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Mixing Methods and Sciences: A Longitudinal Cross-Disciplinary Mixed Methods Study on Technology to Address Social Isolation and Loneliness in Later Life

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Abstract

Despite a growing interest in longitudinal mixed methods research, the literature offers few examples of complex designs. To evaluate a communication-based technology to address social isolation and loneliness in later life, we conducted two long-term studies in aged-care homes. We used a longitudinal convergent mixed methods design and a cross-disciplinary approach that employed techniques from social and computer sciences to ensure a comprehensive evaluation. While cross-disciplinary mixed methods research is also growing, a discussion of its methodological practices, challenges, and strategies is still scarce. This article contributes to mixed methods research by providing lessons learned on how cross-disciplinary mixed studies can be designed and integrated from collection to interpretation, particularly when combining convergent and longitudinal approaches. We also show the value of "design-in-action"—that is, the refinement and adjustment of techniques throughout research, as methods "talk to each other."

Keywords

older adults, digital technologies, cross-disciplinary mixed methods, loneliness and social isolation, longitudinal convergent design

Due to their serious health and social consequences, social isolation and loneliness among older people (aged 65+ years) are emerging concerns in industrialized countries (Neves et al., 2019a). While several technology-based interventions have been engaged to tackle the phenomena, we lack comprehensive knowledge on how older people adopt these technologies and their outcomes over time (Neves et al., 2019b; Poscia et al., 2018; Stojanovic et al., 2017). This gap seems related to a lack of mixed methods evaluations, disregard for the interplay of contextual and individual characteristics of users/participants, and short implementation periods or cross-sectional designs (Poscia

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et al., 2018; Neves et al., 2019b). Additionally, frail older people who live in care homes (a top risk group) have been overlooked (Neves et al., 2019b). This limits the applicability and sustainability of technologies used to combat social isolation and loneliness.

Mixed methods research—especially longitudinal designs—can help address this gap, as they have been successfully used to study complex phenomena (Creswell, 2014; Creswell & Plano Clark, 2018). Therefore, our study drew on a *longitudinal convergent mixed methods design* (Creswell & Plano Clark, 2018) to evaluate a communication technology developed with and for frail older people living in care homes and experiencing social isolation and loneliness. This design entails a concurrent collection of qualitative and quantitative data, analyzed separately and integrated with equal weight (Creswell & Plano Clark, 2018). Methods were integrated within two longitudinal studies to provide: (a) a detailed and nuanced picture of long-term adoption, use, and social outcomes of the technology and (b) an in-depth understanding of older adults' needs and contexts regarding technology-based interventions. Data were simultaneously collected via qualitative (interviews, field observations), quantitative (technology logs, psychometric scales), and mixed methods techniques such as usability and accessibility tests. These tests are based on tasks and mixed questions (i.e., qualitative and quantitative) to evaluate how easy, accessible, and satisfactory a technology is for users. We employed a cross-disciplinary approach, combining methods used in sociology (e.g., interviews) and computer science (e.g., usability tests) to grasp the intervention's social and technical dimensions.

While the number of mixed methods studies has been growing since 2000 in sociology and 2002 in computer science (Ivankova & Kawamura, 2010), truly cross-disciplinary mixed methods studies that bridge disciplines such as sociology and computer science are scarce. An exception is the work by O'Halloran et al. (2018) published in this journal, bridging linguistics and social and computer sciences to advance the analysis of multimodal texts from large datasets. Another example is on *iterative convergent design* for health technologies (Alwashmi et al., 2019). Alwashmi et al. (2019) focus on usability testing—a technique also used in our research, as described above—to demonstrate the potential of iterative mixed methods to improve methodology and technology in cross-disciplinary contexts. Nonetheless, cross-disciplinary mixed methods research based on longitudinal designs and several techniques to study complex issues continue to be scant and hard to implement due to the intricacy of collecting, analyzing, and integrating various strands of data over time, disciplinary differences (e.g., epistemology), finite resources, and so on (Hauken et al., 2017). We thus require more examples of these complex studies to offer richer understandings of multifaceted phenomena and to further the development of cross-disciplinary mixed methods.

The methodological aim of this article is to discuss lessons learned from a cross-disciplinary longitudinal mixed methods design. We describe the methodological practices followed in our studies and reflect on the challenges of complex cross-disciplinary data collection, analysis, and integration. We then show the value of a ''design-in-action'' approach to open avenues for cross-disciplinary mixed methods studies. This approach emerged from a constant dialogue between methods, leading to the need to adjust research techniques in the field to better study sensitive contexts. We provide critical insights for mixed methods scholars, cross-disciplinary teams, and researchers evaluating technology-based interventions.

Study Context: Social Isolation, Loneliness, and Technology-Based Interventions

Social isolation relates to a lack of social support and participation as well as reduced social relationships, whereas loneliness relates to feelings of lacking companionship, of not belonging

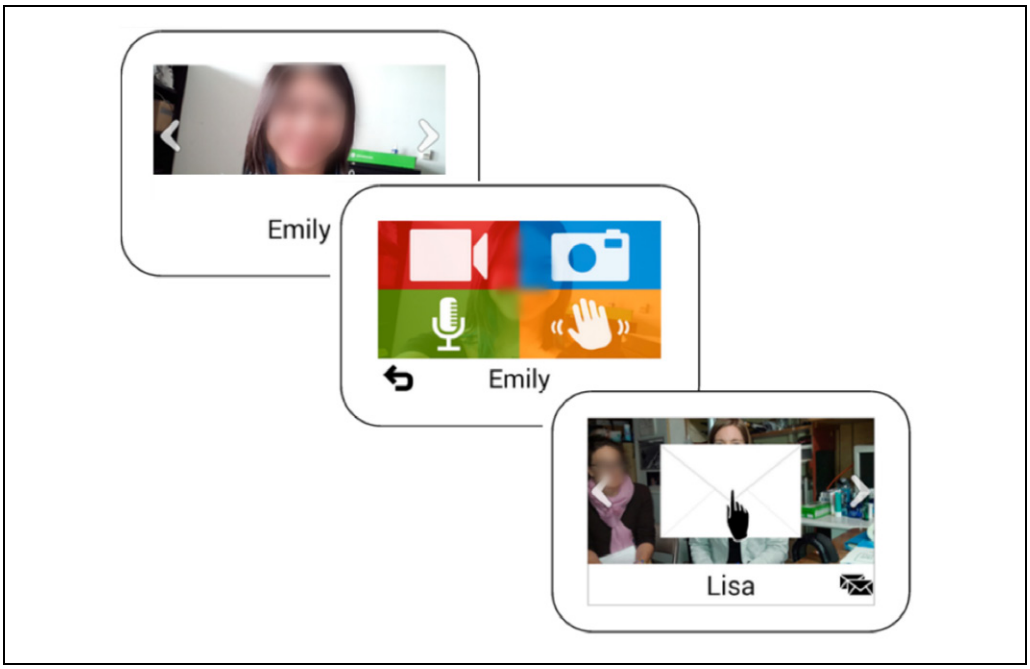

Figure 1. The contact list interface showing one contact (top), the message options interface with four options (middle), the new message notification interface (bottom).

(Neves et al., 2019a; Steptoe et al., 2013). Although different concepts, they have similar damaging effects in later life, predicting cognitive and functional decline and civic disengagement (Neves et al., 2019a; Nicholson, 2012).

Research suggests that digital technologies, such as the Internet, can create opportunities for social interaction and connectedness. In particular, social connectedness—which equals meaningful or deeper social interaction—can help address both social isolation and loneliness in later life (Neves et al., 2018; Findlay, 2003; Poscia et al., 2018). Yet targeted and accessible communication technologies seem more effective than general systems to meet older people's connectedness needs (Stojanovic et al., 2017).

Our study aimed to evaluate adoption, use, and social outcomes (social interaction and connectedness) of an accessible communication tablet-based app, codeveloped with and for frail older people living in care homes. Although far from homogenous, this group is frequently limited by standard digital technologies because of frailty, low digital literacy, or social settings such as care homes (Lee & Coughlin, 2015). Frail and institutionalized older people are especially vulnerable to social isolation and loneliness (Prieto-Flores et al., 2011), yet have received little attention in longitudinal studies of communication technologies due to recruitment and ethical challenges (Neves et al., 2015, 2018; Hall et al., 2009).

The app presents a large icon-based interface, allowing users to send preset text (''waves''), audio, video, and picture messages (see Figure 1). Since most users were frail—suffering from motor impairments and dexterity limitations (e.g., hand tremors due to Parkinson's disease)—the app did not include typing but swiping or tapping. The large icons accommodated users with visual issues and enabled a cross-cultural device. Our design fieldwork indicated that, to address feelings of loneliness and isolation, participants desired more social interaction and connectedness (i.e., deeper social interaction that allows for conversations beyond ''small talk'') with

loved ones. They wanted to communicate more frequently and meaningfully with relatives and friends using accessible technology that afforded different communication forms (Baecker et al., 2014). Participants showed little interest in making friends or communicating with acquaintances, preferring to rely on existing close relationships. Thus, the app was designed to match participants' needs and aspirations: it was based on a closed ecosystem of contacts selected by participants; and it was asynchronous (not real-time communication) as they sought to control their availability. Messages were sent to contacts' e-mail accounts, who could then reply with multimedia messages.

The research team included sociologists and computer scientists following a *social shaping of technology* approach—a sociological framework that considers social, cultural, economic, and technical factors (and their interplay) in the design, deployment, adoption, and evaluation of technology (MacKenzie & Wajcman, 1999; Neves et al., 2018). To facilitate a deeper understanding of adoption and use of the app in sensitive settings, we employed a mixed methods design with techniques from social and computer sciences. An action research approach, wherein problems are tackled in an applied way, was used to improve the app's user-experience (McNiff, 2013).

The study asked the following research questions:

Research Question 1: What sociotechnical factors facilitate or hinder adoption and use of the app amongst frail older people living in care homes?
Research Question 2: How can the app enhance social interaction and perceived social connectedness amongst this group?

Mixed methods were used to address both research questions, which allowed us to benefit from the advantages of each method to obtain an in-depth evaluation of the app and capture technology adoption, use, and its social outcomes over time.

Method

Research Design

We deployed our app in two retirement homes (Study 1 and Study 2) following a *longitudinal convergent mixed methods* design (Creswell & Plano Clark, 2018; Plano Clark et al., 2015). This means that quantitative and qualitative data were collected concurrently over different time-points (pre-, mid-, and postdeployment phases; see Figure 2), analyzed separately, and iteratively integrated (see Figure 3) through a process that attributes equal importance to each data strand (Creswell & Plano Clark, 2018). The study included interviews, psychometric scales, usability and accessibility tests, logs, and field observations (see Figure 3).

The research timeframe (Figure 2) had to be adapted to the sensitive sites. In the first case, we were only able to negotiate a 2-month study with our ethics committee and the aged-care institution; in the second, we negotiated a 3-month study. Because of access and ethical challenges of research with frail and institutionalized older people, longitudinal studies are restricted to short time periods compared with other longitudinal approaches. Our longitudinal mixed methods study did not fit within Van Ness et al.'s (2011) typology (prospective, retrospective, fully longitudinal). However, it fits in the expanded model by Plano Clark et al. (2015) as *multi-question/level variation*, since our research included multiple levels and instruments.

The order of the research techniques changed from the first to the second study, due to factors identified from a constant dialogue between methods and the need to adjust to sensitive settings. We further explore this need in the results; here, we outline pre-, mid-, and

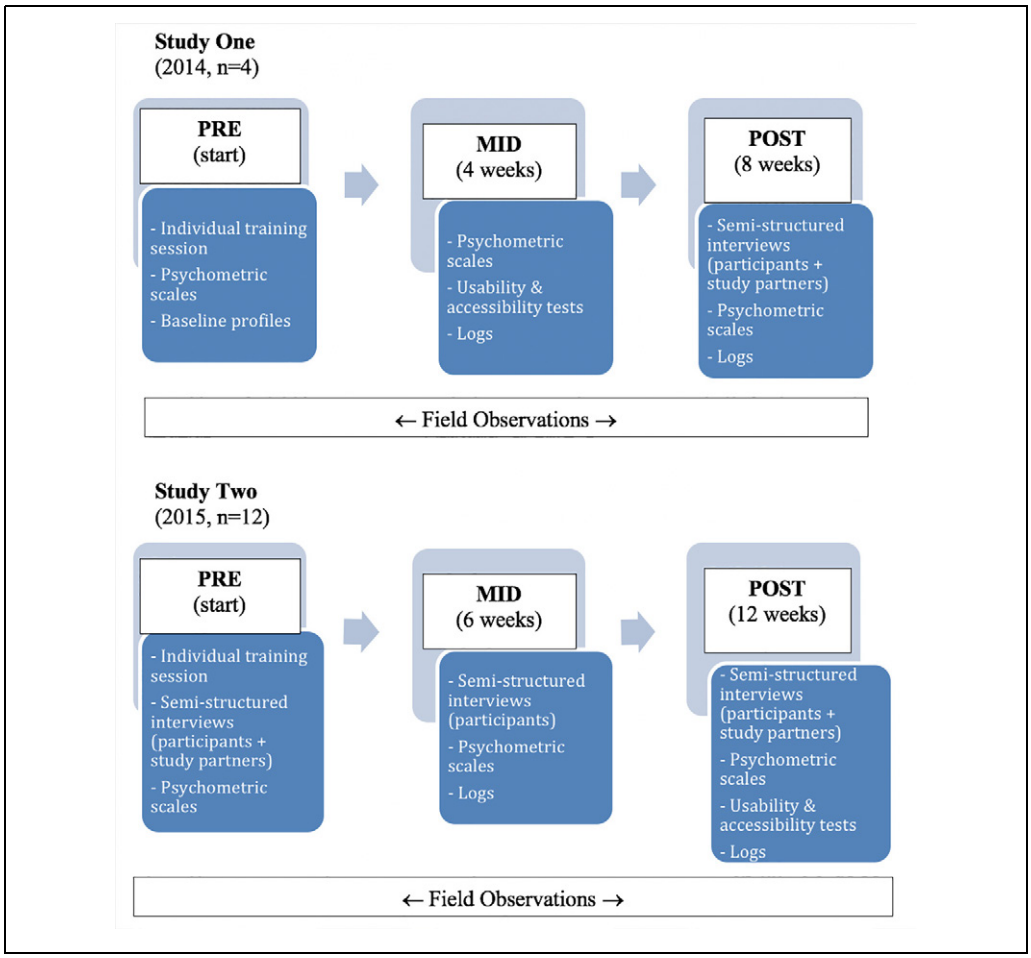

Figure 2. Deployment phases of Study 1 and Study 2.

postdeployment changes (Figure 2). At predeployment, we conducted semistructured interviews with participants (residents aged 65 + years) to collect sociodemographic information and baseline data on their prior use of communication technology and contact with their social ties, administered short psychometric scales to measure loneliness and social interaction and support, organized an individual training session to show them how to use the technology, and gave participants a tablet with our app to use as they saw fit over the course of each study. In Study 2, we also interviewed study partners (a relative or friend) at predeployment to collect data on participants' interests and social networks.

At middeployment (1 or 1½ months after the initial training session), we re-administered the scales, conducted semi-structured interviews with participants to gauge their experience with the app (Study 2), and ran usability and accessibility tests to understand how easy-to-use and accessible the technology was (Study 1). Usability testing, as employed within computer science (Human-Computer Interaction), requests users to perform representative tasks on a technology to find its major flaws (Franz & Neves, 2019). For example, usability testing evaluates speed of task performance and type of errors executed by users. Specific usability techniques—such as *Think Alouds*—instruct users to verbalize thoughts during task performance to elucidate their

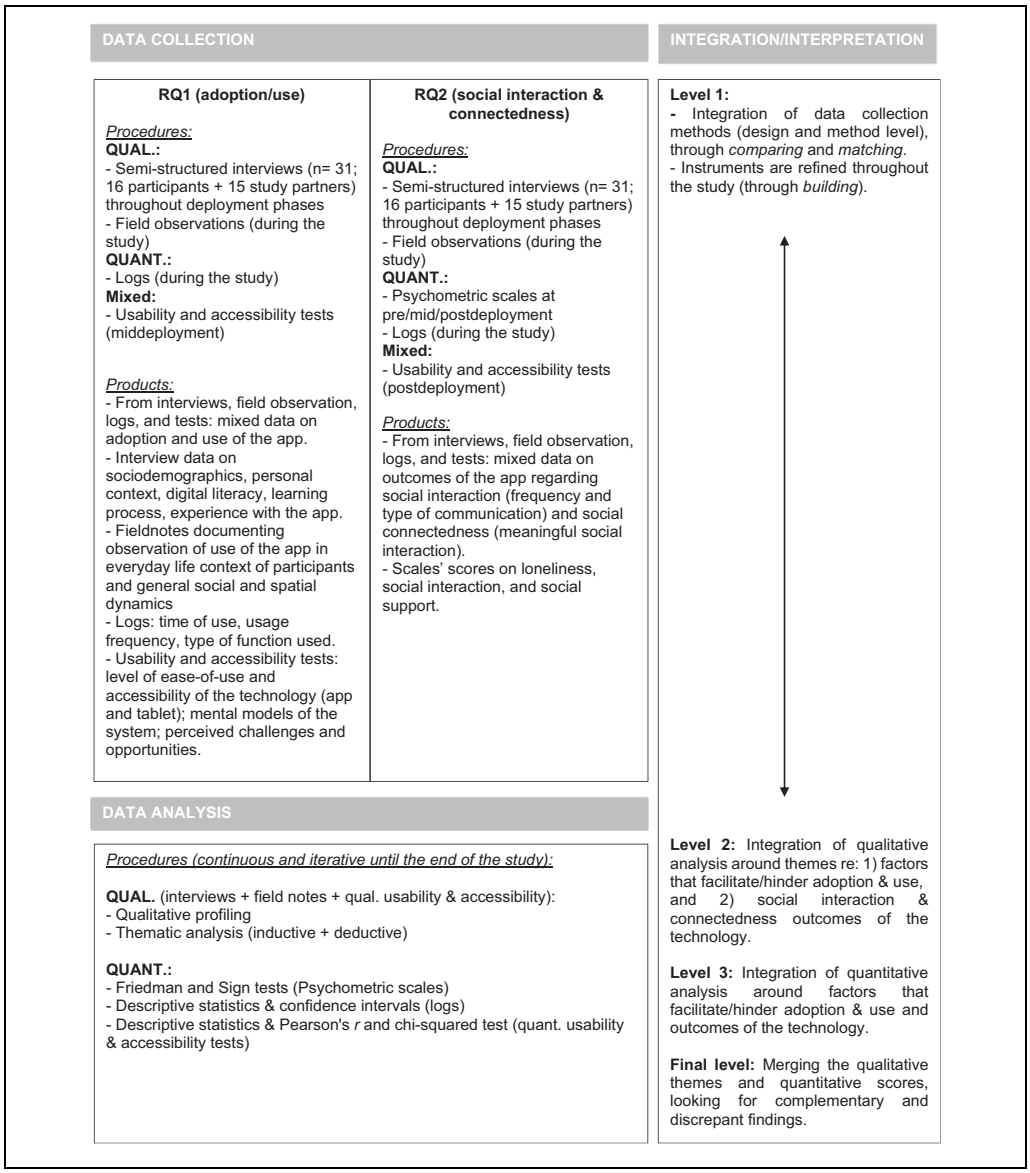

Figure 3. Procedural diagram of the studies.

technology models and perceptions (Franz & Neves, 2019; Lewis, 1982). As accessibility can be a main obstacle for technology use in later life (Franz & Neves, 2019), we evaluated if the app met accessible design standards. But rather than using experts' assessment, our participants were the evaluators. While providing technical data, the tests offered rich sociological data on how people perceive and engage with technology. Usability and accessibility tests were conducted at postdeployment in Study 2.

At postdeployment, we interviewed participants and study partners and repeated the scales. Throughout the studies, we collected field observations and logs. *Logs*, broadly used in computer science, are actions recorded by a device, such as type and frequency of use (Dumais

et al., 2004). Logs capture actions instead of perceptions of actions (e.g., participants' reported use). We did not want to replace participants' perceptions with ''real'' traces of use; we aimed to compare them to uncover patterns and differences. As logs indicate ''what'' action was completed, not ''why'', ''how'' or its impact, they must be merged with other data (Dumais et al., 2004).

The combination of these techniques allowed us to examine and integrate different dimensions of adoption, use, and outcomes of the app. Data were also used to refine the app.

Settings. Studies were conducted in a Canadian long-term care facility (2014) and retirement home (2015). The first setting (Study 1) is a care home where residents require 24/7 assistance, whereas the second (Study 2) included different levels of care. Residents in the first setting shared bedrooms and were mostly Chinese Canadians (80%). Their bedrooms were small, only including beds and a bedside table. Public areas were scant. The second setting encompassed mostly individual units, several communal areas, and a computer room. Residents had more diverse cultural backgrounds, from British to Latin American.

Participants. Participants were four residents (''oldest old'', people aged 80 + years) of the long-term care facility (Study 1) and 12 residents (aged 74 + years) of the retirement home (Study 2). Study 1 started with five residents, but one withdrew because of cognitive decline. In Study 2, one participant withdrew due to disinterest. Studies included study partners (n = 15)—one relative or friend per resident, according to participants' preferences. As we were evaluating a communication tool, we needed at least one social tie included in the project. Recruitment was assisted by staff, who reached out to residents following our selection criteria that excluded people cognitively unable to provide consent. Studies were approved by the University of Toronto Research Ethics Board; participants gave written and verbal consent and could withdraw at any time during the study.

Ages of participants ranged from 74 to 95 years (M = 83.9 years; SD = 5.5). Of the 16 participants, 6 were men and 10 women. Table 1 shows additional sociodemographic information under pseudonyms. Participants in Study 1 were Chinese Canadians and mostly Cantonese speakers. Data were collected in Cantonese and Mandarin with staff support and a Cantonese-speaking researcher. Three of the four participants had never used a digital device before (digitally 'illiterate') and had to learn to interact with the screen. They had basic or no formal education. Participants were joined by relatives as study partners: a granddaughter, a daughter, and two sons. Study partners could be interviewed in Cantonese or Mandarin, but preferred to be interviewed in English. In Study 2, participants were Canadians, including those from American, British, Italian, Latin American, and Japanese backgrounds. All had secondary or higher education and were fluent in English. Four were digitally 'illiterate'; eight had used a computer before but displayed a basic- or medium-level understanding of the system. Couple Paul and Martha decided to share one device. As in Study 1, participants predominantly chose relatives as study partners: three daughters, three sons, one sister, and one granddaughter. Four participants selected friends. All residents participating in the studies had health limitations—from motor impairments to Parkinson's disease—and were considered frail by staff based on psychosocial and biomedical factors.

Research Team. The team was co-led by the first (sociologist) and second author (computer scientist), both mixed methods scholars and responsible for the research design and implementation. The team also included a group of research assistants from computer and social sciences to support data collection and analysis. At least one sociologist and one computer scientist were involved in each method and stage of data collection and analysis. Some methods were led by

Table 1. Participant Sociodemographic Characteristics.

Study	Pseudonym	Gender	Age (years)	Marital status	Previous occupation	Health situation
1	Bei	Female	81	Widowed	Factory worker	Parkinson's disease
	Chris	Male	88	Married (wife lives separately)	Businessman	Stroke survivor, wheelchair-user, one-handed
	David	Male	84	Widowed	Teacher	Stroke survivor, wheelchair-user, one-handed
	Evelyn	Female	93	Widowed	Farmer	Visual and motor limitations (age-related; no diagnosed illness)
2	Gaby	Female	84	Widowed	Homemaker	Mild vision problems, needed a cane, speech disorder, rheumatoid arthritis
	Diana	Female	85	Widowed	Early childhood educator	Mild vision and auditory problems
	Jen	Female	80	Single	Librarian	Mild vision problems, used a walker, intense rheumatoid arthritis
	James	Male	86	Married	Minister and university instructor	Mild vision problems
	Kevin	Male	95	Widowed	Medical doctor	Vision problems (blind in one eye, wears glasses), memory problems
	Ike	Male	74	Married	Engineer	Vision problems, Parkinson's
	Paul ad Martha (used one device together)	Male and female	80 and 77	Married	Accountant and mathematics teacher	Mild vision problems, mobility problems
	Pam	Female	86	Widowed	Homemaker	Vision and reading problems
	Bree	Female	79	Single	Teacher	Stroke-related health issues, memory problems, aphasia
	Jane	Female	87	Widowed	Nurse	Macular degeneration, auditory problems (two hearing aids)
	Lily	Female	83	Widowed	Teacher	Mild vision and auditory problems (hearing aid)

computer scientists with the assistance of sociologists (e.g., logs), whereas others (e.g., interviews) were conducted by sociologists with the support of computer scientists. Details about their involvement in data collection and analysis are specified in the next subsections. To ensure all team members were familiar with the methods used, we ran preliminary workshops on each method. Additionally, weekly debriefing meetings took place during the studies. The workshops and meetings ''integrated the expertise'' of the different team members (Fetters & Molina-Azorin, 2017), facilitating a sustained methodological exchange.

Data Collection and Analysis

Data collection included semistructured interviews, field observations, psychometric scales, logs, and usability and accessibility tests in all or different deployment phases (see Figure 2). Data analysis encompassed qualitative profiling, thematic analysis, descriptive statistics, correlations, and nonparametric tests.

Qualitative Data Collection. The interviews drew on a semistructured guide, combining structured and unstructured approaches and allowing for flexibility and reflexivity (Seidman, 2006). Interviews with participants averaged 50 minutes and included questions on: sociodemographic data, contact with social ties, media use, and prior experience with digital technology (predeployment); general experience with the app, app's use, frequency of contact with ties, and other media usage (middeployment); and similar questions in postdeployment alongside queries about the challenges and opportunities of the app (see Table 2). Semistructured interviews with study partners averaged 30 minutes and included questions (Table 3) on social ties of the resident, social activities (pre) and experience with the app from the receiver's perspective (post). All interviews were audiotaped and transcribed.

We also conducted weekly field observations throughout the studies, totaling 375 hours of unstructured participant observation (Mckechnie & McKechnie, 2008). We observed use of the app and general social and spatial dynamics. Observations were a mix of participant and nonparticipant unstructured formats, involving notetaking when possible (Pretzlik, 1994). Field notes documented use of the app and interactions between participants, relatives, staff, researchers, other residents, and spaces. We drew on positionality/reflexibility (distinguishing between descriptive and analytical insights) and multiple perspectives (different researchers and participants) to heighten quality and trustworthiness of the field observations (Mckechnie & McKechnie, 2008).

Quantitative Data Collection. To measure levels of social interaction and connectedness, we used two psychometric scales: *Abbreviated Duke Social Support Index*, containing social interaction and satisfaction subscales (Wardian et al., 2012), and the *Short-Revised UCLA Loneliness Scale* (Hughes et al., 2004). Table 4 describes items and scores. Scales were administered individually in pre-, mid-, and postdeployment to assess scores over time.

The app recorded logs measuring time of use, usage frequency, and functions used. This provided a general quantitative understanding of usage and was valuable to contrast with participants' perceptions of use. Message content was not recorded for ethical reasons. Participants were aware of what was being logged.

Mixed Methods Data Collection. The design facilitated a constant dialogue between qualitative and quantitative methods across the different phases of data collection (see Figures 2 and 3). Additionally, the usability and accessibility tests drew on both qualitative and quantitative techniques. The tests included tasks, such as asking participants to send messages and access

Table 2. The Interview Guide Pre- to Postdeployment (Participants)

Phase	Study	Main topics	Main questions
Pre	1 (baseline profile) 2	1. Self-presentation 2. Ties and contact 3. Technology use 4. Expectations	1. Could you tell us a little bit about yourself? 2.1 Could you tell us a little bit about your close family members/friends? 2.2 How often do you talk to them? Do you talk on the phone? Face to face? 2.3 Are there family members/friends you would like to talk to more often? 3.1 Do you have a mobile phone? If yes, do you use it? How? How often? What do you feel about it? If not, have you ever thought of using one? Why? 3.2. Have you ever used a computer? If yes, do you still use it? For what? If not, have you ever thought of using one? Why? 4. What do you think about participating in this study? What are your expectations?
Mid	2	1. Experience 2. Usage and ties 3. Usability 4. Learning 5. Suggestions	1.1 How would you describe your experience using the app so far? 1.2 How do you feel when you are using the app? Why? 1.3 Does the app offer you something you were not able to do before? If so, what? 2.1 Could you give me examples of ways that you have used the app so far? 2.2 Who do you communicate with through the app? 2.3 How often would you say you get in touch with each of them through the app? 2.4 How does that compare to how often you talk to each of them in person? And on the phone? 2.6 Has the app changed what you talk about with these family/friends? If so, could you give an example of this and explain why you think it changed? If not, what do you talk about? 2.7. Has the app affected your relationship with each of them? Why? How? 2.8 How many contacts do you have in the app? Who are they? 3.1 What's easiest about using the app? 3.2 And what's challenging about using it? 3.3 What do you think about the manual? How frequently do you use it? 4.1 How could we improve your learning experience with the app? 4.2 Is anyone else helping you besides us? 5.1 Is there anything that you would like the app to do differently? 5.2 Is there anything that the app does not do that you would like it to do?

(continued)

Table 2. (continued)

Phase	Study	Main topics	Main questions
Post	1 2	1. Experience 2. Usability/functionality 3. Usage and ties 4. Challenges 5. Opportunities	1.1 How would you describe your overall experience using the app? 1.2 How do you feel when you are using the app? Why? 1.3 Does using the app offer something you were not able to do before? How come? 1.4 Do you feel different since you have been using the app? How? Why? 1.5 Do you think other residents here would like to use it? Why? 2.1 What was the easiest part of using the app when you first started? 2.2 What do you like most about using it? Why? 2.3 What are your favourite functions? Why? 2.4 What do you like least about the app? Why? 2.5 What are your least favourite functions in the app? Why? 3.1 Could you give examples of ways you have used the app over the past weeks? 3.2 Who do you communicate with through the app? 3.3 How often would you say you get in touch with them through the app? 3.4 How does that compare to how often you talk to them (people you mentioned above) in person? And on the phone? 3.5 Has the app changed what you talk about with your family/friends? (examples) 3.6 Has using the app become part of your routine/day? If yes or no, why? 3.7 When do you normally use it? 4.1 What did you find to be the most difficult part of using the app? Have you ever had any problems with it? Could you give me an example of what happened? 4.2 What did you do when you tried to use it and found it difficult? 4.3 What did you think about the paper manual? (Have you used it? When? Was it useful? Did you use it when you experienced difficulties with the app?) 4.4 What do you think would be difficult about the app for other residents here? 5.1 How could we make the app better? What do you think is missing? 5.2 If the app could do anything you want it to (doesn't have to be realistic), what would you want it to do that is doesn't do already?

Table 3. The Interview Guide Pre- and Postdeployment (Study Partners).

Phase	Study	Main topics	Main questions
Pre	2	1. Presentation	1.1 Could you tell us a little bit about [insert name]?
		2. Expectations	1.2 How often do you talk to her/him? Do you talk on the phone? Face-to-face?
			2. What do you think about participating in this study? What are your expectations?
Post	1	1. Experience	1.1 How would you describe your overall experience communicating with her/him now that she/he uses the app?
	2	2. Usage	1.2 What do you like most about having she/he using the app?
		3. Challenges	1.3 Does using the app offer you something that was not possible before? If so, what?
		4. Opportunities	1.4. Does using the app offer her/him something that was not possible before? What?
			1.5 Have you noticed any changes in her/him in general since she/he started using the app? If so, could you give me an example of this? Why do you think it changed?
			2.1 Has it changed the frequency with which you communicate with her/him? How come?
			2.2. In your opinion, how frequently he/she uses the app?
			2.3 Did the app make communicating with him/her easier? How? Why?
			2.4 How does the app compare to other forms of communication with her/him, such as telephone and face-to-face visits?
			2.5 Did the app make communicating with other relatives/friends easier for her/him? Why?
			2.6 Has the app changed what you communicate about? (i.e., what you talk about?) If yes, could you give examples?
			2.7 What type of messages do you send to her/him? Do you have any preference? Why?
			2.8 What do you think was the easiest part of learning to use the app for her/him? What was the easiest part of using the app for her/him?
			3.1 What do you think was the most challenging part of using the app for her/him?
			3.2 What did/do you like the least about having her/him using the app?
			3.3 Do you have any suggestions for overcoming the challenges she/he/you faced?
			4.1 How could we make it better for seniors? What do you think is missing?
			4.2 If this device could do anything you want it to in terms of connection and communication (doesn't have to be realistic), what would you want it to do that it doesn't do already?

Table 4. Psychometric Scales.

Duke Social Support Scale (DSII-10):

I. Social interaction

1. Number of family members within 1 hr that you can depend on or feel close to.
2. Number of times past week spent with someone not living with you.
3. Number of times in past week talked with friends/relatives on the telephone.
4. Number of times in the past week attended meetings of clubs, religious groups, or other groups that you belong to (other than work).

II. Social satisfaction

1. Does it seem that your family and friends understand you?[a]
2. Do you feel useful to your family and friends?[a]
3. Can you talk about your deepest problems with at least some of your family and friends?[a]
4. Do you know what is going on with your family and friends?[a]
5. When you are talking with your family and friends, do you feel you are being listened?[a]
6. How satisfied are you with the kinds of relationships you have with your family and friends—very dissatisfied, somewhat dissatisfied, or satisfied?

UCLA Loneliness Scale:

1. How often do you feel that you lack companionship?[b]
2. How often do you feel left out?[b]
3. How often do you feel isolated from others?[b]

Note. Scoring DSSI: Social Interaction Subscale: Item 1: none = 1, 1-2 people = 2, more than 2 people = 3. *Item 2*: none = 1, once, twice =2, three to seven or more times = 3. *Items 3 and 4*: none, once = 1; twice, three times, four times, five times = 2; six or more times = 3. *Satisfaction subscale*: 1 = hardly ever, 2 = some of the time, and 3 = most of the time. Scores are summed to obtain: (1) a social interaction score ranging from 4 to 12, where higher scores indicate more social contact and (2) a satisfaction score ranging from 6 to 18 where higher scores indicate a greater level of satisfaction with social support. *Scoring UCLA*: 1 = hardly ever, 2 = some of the time, and 3 = often. Each person's responses to the questions are summed, with higher scores indicating greater loneliness (Hughes et al., 2004; Pachana et al., 2008; Wardian et al., 2012).

[a]Most of the time, some of the time, or hardly ever. [b]Hardly ever, some of the time, often.

messages sent by researchers during the session. Participants were asked to verbalize their thoughts when feasible, following *Think Aloud* techniques. Tests also included a questionnaire on ease-of-use and accessibility, including tablet weight, color contrast, font size, volume, etc. Most questions were based on Likert-type scales (1 to 5, from *strongly agree* to *strongly disagree*), although in Study 2 we opted for open formats—that is, open-closed and comparative questions. The tests were video-recorded to evaluate how participant's hands interacted with the device and the speed, performance, and issues encountered, as we aimed to improve the user experience. While the tests did not directly measure users' ability to interact with the device, an understanding of their abilities was included in the assessment of ease of use and accessibility of the technology (Franz & Neves, 2019). The tests averaged 40 minutes and were conducted at middeployment in Study 1 and postdeployment in Study 2.

The usability and accessibility tests were undertaken by a computer scientist, with the assistance of a sociologist. The interviews, psychometric scales, and field work were primarily led by sociologists, with computer scientists involved. Field observations were mainly conducted by sociologists, whereas logs were maintained by computer scientists.

Mixed Methods Data Analysis. We followed an iterative approach to data analysis during the study, analyzing data as it became available and returning to the analysis as the study progressed (see Figure 3). First, we employed intramethod analytics, analyzing data with corresponding methods (e.g., interviews with thematic analysis); then, followed core and advanced mixed

Table 5. Cross-Disciplinary Integration Levels for the Usability and Accessibility Tests.

Level	Type	Examples	Lessons
Data collection	Comparing	Comparing tasks (task completion, speed, mistakes performed, issues encountered) + *Think Aloud* (verbalization of the steps taken to perform a task) + qualitative questions about usability and accessibility + scales on ease-of-use and accessibility + field observations.	• Videorecording the tests helped with comparison throughout and after data collection. • Including a member of each discipline eased an integrated interdisciplinary approach to data collection, due to ongoing dialogue on what dimensions to focus on and how to bridge them.
	Matching	Matching tasks with qualitative and quantitative questions: e.g., asking to send a video message, following up with a quantitative question on easy-of-use (Likert-type scale, score 1-5), and then a qualitative question on why they gave it that score.	• Including warm-up questions about the app—e.g., about what the icons meant before asking to perform tasks – enabled a better understanding of participants' grasp of the technology. • *Think Aloud* did not suit all participants due to cognitive and emotional issues; different forms of *Think Aloud* should match participants' abilities and contexts (Franz et al., 2019).
	Building	• Change from Likert scales to open-ended and comparative questions for next study. • Need for a design-in-action approach to adjust instruments in the field.	• Building can lead to a design-in-action necessity. • Integrating a design-in-action allows openness to "building" and changing instruments iteratively.
Data analysis	Intramethod analytics and core integration	Data were analysed with corresponding methods, following intramethod analytics; we then focused on common threads (core integration) as guided by our research questions.	• Mixing in data collection facilitated core integration.
	Advanced integration	Results improved instruments and informed the design of Study 2.	• A design-in-action approach facilitates a constant reflection of methods used and how to integrate them.
Data interpretation	Confirmation and complementarity	Usability and accessibility tests confirmed and complemented data on the app's usability and accessibility, but also on users' preferences and grasp of the technology.	• Openness to divergence does not mean that divergence will always be encountered. • A design-in-action facilitated complementarity as refinements improved data interpretation.
	Expansion	In combination with other methods, the usability and accessibility tests provided further data on sociotechnical factors (Research Question 1) and social connectedness (Research Question 2).	• Ensuring that all methods continually speak to each other enables expansion.

methods integration to incorporate the data (Fetters & Molina-Azorin, 2017). The qualitative coding and quantitative analyses were conducted by one team member involved in data collection and one team member not involved in data collection, bridging emic (insider's) and etic (outsider's) perspectives. This strategy helped enrich trustworthiness (qualitative) and reliability and validity (quantitative) of the analysis (Olive, 2014). As with data collection, sociologists and computer scientists were included in the analysis. The analyses of usability and accessibility tests and logs were led by computer scientists; the remainder were led by sociologists.

Qualitative Analysis. Interviews and the qualitative component of the usability and accessibility tests (open-ended questions and video-recorded interactions) were analyzed with qualitative profiling and thematic analysis (see Figure 3). Qualitative profiling was employed to provide contextualized profiles for each participant (Seidman, 2006). Thematic analysis was used to identify themes within and across cases. Themes were detected inductively—directly from the data—and deductively, drawing on a priori categories such as technology-related codes. We followed Braun and Clarke's (2014) steps of thematic analysis: First, we read and reread the transcripts and fieldnotes, getting familiar with the data and recording initial ideas; second, we generated initial codes through a systematic analysis of the data; third, we grouped codes into potential themes; fourth, we reviewed themes in relation to codes, quotes, and the whole data set, developing a thematic map; fifth, we refined the themes, producing names and definitions for each theme; and finally, we generated a report that included all cases and connected themes with our research questions. The first author and a research assistant coded independently, then collectively tested for convergence. A third researcher confirmed a basic interrater reliability (Patton, 1990) of 50% of the data by manually tallying divergences in the assignment of themes, attaining 90% of reliability for interviews and tests. The process also included considering the trustworthiness of the coding, mostly in relation to confirmability (Guba, 1981)—that is, how it represented the participants' experiences and how themes were linked to the data and not emerging from coders' preassumptions and values. This was done by contrasting themes with the transcripts and having coders who participated in the data collection and those who did not, integrating emic (insider's) and etic (outsider's) perspectives (Braun & Clarke, 2014; Olive, 2014). Fieldnotes complemented the interviews and contributed to the qualitative profiling, expanding our grasp of participants' contexts, app adoption and use, and the involvement of researchers.

Quantitative Analysis. Psychometric scales were analyzed descriptively and with Friedman and Sign tests (see Figure 3), which are nonparametric techniques matching our sample (Hollander et al., 2013). We measured scores over time, from pre- to postdeployment. As health practitioners use these scales to assess individual patients at different time-periods, we followed a liberal criterion concerning our sample size (n = 16; Pett, 2015). Scales gathered baseline information on loneliness and social interaction and support of our participants, since advanced statistical analysis was not reliable with our sample. Logs were analyzed with descriptive statistics and confidence intervals, as the purpose is to consider effect size and its practical significance (Dumais et al., 2004). The quantitative component of usability and accessibility tests were analyzed with descriptive statistics and correlations to measure: number of tasks completed, speed of performance, and ratio of issues encountered (Franz & Neves, 2019). The authors analyzed these data with the support of two research assistants.

Mixed Methods Integration Dimensions. Our mixed methods integration occurred throughout the study, in data collection and analysis/interpretation (see Figure 3), enabling a continuous dialogue between methods. In data collection, we used instruments with both qualitative and

quantitative components (e.g., usability and accessibility tests) and employed *comparing, matching*, and *building* integration techniques (Fetters & Molina-Azorin, 2017). For example, while conducting the interviews we also administered the scales, which allowed *comparing* qualitative and quantitative data to contrast, validate, and complement insights on social interaction, social support, and loneliness. We were *matching* as well, meaning that some interview questions matched the constructs measured by the scales (e.g., Duke Social Support Scale on social interaction/satisfaction and interview questions on close ties and social interaction; UCLA Loneliness Scale and interview questions on ties, social interaction, and current feelings). Finally, we were *building*—the interview questions for subsequent phases were informed by the mixed methods data collected in the previous phase(s). For instance, in Study 1, the mixed methods data of pre- and middeployment informed the postdeployment interview guide (adding questions about feelings and experiences) and showed the need to include a middeployment interview for Study 2. As with the interviews and the scales, we integrated usability and accessibility tests at data collection through comparing, matching, and building.

Regarding data analysis, after the *intramethod analysis* (analyzing data strands with corresponding methods), we employed a *core integration* approach, focusing on common threads or themes. First, we integrated the interviews, field observations, and usability and accessibility tests around two main overarching themes relating to our research questions: (1) adoption/use (what facilitated and what hindered adoption and use of the app and of the tablet) and (2) social interaction and connectedness outcomes of using the technology (see Figure 3). Then, we integrated the quantitative data—scales, logs, and usability and accessibility tests. The interpretation of these findings was informed by the qualitative profiling and thematic analyses. For example, the scales' scores over time or the logs indicating technology usage were both contrasted and contextualized with the qualitative profiles and the themes identified in the interviews and fieldnotes. Likewise, the qualitative component of the usability and accessibility tests (e.g., mental model of the system explained by the participant) was compared to the quantitative component (e.g., number of tasks successfully completed).

Our subsequent core integration step was to identify sociotechnical factors of adoption and social outcomes of the app represented in both qualitative and quantitative data sets through comparison and synthetization of results from the three deployment phases. We looked for triangulation, complementarity, and contrasting results (Onwuegbuzie & Johnson, 2006). This allowed us to explore changes over time and make sense of changes and continuities with the mixed methods data: by looking not only for similarities across the data sets but also for discrepancies, data were in a dynamic conversation and provided a deeper understanding of the findings (Creswell & Plano Clark, 2018; Hauken et al., 2017; Teddlie & Tashakkori, 2010). The last step of interpretation was based on a reflection of the merged mixed methods analysis, ensuring a sum greater than the individual parts or the 1 + 1 = 3 mixed methods model (Creswell, 2014; Fetters & Freshwater, 2015). This last step facilitated an *advanced integration*, as findings improved the instruments used and the design of Study 2. In terms of data interpretation, three types of integration procedures—namely confirmation, complementarity, and expansion—allowed us to answer our research questions and meet our research aims. Table 5 describes these various cross-disciplinary integration dimensions—at data collection, analysis, and interpretation—based on the usability and accessibility tests as an example. The table draws on the integration types described above, used with the different methods and throughout the study. The table also offers lessons learned such as the need for a design-in-action, which is further explored in the results.

Finally, considering epistemology and its methodological ramifications, although team members shared a theoretical approach to technology and valued empowerment of older people and positive social change (axiology), epistemological and ontological paradigms differed, ranging

from postpositivist and objectivist assumptions (more common in computer science) to interpretivist and realist assumptions. This is expected in cross-disciplinary studies with collaborative teams, so we took a practical approach to these differences and drew on pragmatism as a philosophical underpinning; however, we drew on a flexible form of pragmatism that respected multiple epistemological understandings (Creswell, 2014). We later found that *dialectical pluralism* was better suited to describe this flexible approach, because it accepts and attempts to include different epistemologies rather than using a general term that can often mask differences and the need for ongoing reflection and dialogue (Johnson, 2017). Dialectical pluralism (DP or DP 2.0) is a metaparadigm and process philosophy that warrants plural epistemologies and ontologies when conducting research—team members following different paradigms engage in a dialogue to ''combine divergent ideas and values and add a ''metavoice'' to social science research and practice'' (Johnson, 2017, p. 159). Though we did not follow the steps outlined by Johnson (2017), our practices matched DP. We focused on listening, dialectically, to multiple perspectives, reflecting on aims and perspectives, and agreeing on how to proceed. For example, while computer scientists wanted to solely rely on logs to measure technology usage (postpositivist), sociologists were also interested in users' perceptions (interpretivist). After discussing the issue, we reached consensus on having both forms of inquiry. We were purposively mixing more at the methodological level than at epistemological/ontological levels—although they, of course, interact (Johnson, 2017).

Results

In this section, we report both empirical and methodological findings. Following our mixed methods integration, we first present the merged data to address our research questions and then describe the design-in-action approach that emerged from the mixed methods research.

Adoption and Use of the App

All users adopted the app throughout the project, although at the studies' completion two users stopped using the app. Chris (Study 1) did not receive messages from his son, the only contact in the app; Martha (Study 2) preferred to devote her time to knitting, as family usually called her telephone. Frequency of use stabilized over time as some users moved from ''practicing using'' the app to employing it to communicate with their ties: at postdeployment, 11 participants used the app on average 2 days per week and three used it once every 2 weeks. Qualitative reports and logs were fairly consistent in terms of frequency of use. Most participants preferred to receive text messages and send audio messages, but friends and relatives typically sent video and picture messages. This intergenerational disconnect was also observed in terms of reply times (e.g., grandchildren thought their grandparents took too long to reply) and expectations (e.g., family wanting a real-time app, whereas participants enjoyed its asynchronicity).

The integrated analysis and interpretation of interviews, field notes, and usability and accessibility tests identified five main sociotechnical factors that could both facilitate or impede adoption of the app, addressing our Research Question 1. These factors were the following: social, attitudinal, physical, digital literacy, and usability (see also Neves et al., 2018). Social factors encompassed context, levels of social support, and cultural issues. For instance, in Study 1, small living spaces and lack of privacy were mentioned by participants as deterrents to using the app, whereas several participants of Study 2 commented on their ''beautiful dining area'' and gardens, facilitating picture or video taking. Across both studies, those who had study partners and relatives/friends engaged in the project were able to more quickly adopt the app and become frequent users—even among participants such as Bei and Evelyn, who had never used

a digital device before. Cultural issues were observed in Study 1: the icon for the ''wave'' (preset messages) was a waving hand, which for our Chinese Canadians meant stop, preventing use of this function. The intended meaning of the function was explained through the study, but their cultural signifier seemed stronger. Attitudinal factors included perceived usefulness of the technology and attitudes toward learning. Participants (even Chris and Martha, who stopped using the app) indicated high perceived usefulness of the app, because they saw its communication options suiting different circumstances and recipients. All displayed positive attitudes toward learning, but study partners described participants having more learning issues than reported by participants. Digital literacy was related to previous and current skills regarding digital technologies. Those who had previously used a computer could better grasp some functions; nonetheless, comparing the app to a computer would sometimes create confusion about what could be done with the app. Physical factors comprised motor and visual abilities, including dexterity issues, ''fat fingers'', and ''can't see very well'', which were inhibitors. Finally, usability factors involved ease of use of the app and the tablet—we could see during the usability and accessibility tests that the app was generally accessible and progressively easy to use. Nonetheless, all participants, except two (James and Diana), seemed unsure of when to swipe or when to tap. Additionally, the tablet was standard, and we saw half of the participants struggling with finding the on/off button embedded in the tablet's case.

Social Outcomes of the App: Social Interaction and Connectedness

Addressing Research Questions 2, integrated data and interpretation from interviews, observations, logs, and scales show outcomes related to social interaction and social connectedness (meaningful social interaction). The app increased perceived social interaction—frequency and type of communication (e.g., pictures, etc.)—with relatives and friends for all participants except Chris, Jen, and the duo Paul–Martha. While Chris sent messages to his son (only tie in the app), he did not receive any replies. Chris's son indicated in the postdeployment interview that the technology asynchronicity was unsuitable for them. Jen also had low social interaction with family and friends, which shaped her app usage and quantity of messages received. Martha mainly used it through Paul (husband), and Paul reported that the asynchronicity and lack of a keyboard limited communication with relatives.

Six participants (Bei, David, Gaby, Pam, Bree, and Lily) reported high perceived social connectedness at the study's completion. These participants had family living afar or abroad and used the app to reconnect, interact more frequently, and deepen relationships with those relatives. Having geographically distant relatives enhanced the feasibility of the app for higher social connectedness, helping to address social isolation and loneliness. Globally, the psychometric scales showed a positive increase in social support scores for social interaction and social satisfaction and a decrease in scores for loneliness from pre- to postdeployment; however, they were not statistically significant ($p > 0.5$). Data from participants and study partners regarding these social outcomes were mostly consistent (see Neves et al., 2018, 2019b, for an in-depth description). Nonetheless, it is important to note that the technology might have enhanced awareness of social isolation and loneliness for Chris and Jen, who did not receive any or frequent messages from ties. Negative outcomes also need to be considered—the mixed methods design helps illuminate these distinct insights.

Design-in-Action

While conducting the studies, we encountered the need for what we termed a ''design-in-action'' approach—that is, the ability to refine research techniques (instruments and

procedures) during and across studies. It draws on flexible design, as used in, for example, in-depth interviews, which allows interviewers to add questions and change prompts throughout data collection (King & Horrocks, 2010). However, our design-in-action is not single-method—rather, it relates to mixed methods. This approach emerged from a cross-disciplinary, longitudinal, mixed methods design, which shed light on the limitations of each method and instrument as well as their interplay in sensitive settings. Our design-in-action improved the methodological plan and technology within and across Studies 1 and 2. It also functioned as a strategy to reduce overburdening participants in longitudinal studies through adapted protocols (Plano Clark et al., 2015). Changes regarding (1) *research design and deployment phases*, (2) *research techniques*, and (3) *technology*—and the rationale for and outcomes of the design-in-action—are reported herein.

Research Design and Deployment Phases. While conducting Study 1, mixed data (from interviews, observations, and usability and accessibility tests) highlighted a lack of knowledge of dimensions that could prevent a comprehensive view of adoption, use, and outcomes of the technology. For example, we missed previous technology use of participants (e.g., to fully understand participants' mental models of technology during the usability and accessibility tests), their expectations around the app, and richer data on intergenerational communication. As these could influence how older people adopt/use/perceive the app, we included these topics informally in Study 1 during interactions and field observations and then added them to Study 2 interviews with participants at pre- and middeployment. We also added interviews with study partners to predeployment. This gave us a sense of the participant and their social ties from the relative/friend's perspective, as well as the partner's expectations.

With some instruments, such as usability and accessibility tests, we faced circumstances that could stress our participants and originate inconsistencies between the test's qualitative (open-ended questions about the technology) and quantitative data (rating scores) due to validity issues. In Study 1, participants were still learning to use the app at middeployment, showing distress and engaging in *impression management* (efforts to impress us; Goffman, 1956). Users were overly positive about the app, while we could observe them struggling with it. This divide between their quantitative report and their actions also stressed them about ''failing'', despite our persistent input that the fault rested with the technology. Thus, we moved the tests from mid- to postdeployment. In Study 2, although impression management was still visible, participants seemed more relaxed about the tests and more critical about the technology.

Research Techniques. The design-in-action approach was also the result of mixed cross-disciplinary gains. For instance, the usability and accessibility tests gained from a sociological lens and vice versa. The sociological analyses identified that: the Likert-type scales were not the best option for our participants as most would narrate a story rather than selecting a score or relay confusion about the scale; strong *impression management* was observable during the tests, namely being positive about the app and pleasant to researchers through the downplay of health impairments, understandings of the app, and tablet's inaccessibility. For example, in Study 1, Chris and David reported that the tablet was easy to lift and carry despite having only the use of one arm, but we had observed their difficulty during the study. Two other participants, Bei and Evelyn, indicated that the app was ''great'', they ''liked everything about it'', and it was ''easy to use'', while we detected preferences regarding communication options as well as issues with taking pictures or recording videos. Evelyn would consistently engage in self-deprecation when unable to complete a task: ''I'm old and dumb.'' The tests were implemented as informal sessions, but participants' feelings of being assessed were shaping outcomes.

The team was able to adjust to these circumstances, following the design-in-action: we requested participants to perform actions (e.g., lift the tablet) before answering related questions and followed up the scales with open questions (encouraging the storytelling noted before). These changes guided the design and implementation of the usability and accessibility tests for Study 2. We developed more task-based questions since we saw valuable changes when introducing this format in Study 1. The participants who reported that the tablet was easy to lift and carry changed their response when we asked them to lift it first. Furthermore, we emphasized that participants were experts and their role was to find problems with the app. We also included questions about how other older residents would see the technology. This helped address impression management, as participants critically embraced their roles. Lastly, we used open and comparative questions to grasp their preferences and conceptions of different features.

The usability and accessibility tests were a gain for mixed-methods sociological practice, as by adding these techniques to the social methodological repertoire, we were able to study simultaneously how people use, engage, and perceive technology. Moreover, it provided a better understanding of social dynamics and performances (by participants and researchers alike) involved in using sociotechnical systems. For instance, the video-recorded tests led to identifying how participants would proactively try gestures (not taught by us) when tapping or swiping was not working.

Technology. We adjusted some features of the technology during fieldwork as a response to the data encountered (e.g., screen response time) and further used the findings to improve the app. We expanded the preset messages (''waves''), as the only original wave was ''I am thinking of you.'' Participants and study partners noted in the interviews that more options would elicit additional bidirectional interaction. Logs and field observation data were consistent with that finding as waves became the least used feature. In Study 2, we had four waves that could be customized (e.g., ''What are you up to?''). The wave icon (waving hand) was also redesigned as Chinese Canadians participants saw it as a stop sign.

To conclude, our longitudinal mixed methods and cross-disciplinary research provided rich and complex data on adoption, use, and outcomes of an app designed to address social isolation and loneliness in later life. This design also demonstrated the empirical and axiological need and importance of a design-in-action approach.

Discussion

This article illustrated a cross-disciplinary longitudinal mixed methods study of complex phenomena. In this section, we reflect on the implications of the findings and on the lessons learned regarding the mixed methodology. We start by discussing the relevance of our results to technology and aging fields, followed by contributions to mixed methods research.

Technology-Based Interventions to Address Social Isolation and Loneliness in Later Life

Findings show that an accessible communication technology can enhance social interaction and connectedness to help address social isolation and loneliness in later life, as suggested in the literature (Findlay, 2003; Poscia et al., 2018). Enabled by the mixed methods design, we demonstrate how such technologies can be adopted and used to achieve those social outcomes. The app's adoption was both facilitated and limited by a set of sociotechnical factors, from social to usability factors. For instance, living settings in Study 1 inhibited adoption and use, while facilitating them in Study 2. Our mixed methods data elucidated the interplay of those factors, as some seemed to compensate for others: for example, family support seemed to compensate for

nonexistent or low digital literacy. This implies that technology adoption models must account for this interplay.

Using the app increased social interaction for most participants, while social connectedness outcomes were heightened by having geographically distant social ties (see also Rodríguez et al., 2009). Communication apps can facilitate social connectedness, addressing feelings of loneliness and isolation, if participants have adjustment periods to learn to use the technology and to adapt to different intergenerational norms and preferences.

However, our research also highlighted potential negative outcomes, underexplored in comparable studies, such as increased awareness of loneliness. Technologies can be limiting when there is reduced or no interaction with social ties, making lack of interaction or support more visible. Furthermore, older people seemed to prefer relationships with family and close friends (Cotten et al., 2013)—our participants were resistant to making new friends with other residents. This was more visible in Study 1, but also observable in Study 2, which can be explained by network selectivity in later life (Cornwell & Schafer, 2016).

Contribution to Mixed Methods

This article adds to a very limited literature on complex cross-disciplinary mixed methods approaches, especially when combining convergent and longitudinal dimensions to study sensitive topics (Hauken et al., 2017). While drawing on different sciences, our approach expands on the mixed methodology ''eclecticism'', as we selected and integrated ''the most appropriate techniques from a myriad of qualitative, quantitative, and mixed methods to more thoroughly investigate phenomena of interest'' (Teddlie & Tashakkori, 2010, p. 8). Collecting cross-disciplinary qualitative, quantitative, and mixed data as well as giving equal weight to each data strand meant embracing the messiness of deployments and the complexity of integration. As outlined in our methodological aim, our purpose was to go beyond the illustrative example and reflect on the lessons learned, namely challenges and opportunities. We thus discuss next: integration, cross-disciplinary and longitudinal studies, and the design-in-action approach.

Starting with integration, we showed how cross-disciplinary methods can be integrated at the collection and analysis stages. While looking for convergence and divergence at the analysis stage, we found a high corroboration of the quantitative and qualitative data, as the strands supported each other. For instance, the logs were generally consistent with self-reports; the quantitative data of the usability and accessibility tests matched the qualitative data of the tests (when adjusting for impression management); even the scales, although not statistically significant, provided relevant baseline information in each deployment phase, matching field notes and interview data. A plausible main reason for this is that instruments and procedures were continuously refined throughout data collection, following our design-in-action approach. For instance, as shown in Table 5 (lessons), the *building* technique in data collection can reveal a design-in-action need; concurrently, the design-in-action approach eases openness to *building* and refining instruments iteratively. A design-in-action can assist with integration procedures, particularly if the research is not conducted in a laboratory and accounts for people's contexts and everyday experiences. Alwashmi et al. (2019) also demonstrate the role of iteration in facilitating mixed methods integration. Our iteration in a design-in-action approach is, however, done in relation to the constant improvement of techniques in the field. Furthermore, corroboration was found even when employing cross-disciplinary techniques, which emphasizes the role of mixed methods research across different disciplines.

Although data integration processes are challenging, their integration occurred fairly naturally around critical concepts, transcending the project's individual components (Fetters & Freshwater, 2015). We illustrated these aspects in Table 5, using the example of usability and

accessibility tests to reflect on lessons learned. Mixing and integrating in the data collection stage and not just the analysis stage facilitated core integration. Additionally, being open to similarities and differences when bridging the data sets might have offset some of the common integration issues. Including a member of each discipline in data collection and analysis and ensuring researchers had a good grasp of all data strands enabled a continuing dialogue on important dimensions and themes, helping merge the data. The constant dialogue between team members and methods—enhanced by the design-in-action approach—aided data interpretation namely confirmation and complementarity (as refining methods in the field improved interpretation) and expansion (as methods ''spoke to each other''). But integrating results from different strands might inadvertently give more weight to one strand than others (Hauken et al., 2017). We employed standard procedures when analyzing data with several strands and presented all sets as equally as possible (Creswell & Plano Clark, 2018; Hauken et al., 2017). Since we found no critical divergence in the results, we can add that to the findings' trustworthiness (Hauken et al., 2017).

In addition to integration challenges, complex mixed methods longitudinal studies can be constrained by time and funding resources (Creswell & Plano Clark, 2018; Hauken et al., 2017)—and, in our case, by involving vulnerable groups and cross-disciplinary approaches. Due to participants' frailty and ethical issues, our studies were limited by a convenience sample (n = 16; study partners = 15), so results cannot be generalized. Yet, this sample allowed us to deploy the app for 2 and 3 months in real-world settings, collecting mixed data from the same participants in three time points, which is a major research strength (Hauken et al., 2017). While multiple-perspective evaluations are valuable, a cross-disciplinary approach can be challenging when bridging diverse expertise and epistemologies. Relying on a dialectic approach to collaboration and including team members from different disciplines in each stage helped embed multiperspectives throughout the research. By bringing together computer and social research methods, we improved our mixed-data collection, analysis, and interpretation. This provided a comprehensive examination of technology adoption and its outcomes for older participants and highlighted the interplay of sociotechnical factors of adoption. On the one hand, social research methods such as semistructured interviews, psychometric scales, and participant observation contextualized adoption, long-term app use, appropriation of the technology, and perceived impacts of the app. On the other, computer science/human–computer interaction techniques, such as logs and usability and accessibility tests, provided real-time information on usage frequency and type, interaction with the app, and perceptions and performance around technology.

Moreover, closely involving researchers in cross-disciplinary teams and relying on different groups (e.g., older people and study partners), can enhance research validity as we established long-term rapport with participants (which supports dependability of reports) and included different users/perspectives—but it can also undermine researchers' objectivity and data's trustworthiness (Hauken et al., 2017). To counterbalance this, we combined different data, adjusted instruments and procedures to heighten authenticity of the findings while addressing issues such as impression management, and employed a diverse team in all research stages. All stages were conducted and closely supervised by the authors. Nonetheless, it is impossible to fully control for ''objectivity versus active involvement'' in this type of study design (Creswell & Plano Clark, 2018; Hauken et al., 2017).

Finally, a design-in-action approach was identified from a dialectic dialogue between methods, as we had to adjust research techniques in the field to better study complex and sensitive settings. We have numerous instructive examples of this. First, field observations and interviews helped understand the frequency and type of use demonstrated by the logs, revealing that some of the initial use was to learn how to use the device. Second, the scales were useful beyond psychometric scores, as participants would share feelings and tell stories to supplement their responses, providing a comprehensive picture of their perceptions. This was possible due

to the longitudinal and mixed methods nature of the project. Third, the usability and accessibility tests, coupled with field observations and interviews, allowed us to explore in situ adoption styles, usage types, performances, and social expectations. These findings and the design-in-action would not have been identified by only one data strand. A mixed methods integration and its employment for evaluating complex interventions can, in fact, improve validity and reliability by bringing together the strengths of each design, therefore counteracting their weaknesses (Creswell & Plano Clark, 2018; Hauken et al., 2017; Onwuegbuzie & Johnson, 2006).

This design-in-action strategy may also be an asset for longitudinal mixed methods research, as it facilitates refining the design to adjust to hard-to-reach populations, vulnerable participants, changing timeframes, and integration processes. The approach yielded several strengths, especially regarding efforts to increase validity, trustworthiness, and legitimation (Onwuegbuzie & Johnson, 2006; Teddlie & Tashakkori, 2010). Legitimation as an iterative process supports our approach—through this practice, we added to the study's ''significance enhancement'', that is, ''facilitating thickness and richness of data; augmenting interpretation and usefulness of findings'' (Onwuegbuzie & Johnson, 2006, p. 54). The design-in-action aligns with the methodological eclecticism and dialectic pluralism of mixed methods, as researchers have to ''select the best techniques available to answer research questions that frequently evolve as a study unfolds'' (Teddlie & Tashakkori, 2010, p. 8).

While design-in-action might sound similar to action research, these are different approaches. Action research focuses on studies with applied and often transformative social outcomes (Somekh, 2005), whereas design-in-action refers to the refinement of research instruments and designs in the field, throughout a mixed methods study, as methods ''talk to each other''. Furthermore, not all action research is based on mixed methods. The design-in-action emerged from and adds to mixed methods, contributing to integration, methodological eclecticism, and other mixed methods procedures that value overcoming rigidity and embracing the messiness of complex research and sensitive fieldwork. Due to its applied nature, action research can greatly gain from a design-in-action as techniques are iteratively adapted to varying contexts and interventions. In fact, we used an action research approach to support an applied component of our study: the refinement of the app for social connectedness. Nonetheless, the core of a design-in-action approach is a mixed method design because of its dialogical essence—that is, based on linking and integrating different methods.

A limitation of the design-in-action is that adjusting instruments and procedures during the research can compromise reliability, especially in longitudinal approaches. We felt, however, that what was gained by capturing what we were supposed to, considerably enhanced validity and trustworthiness (Onwuegbuzie & Johnson, 2006). To safeguard reliability, we drew on the strengths of mixed methods to increase consistency and dependability across studies (Teddlie & Tashakkori, 2010). Nonetheless, when engaging with design-in-action approaches, it is crucial to describe, justify, and reflect on methodological changes.

Conclusion

This study contributes to the growing research on technologies for social connectedness in later life, by innovatively combining cross-disciplinary and longitudinal mixed methods research. We illustrated how this design provided a comprehensive understanding of adoption and use of a communication app among frail older people living in institutions. Additionally, this cross-disciplinary study—bridging sciences and pure and applied research as well as integrating methods at different stages—offers important methodological insights. It contributes to mixed methods research by discussing the design and integration of cross-disciplinary convergent longitudinal studies as well as their benefits and challenges. It also shows the value of a design-

in-action approach that emerged from and added to the mixed methods research. A constant dialogue between methods, disciplines, and researchers showed the need to continuously adjust research instruments and procedures during the studies. This design-in-action approach is particularly useful in longitudinal research with vulnerable populations in sensitive settings, although cross-sectional research and studies with other groups can also benefit. Future research should discuss further challenges and applicability of these designs.

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