trust and respect) is an important facilitator of TDR [22, 25, 31, 33, 41]. In addition, ensuring a diversity of stakeholders whose expertise is relevant to the problem space [25], and who share a personal and collective level of 'openness' or 'tolerance towards' the ideas of others, and are comfortable with uncertainty [22, 28, 37, 38] was identified as key to achieving TDR.

Although the articles claim that TDR generates innovative outcomes, it was noted that this approach is challenging to implement, and barriers that can impede its success were identified. For example, the elongated timespans and labor intensive requirements of TDR as compared to research that involves fewer stakeholders were discussed [22, 25, 27, 29, 30, 31, 32, 33, 34, 37, 39, 40]; TDR also brings with it uncertainty with respect to final outcomes of the research [37]. Identified barriers may be exacerbated by the current academic reward mechanisms and modes of working (e.g. expectations of uni-disciplinary training, focus of research versus expected focus in the field, number of products produced, competition vs. sharing of credit) that can make TDR appear professionally 'risky' or challenging [26, 27, 33, 34, 36, 38, 39]. However, given that there is also evidence that TDR may have a beneficial impact on advancing career trajectories [27], more research is needed to determine the extent to which this is a perceived barrier or an actual one.

Second, the size and composition of the team, lack of knowledge on how to do transdisciplinarity as well as insufficient planning and reflection around engagement of stakeholders may also be barriers. For example, it may be difficult to attract the necessary stakeholders, especially non-academics to participate [27, 39]. Geographic distance may also hamper collaboration [22, 25], and the use of online communication forums (e.g. primary or sole use of virtual communication strategies or virtual interaction forums) may make it more difficult to achieve mutual trust, complicity, and diplomacy between stakeholders [28, 29]. However, communication difficulties may also result from heterogeneity of background, training, and specific disciplinary language of stakeholders [22, 25, 27, 28, 34]. Personal values and working practices of stakeholders may also be problematic, especially 'closed mindedness' about the validity of the disciplinary methods and practices of others [22, 25, 26, 34, 36]. Finally, unaddressed hierarchies/asymmetries in expertise and authority between stakeholders [22, 32, 33], and inflexible models of involvement [22, 32] may result in mismatches between scientific and experiential stakeholders' expectations [26] which can lead to neglect of stakeholders' concerns [32]. All of these barriers may impede collaboration and knowledge integration between scientists and experiential stakeholders.

Discussion

This review included evaluation of TDR that spanned 10 years and across aging, health and technology literatures. Despite the call to adopt TDR in aging and technology, and evidence that such research and practice is already occurring [1, 6, 42, 43], our review did not find any published articles that have evaluated TDR in this context. This is concerning as our review provides evidence from

related fields that suggests that this approach may enhance successful development and commercialization of new technologies by ensuring that these are both meaningful and useful, as well as readily accessible to those who need them.

Our findings regarding the effectiveness of TDR have a number of important implications to inform future efforts to support and evaluate TDR in the field of aging and technology. We found that TDR is an effective research approach that has shown to have benefits for both researchers and for society, and in particular it supports both integration of diverse knowledges and enhances the capacity to engage with non-academic researches and to conduct translational forms of research. However, supporting successful implementation of TDR requires explicit and ongoing investment of personal and structural resources that build the requisite capacity needed across disciplines and sectors for engaging in meaningful dialogue and co-production of knowledge. This type of investment will be critical for supporting the success of aging and technology TDR initiatives given identified barriers to optimizing the adoption of new technologies in this field. For example, while there is growing interest in enhancing the quality and sustainability of health care systems using new technologies, there remains multiple regulatory barriers and challenges with procurement and disinvestment, that constrain adoption of technological innovation within healthcare systems [44]. While TDR offers a promising approach to incentivizing the adoption of technologies by involving key non-academic stakeholders in their co-development, realizing this promise will require investment in structural resources and building of organizational and individual capacity to engage in this type of research. Our findings further highlight the importance of attending to team composition and dynamics and supporting collaborative synergies between and across diverse and geographically dispersed stakeholders using multiple methods and means of involvement. This is critical in order to support future TDR research in aging and technology since synergy is not necessarily an ‘inherent’ property of

cross-disciplinary research approaches such as TDR, but rather is something that requires conscious and reflective efforts to ensure that stakeholders not only work *in a group*, but work as 'a [coherent] team' [11, 45].

Our review identifies a number of significant gaps in the evidence base of TDR, and in particular, limitations of existing knowledge for guiding future TDR efforts. We found that evaluations of TDR continue to focus on assessing traditional outputs such as academic publications, with limited attention paid to evaluating the knowledge production process itself (including how epistemological integration of knowledge happens across diverse actors, disciplines and sectors). In particular, little research has explored how TDR enhances the impact of knowledge production and exchange in the 'real world' through changes in practice and policy. Even fewer articles described specific social practices or strategies that were used to effect social impact or change. This was captured by our quality appraisal that found that only six articles reported that the initiative was transformative, or that TDR led to some form of social impact. This is concerning for aging and technology research as there is already noted concerns in this field that despite major investment in research and development, there has been little return on investment in terms of commercialization and adoption of developed technologies [3]. While this suggests that aging and technology efforts to date have had limited real-world impact, as Ottoson et al [41] suggest, this may in part be due to the lack of appropriate metrics for capturing this type of impact. As such, there is a need for future research to inform the development of methods and frameworks to evaluate the knowledge production process and real-world impact of TDR research for the field of aging and technology. Here we concur with Shaw et al [5] that theoretically-informed research that attends to the complex and situated nature of technology use and adoption (or lack of thereof) will be critical to fulfilling funders' and policymakers' commitment to rapid scaling-up and spread of developed technologies.

Finally, we found that articles rarely reflected on the added value of TDR for producing complex solutions to complex problems, or how these types of solutions might have been different (or less effective) if TDR had not been used. Limited research has also explored how TDR adds value to traditional (uni-disciplinary) academic training, or how it advances career trajectories as a result of collaboration with diverse stakeholders within and across academia. Given that integration of knowledge is thought to be crucial for the creation of solutions that 'transcend' disciplines and sectors, the existing evidence base may not provide us with sufficient information for the development of robust quality criteria that can assess this in practice. As such, while there is some evidence that suggests that TDR has social impact, more research is needed to strengthen the evidence base to support the claim that TDR produces "socially robust results" that contribute to solving' real-life problems [11] (p.113). This is particularly an important gap to address in aging and technology, given the potential of TDR to mitigate the challenges the field faces. In-vivo evaluations of current TDR initiatives in aging and technology are thus urgently needed to support the design and greater adoption of TDR across Canada and beyond. This is something that the authors of this review are currently involved in through a longitudinal research study exploring TDR practices across members of a national research network on aging and technology [43].

Limitations

Two main limitations exist. This scoping review only included evaluations of TDR from English-language sources in the fields of aging, technology and health/medicine published between 2005 and 2015 and indexed in three academic databases. There may be relevant literature on the effectiveness of TDR that has been produced in other languages, or may be found in other fields and

databases, including grey literature. The second main limitation is that we restricted our search to studies that explicitly used the term ‘transdisciplinary’ or ‘transdisciplinarity’ to describe the research initiative or approach. Although placing this restriction on the inclusion of sources was necessary in order to keep the review manageable, transdisciplinarity is a relatively new term in aging and technology research and there is some disagreement as to whether it is conceptually different from other types of cross-disciplinary research [8]. As such, we acknowledge that we may have missed other potentially relevant research evidence due to our chosen inclusion criteria.

Conclusions

Adopting a TDR approach to research and innovation has potential to enhance the successful development and adoption of technologies that support independence, health and quality of life of older adults. This review is the first time that the extent and nature of the effectiveness of this approach has been mapped and analyzed. Our findings suggest that there is evidence of effectiveness, however, this remains outside of the field of aging and technology. Further rigorous research on this approach, and how it enhances the quality and success of aging and technology research processes, outcomes and impacts is recommended. We hope that in demonstrating that TDR can enhance some research outcomes and processes, this review will be useful for guiding researchers, organizations, and funders interested in improving the effectiveness and social relevance of research in aging and technology.

List of abbreviations

TDR Transdisciplinary research

Declarations

Ethics approval and consent to participate

Not applicable.

Availability of data and material

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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