"Back to Real Pictures": A Cross-generational Understanding of Users' Mental Models of Photo Cloud Storage

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Personal pictures storage is currently split between a myriad of physical and digital tools. Cloud photo storage and social networks are seeing increasing adoption, and are being recommended to families (especially older generations) as digital pictures solutions. The ubiquity of these platforms raises the question of whether the design of their photo-based operations consider the mental models of their cross-generational users. Understanding mental models is a key factor for the usability (and adoption) of these technologies. Previous works have observed that perceptions of digital storage limit adoption, especially for older users. However, we do not yet understand users' mental models of these applications. This impedes efforts to design applications better matching diverse user needs. We present here a cross-generational investigation of users' mental models of ubiquitous picture technologies, including cloud storage and social sharing. We find that mental models are split (both between generations and domains), contributing to lower adoption by older adults. Our analysis reveals that digital tools need to understand their roots in physical pictures and bridge this divide by including physical concepts as an aspect of use, if we are to support cross-generational interactions with personal and family pictures.

CCS Concepts: • Human-centered computing → Ubiquitous and mobile computing theory, concepts and paradigms

KEYWORDS[1]

Exposing mental models, technology and older adults, digital picture management

ACM Reference format:

Benett Axtell and Cosmin Munteanu. 2019. "Back to Real Pictures": A Cross-generational Understanding of Users' Mental Models of Photo Cloud Storage. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 3, Article 74. https://doi.org/10.1145/3351232

1 INTRODUCTION

Managing family collections of pictures has always required time and effort. As these pictures have moved from film and physical prints to digital storage and sharing, this effort has not decreased. If anything, it requires more effort as users are faced with a growing selection of apps and services to store, view, and share their pictures [10]. Maintaining personal pictures is an important aspect of family social connection and storytelling, and supports a continued sense of self identity and reduces social isolation, especially in older adults [9,29]. The issues of time and effort, along with lack of motivation, have been found to severely limit older adults' adoption and use of available tools for reminiscence and documentation [62].

Pictures and picture tools are ubiquitous and have been for some time, but many of these tools are focused only on either sharing or telling a story or on storage, without consideration for the realistic use of personal pictures. Additionally, access to physical pictures is declining. Users have been moving their picture interactions into these new digital spaces, like social media networks (SMNs) and cloud storage, but there is not yet an understanding of how these new tools compare to existing physical ones. In particular, we need to understand

users' mental models of digital picture applications, alongside physical ones, so that designs of such tools can better serve users in this important space which allows for documentation of self and family for future generations.

A user's experience (both direct and indirect) with a digital technology forms their mental model of that system, including how they expect it to work and how they believe they can interact with it. Norman (among others) emphasizes the importance of exposing mental models in order to improve usability of an interface [45]. This demonstrates the importance of uncovering mental models (which may be individual) and finding their common patterns (regardless of individual differences) in order to improve an interface that will ultimately be used by a larger group of people. As such, exposing mental models across a group of users exposes trends in user understanding and can reveal, for example, potential adoption barriers [61].

The shift to digital pictures is recent, and most families still find themselves between spaces with many albums or boxes of physical pictures and no clear path for them, alongside folders of digital pictures with no simple, familiar format to socially view them. More digital storage tools are including options to order printed books from your digital collection, but the spaces are still largely separated. Older adults are particularly affected by this, as they are often excluded from new technologies and are at increasing risks of being "digitally marginalized". This is due to several factors, such as declining tech savviness as seniors retire from the workforce [19] and social isolation [43], which reduces the available peer support that can provide assistance and encouragement in adoption of online technologies. The issue of digital marginalization emerging from this combination of lack of social support and uneven technological literacy, may be further compounded by aspects of usability and perceived utility of digital (online) technologies.

Research shows that many personal or cultural factors represent additional barriers to the adoption of ubiquitous technologies, like popular SMNs [37,42]. One such factor that interconnects with and permeates through all others (cultural, personal) is the mismatch between users' perception and understanding of how that technology works – a mental model mismatch [45]. While this is relevant to the design of any interactive application [45], it is particularly critical for older adults. This has been demonstrated in research studying barriers toward the adoption of daily technology by older adults, like online banking [61].

In this research, we explore how users explain and understand various tools for personal pictures. We focus on differences between ages to better understand how differences in lived picture experience, along with digital marginalization, influence use. As these digital tools, especially SMNs (e.g., Facebook), are more easily adopted by younger adults and are generally designed specifically to attract younger users [41], they risk marginalizing older users and separating them from their pictures. The difference in adoption levels are caused by many factors. Motivation, however, is rarely such a factor. In fact, older adults are often well motivated to adopt such technologies in order to stay connected to family members and peers [42,49]. While older adults' motivations to adopt such technologies are often surprisingly similar to those of young adults [9], their perception of many design and functional aspects can lead to differences in adoption and use. Due to the large number of available apps, we need to better understand how users generally perceive their inner workings and how users' mental models vary across generations. Mismatched mental models are a major source of usability issues. Understanding these models, and their differences between ages, will allow tools to better align to or correct user expectations and improve adoption, especially among older adults [38].

As such, the goal of our research is to understand variations of mental models across generations when using ubiquitous picture applications as a factor influencing their usability, adoption, and use. Mental models have been shown to be a key factor in the adoption of new technologies across various demographics, but particularly for older adults [42,47], and often independent of technical or domain expertise [60]. At the same time, poor usability represents a significant barrier to technology adoption by older adults [4,12], with mismatches between users' mental models and the actual design (or usage envisioned by designers) being a key source of poor usability [45]. Therefore, understanding users' mental models will help designers and developers better address the needs of user groups (such as older adults) who are often ignored during the design process but who can greatly benefit from increased access to such tools. These benefits are varied and include, for example, reduced social isolation [63], increased connection to grandchildren [49], reduced perceived loneliness (and its associated health benefits [11]), and increased digital participation [38].

We aim to achieve the above-stated research goal by answering the following research questions:

1. How do users understand and use picture storage tools, both physically and digitally, and how does this differ between older and younger users?
2. How does the motivation to use various tools differ both between tools and between older and younger users? Is their use influenced by perceived risks and what is the origin of those risks?

We hypothesize that older adults will have less well-formed mental models of the digital tools they are using. We further hypothesize that older adults are more wary of the risks involved with digital storage, particularly losing pictures, and this limits or otherwise influences their use of such tools. In this paper, we propose to focus on understanding (older) users' mental models of online digital picture storage. We focus on this space primarily for two reasons: 1) engaging in narratives around pictures has been shown to bring positive benefits to older adults, such as reduced social isolation [63]; and 2) the adoption and use of photo-centric social media platforms is markedly lower for older adults than for younger users [56].

We divide online digital picture storage into two main categories, based on a large body of existing works exploring the digital split between narrative and database [21,33] and particularly the distinct user experiences forced by these separate spaces [32], suggesting separate user mental models. Narrative tools (Facebook and other SMNs) prioritize sharing and telling users' stories. In contrast, database tools (cloud services like Dropbox) provide static storage of pictures with little interaction. We investigate these two digital spaces alongside physical picture storage, like albums, which encompass both database and narrative storage. These categories help to find commonalities in users' mental models across various tools and emphasize the differences in use between age groups.

The study consisted of individual interviews with older and younger users around their use and understanding of picture tools and storage. Using the pictures tools most familiar to each participant to represent each category, they explained their understandings of the general functionality of physical, narrative, and database picture tools, and then their personal use of each physical and digital pictures. As participants described their processes, they illustrated their models on a whiteboard, as is common in mental model research [1,53,58]. The order of tools was counterbalanced between participants and we gathered self-reported measures of familiarity with technology and use of various tools for pictures in order to ensure a representative sample of picture users within both age groups. These interviews exposed their general understanding of how narrative, database, and physical picture tools are used, as well as their own specific uses of these tools. Through these, we build a stronger understanding of how users perceive these tools, what motivates their choice of tool, and what facilitates or blocks adoption and ongoing use.

Older and younger adults share many similarities for their motivation and use of (social) photo tools, such as staying connected to family members or peers [9] (with self-expression, e.g., "selfies", being one of the very few differences [57]). Exposing older adults' mental models of these types of online digital picture tools, and contrasting these with younger users' models of the same services, will enable an understanding of users' expectations of how technology should work – an understanding that is deeper than what more surface-level indicators such as motivations, socio-demographic background, or cultural norms and expectations [37,42] can provide us. This will help us design better tools that overcome older adults' adoption barriers, allowing them to more fully benefit from these services. Through this, these tools will better cater to all users.

2 RELATED WORK

While this space still lacks a strong understanding of users' mental models, there are many works that begin to explore this. These include research into what people do with digital pictures, how users understand their permanence, and the motivations for use of social media and cloud storage. We also review methods to expose mental models and why mental models should be used as a tool towards meaningful design.

2.1 Family Pictures and PhotoUse

Previous research has sought out definitions of what we do with family pictures and how. Frohlich's formative work on family photoware mainly considers the desktop software that was available at the time, but also looks ahead to future options and examines use of physical pictures as a comparison [15]. More recent work has built on this, exploring photowork, specifically in terms of photo browsing and the role of searching in digital picture browsing [27]. A recent follow up on these works investigates the modern state of photowork and contributes a definition and model for photouse, including reminiscing and sharing [10]. These do not consider particular tools but rather seek to generally illustrate what is involved in picture activities.

There is increased commercial activity (e.g., Google Photos) and research [3] looking to make these processes easier from a technology perspective through more intelligent organization of pictures. This often entails delegating to cloud services. However, use of these features is not well understood, further supporting the need for the mental model research presented here.

2.2 Understanding Social Media Use

Previous works investigate how social media is used by various users and what motivates them to continue use (or not). For example Miller and Edwards observe a split in digital photographers: some continue traditional "Kodak Culture" digitally, sharing few pictures with close family and friends, and others who take pictures for the sake of sharing and share with a much larger group [36]. While there are numerous examples of social media use and the various benefits and downsides of sharing pictures, we highlight those that focus on older adults' use.

Coelho and Duarte present a literature review of older adults' use of social media and find a preference for family-specific interactions, a need for easier picture-centred interactions, and a desire for more tangible tools for sharing. They also identify privacy concerns as the major barrier to adoption [14]. Quan-Haase and Elueze have specifically explored these privacy concerns in older users and non-users of social media and find that both groups have overlapping concerns, primarily unauthorized access of information [51]. This overlap suggests that these concerns are not directly a barrier to older adults' adoption. As older adults still have these concerns whether or not they are users, this reflects their understanding of the system and what they need to do to protect themselves.

Jung et al research the motivations of older adults to use Facebook and find the ease of sharing over distances and of sharing photos specifically to be the main motivators. They also identify privacy and the chief motivation to *not* use Facebook, along with a desire for deeper personal meaning to the communication [23].

2.3 Understanding Digital Picture Storage

Fewer works have considered cloud storage use separate from social media, but there are examples looking into users' use and concerns for cloud storage. Ion et al compare opinions on cloud storage between Swiss and Indian users and found that Indian users consider cloud storage to be safer than Swiss users do [22], demonstrating the influence of culture on adoption and use.

Kang et al also consider privacy concerns in cloud usage by comparing mental models of the Internet between users with computer science backgrounds to lay people. While there was a difference in detail of mental models and awareness of risks between groups, there was no significant difference in actions taken to protect against risks [24]. Clark et al specifically consider picture storage on clouds and users' awareness of their use of these systems. The majority of their users found pictures on their cloud that they had not intentionally uploaded or knew were there [13]. Khan et al presented users with 10 examples of their own cloud storage and found that most users wanted to remove at least one document and identified a disconnect between preferred file management and the effort of managing their large collections [26].

These works, along with those looking at social media use, begin to expose users' mental models. However, there has been little work looking at specific ages of users. More has been done with older adults, as seen above, in order to better understand lack of adoption, but very little explores younger users specifically, perhaps

because their adoption does not seem to be an issue. Without this cross-generational understanding it is unclear how that will change as they age. Next we explore existing works around perceptions of digital media and then briefly explain how mental models can be useful and the methods used to expose them.

2.4 Permanence of Digital Pictures

Of particular interest in the area of digital picture use is adoption by older adults and their concerns towards digital storage. Several works have found that people are not taking steps to protect their digital pictures despite seeing the medium as impermanent. This general concern has been seen as early as 1998, when Kuny asked if we were entering the "digital dark ages" as there was no consistent strategy for data archiving in the face of quickly evolving media [28].

Petrelli et al find that, when selecting mementos, very few digital items are chosen as users could not be sure they would still be able to access them [48]. Looking across ages of users, Keightley and Pickering observe that digital pictures are seen as more disposable and less viewable than physical ones and that there is an "intense fear" of losing digital pictures [25]. There is clearly a long-established mistrust of digital pictures. What remains to be seen is how this lines up with the various tools available to users, especially for older users who are assumed to be more distrusting of technologies, and considerations for these technologies going forward.

2.5 Exposing Mental Models

Within a technology space, mental models define what a user believes about how an interactive system or digital technology works. That is, a mental model captures how users understand a system, for example a website. For example, the ability to type in search terms in the "address bar" of modern (as of 2018) browsers is a feature added in response to users' mental model of entering terms into browser or website elements that have the appearance of a search box – this mental model likely developed as the results of users' accessing the websites of online search engines such as Google [64]. In terms of picture storage, a user's mental model is their knowledge of what they can do with their various tools for storage and sharing and how those tools store pictures.

There are several examples which use various methods to expose users' mental models of specific aspects of technology. A common method is to ask users to draw out their process as a visual diagram, often along side a verbal description. This has been used to better understand gaps in user knowledge, such as by visualizing users' mental models of the Internet [58]. It can also be used to discover what users expect from a potential tool, such as a reminder system for older adults [1]. Both these examples use illustration as a tool to support users in explaining their views. This method has been expanded in recent work by with the introduction of premade cards or magnets that represent common elements in the models (e.g., a smartphone, Facebook) [53]. This eases the process for participants and provides a starting point instead of a blank page. We use this method to expose users' mental models of picture use across different types of tools, as well as their opinions on the limitations and future of picture use.

3 METHODS

As seen in the previous section, there have been several examples investigating the use of pictures generally [10,27] and exploring adoption and use of social media, especially for older users [14,51]. These contribute to a larger, general understanding of users' engagement with pictures, but do not consider how the processes of different picture tools are understood by different types of users.

In this study, we specifically seek out mental models of three categories of picture storage:

1. **Physical**: traditional formats storing and displaying paper pictures, such as photo albums
2. **Database**: digital picture tools meant primarily for storage. Often on a cloud (e.g., Dropbox).
3. **Narrative**: social media which supports the sharing of pictures (e.g., Facebook). Generally designed around sharing a curated story of your activities.

We explore the differences between physical and digital pictures, and as such we separate physical pictures into their own category including any form of printed or developed picture with their storage, like frames or albums. Database and narrative media are well-established terms that represent the main function of the chosen tool [33]. Social media tools are narrative: they emphasize sharing and communication, with a scrolling timeline telling a story. Cloud storage is a database tool: the primary purpose is to keep things, similar to an archive.

Each of these categories cover a wide variety of available picture activities (e.g., sharing, organizing). Each category encompasses tools with significant overlap in use (e.g., upload posts to narrative tools, long-term storage in databases), which are larger than individual differences between tools. That is, there is less of a difference between two narrative tools (e.g., Facebook and Instagram) than there is between narrative and database tools generally.

There has been much discussion of the divide of narrative and database in digital media. While some see database as pushing out narrative in digital media [33], others see them as "natural symbionts" performing different, but complementary roles [21]. We choose these two groupings as they represent a very clean divide in terms of use. While all narrative tools necessitate some form of database (e.g., Facebook must store picture and user data in some manner) this is not transparent to the user, and their experience is narrative. Similarly, database tools may allow users to form a narrative (e.g., downloading a selection of pictures on Dropbox for a slideshow), but the design is primarily to store and organize, with viewing or sharing a secondary or passive activity.

In physical tools, there is little variation. Albums form the very large majority of physical pictures storage, so this third category is largely uniform. Notably, albums fill the roles of both narrative and database storage, as they store organized pictures and support picture browsing and sharing.

There are, obviously, other lines on which to divide picture tools. We use these categories here first, because of the well-established definitions of database and narrative, and second, as they represent a hard separation of picture activities in digital and physical spaces that we investigate further in this work. Additionally, the discourse within critical media theory is mirrored by the commercial landscape with a similar, quasi-dichotomy.

We compare the mental models of tools from these three categories between older and younger users to expose the perceived processes in the two groups as well as differences reflecting the digital marginalization of older users. Further, we seek to understand how the different generations of users see the future of pictures and related tools. We have observed that current digital options do not correspond to physical ones and have been presented without considering what people want from pictures, digitally or physically. As such, this thorough understanding of processes and perspectives is intended to expose what is critical for both digital and physical pictures going forward.

This study consisted of individual sessions conducted with older and younger adults in order to gather examples of different participants' mental models of database, narrative, and physical picture storage and their perceived benefits, disadvantages, and risks to digital and physical storage options. For each category, we elicit the user's mental model using their most frequently used tool; providing their regular lived experience, rather than their imagining of how to work with a tool they do not use. This also maintains the focus on the general process for each category, rather than for a specific tool, which could expose only what is specific to that tool.

3.1 Participants

Participants were recruited through posted flyers and university groups and email lists for research participants. Recruitment was conducted in a large, predominantly English-speaking North American metropolitan area. Cash compensation was provided at a rate equivalent to the average part-time hourly rate, as well as transit fare to cover the cost of travel to the study.

The protocol and instruments for this study were designed under an integrated ethics approach, meaning the formal application for ethics approval and the study design were carried out as a single activity. This ensured the study was designed with ethical considerations from the beginning, following the overarching principles of our comprehensive national policy on the ethical conduct of research with human participants. The protocol was approved by our university's Research Ethics Board and deemed low risk. Relevant measures were taken,

Table 1. Older Adult (OA) and Younger Adult (YA) Participant Demographics

PID	Age	Gender	MPDQ	CPQ	Phase 1 tools		
					Narrative	Database	Physical
OA1	69	F	33.18	29.00	Facebook	MS OneDrive	Album
OA2	74	M	18.29	26.50	Facebook	Local storage	Album[2]
OA3	75	F	28.58	26.50	WhatsApp	MS OneDrive	Album
OA4	61	M	27.94	24.50	Twitter[2]	Google Drive	Album[2]
OA5	72	F	19.16	24.50	Facebook[1]	Local storage	Album, Scrapbook
OA6	73	M	24.87	24.50	Facebook[1]	Apple iCloud	Album, Framed
OA7	60	F	26.56	28.50	Facebook	Local storage	Album
OA8	67	F	30.75	23.50	Facebook[2]	Apple iCloud	Album
OA9	71	M	27.41	27.00	Facebook[2]	Local storage	Album
OA10	64	F	30.78	21.00	Facebook[2]	Local storage	Album
OA11	64	F	33.18	28.50	Facebook[1]	Local storage	Album
OA12	86	M	28.71	21.00	Facebook[2]	Google Photos, Apple iCloud	Album
YA1	34	F	35.07	28.50	Facebook	Google Drive	Album
YA3	39	F	35.65	28.00	Facebook	Apple iCloud	Album, Box
YA4	38	F	34.05	24.00	WeChat	Local Storage	Album
YA5	22	F	40.0	30.00	Instagram	Google Drive	Album[1]
YA6	33	F	35.3	23.50	Facebook	Google Drive[2]	Album[2]
YA7	21	F	39.0	29.50	Facebook	Google Photos	Album[2]
YA8	21	F	37.82	29.00	Facebook	Google Photos	Album, Notebook, Framed
YA9	23	F	39.23	29.50	Facebook	Google Photos	Album[2]
YA10	31	F	36.05	27.50	Instagram	Apple iCloud	Album
YA11	23	F	37.54	30.00	Instagram, Snapchat	Google Photos	Album, Framed, Box
YA12	30	F	40.0	22.00	Instagram	Baidu Cloud	Album[2], Framed
YA13	39	F	36.48	28.00	WeChat	Baidu Cloud	Album, Framed
YA14	21	F	36.98	27.50	Facebook, Snapchat	Apple iCloud	Album[2]
YA15	30	M	40.0	30.00	Instagram, Snapchat	DropBox	Album[2], Framed

[1]User had not used any tools in this category, so described the default tool as they had observed it used.
[2]User did not currently use any tools in the category, so described what they remembered of the last tool used.

given the demographic characteristics of many of our participants, including provisions for additional breaks, reassurances from researchers regarding embarrassment from (perceived) lack of tech proficiency, and additional privacy-protecting measures (e.g., camera positioned to avoid face capture, participants names stored only on consent forms and not linked in any way with participant ID). As per our ethics practices, (continuous) consent and risks were monitored by the researchers throughout the study; no adverse affects towards the welfare of participants or their continuous consent to participate were observed.

For this study, older adults (OAs) are considered to be those age 60 and over, and younger adults (YAs) are those ages 20-39. This younger age range was selected to gather a sample of users that have grown up with digital technologies and social media and may have young children, but likely not teenage or adult children. As the average age for a first child in North America is 25-28 [17,35], most users under the age of 40 would not have teenage children. We target these younger families as we are interested in the picture processes of the younger adults themselves. Those with older children will more likely be influenced by their children's use of technology.

No participants, as per the posted recruitment exclusion criteria, had a degree, currently pursued a degree, or had any other sort of serious background in computer science or computer engineering. We chose this exclusion criterion as those with a strong technical background would likely present very low-level, technical models and therefore not present a fair and average understanding, regardless of age.

Twelve older adults and 14 younger adults participated in this study. Of the older adults, seven were female and five were male, and ages ranged from 60 to 86 ($M = 69.67$, $SD = 6.91$). Thirteen female and one male younger adults participated, and were aged between 21 and 39 years ($M = 28.93$, $SD = 6.77$). One additional younger adult was excluded as significant language barriers significantly limited the detail of the models and answers provided. This was recognized by both the participant and researchers. Selected tools for each section of the study were chosen by the participant based on what they used most often. Because of this, several younger participants reported using multiple tools, but chose to only discuss one for the session. Participant demographics, and their selected tools for this study can be found in table 1.

All users' familiarity with technology was measured with the Computer and Mobile Device Proficiency Questionnaires (CPQ-12 and MDPQ, respectively), self-reported measures of an individual's technical literacy, based on how easily a participant believes they could do various tasks from 1 (Never Tried) to 5 (Very Easily) [52]. The MDPQ is measured by summing a user's average scores from each section, for a range of 0 (very unexperienced) to 40 (very experienced). The CPQ-12 is measured in the same manner, but with totals ranging form 0 (very unexperienced) to 30 (very experienced). Older users scored 25.42 ($SD = 2.61$) on the CPQ-12 and 27.45 ($SD = 4.57$) on the MDPQ, compared to 27.64 ($SD = 2.52$) and 37.37 ($SD = 1.95$) for younger adults, showing that both groups are very competent users of technology. Using a two sample t-test, YA scores were significantly higher for both measures ($p < 0.001$), which is consistent with the findings of Roque and Boots [52].

While the younger adults in this study scored similarly to the sample presented by Roque and Boot [52], the older adult average in our study (27.45) is higher than the sample in Roque and Boot's research (19.2). This is expected as Roque and Boot's study included older adults who were infrequent users of technology, and our research intentionally included only regular tech users as we aim to uncover mental models of current use of digital versus analog picture tools. Generally, the difference between older and younger users is expected due to both the issue of digital marginalization discussed above, meaning that older adults have less exposure to

Table 2. OA and YA Experience, Respectively, with Picture Tools
(numbers indicate how many participants self-identified with each level of experience)

	Physical		Cloud (DB)		Social Media (Narr.)	
Experience	OA	YA	OA	YA	OA	YA
Currently Use	9	10	7	12	5	14
Previously Used or Family Use	3	4	2	1	5	0
Familiar, but Never Used	0	0	2	1	2	0

new technologies, but also because older adults are more likely to under-estimate their technical abilities and younger adults, over-estimate [34]. Within these considerations, and given our research goals, we estimate that our sample of participants is representative of the use case studied.

All participants owned a smartphone and/or tablet, all used their devices for picture storage, and all (except one OA) used their devices daily. All users either currently or in the past had physical pictures. A slight majority of OAs and almost all YAs currently use a cloud service for picture storage, like Dropbox, and similarly almost half of OAs and all YAs use social media to share pictures. All participants were familiar with tools for both cloud storage and social media, even if they had no personal experience. Details on familiarity with picture tools are in table 2.

Though OAs were less familiar with these technologies, this is representative of the use of these tools (largely by YAs) as influenced by several socio-economic and demographic factors [20]. This does not indicate that our sample of OAs are less active picture users – especially in the context of (digital) social networking, where even if patterns of usage around photos and social sharing differ between older and younger users [31], photos remain a central activity and key motivation of use for those who have already adopted such technologies [14].

Two OAs, for example, are superusers of digital pictures (creating digital albums and sharing through services like Google Reviews), while three YAs have never used Facebook. The differences in usage and tech familiarity, along with the common desire or need to use digital picture tools, highlight the need to understand how age differences influence users' mental models of these tools. This in turn allows for re-designing such tools to better match the models specific to each age group (and particularly older adults).

3.2 Protocol and Instruments

Participants were provided with a whiteboard and markers to illustrate their models as they described them. Additionally, laminated cards representing different tools, apps, and websites (e.g., photo album, smartphone, Facebook, Dropbox) were available and were brought onto the board by the researcher when the participant mentioned them, in order to provide a starting point for their illustration (see figure 1). This was also intended to ease the pressure of starting from a blank whiteboard and has been proposed in previous works exposing mental models [53].

Throughout the study, participants used tools familiar to them in each category. These were decided on by the participant, without pressure by the researcher. If the participant did not understand what types of tools would be included, the researcher would share some common examples, while emphasizing that they should select a tool that they use. As we have structured the study along the fundamental differences of narrative and database, the differences between specific apps they use within a category are not significant. The focus of our exercise was to expose general traits of such apps and highlight use of a representative example of that category.

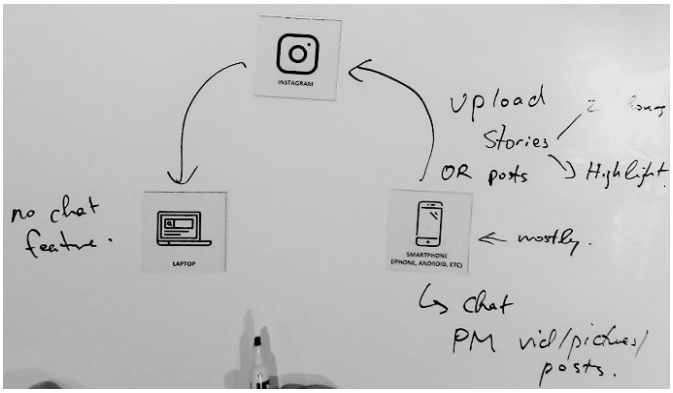

Figure 1. Mental model illustration of a participants' narrative process, showing use of cards and free-hand drawing. Several such whiteboards were captured for each participant. The visual information was coded and synthesized into a workflow model (see figure 2) and aggregated across age groups and types of picture tools (detailed in section 4.1.2).

The study was split into two sections, as well as a warm up exercise which demonstrated the purpose of the whiteboard and cards and a short interview and debrief to wrap up. Throughout the study, the researcher made it clear to the user that they should share how they understood the system without worrying about whether it was exactly technically correct. If they asked for confirmation that their explanation was right, the researcher would avoid answering directly and generally support their explanation (for example, "That makes sense to me.").

By probing for their explanations of functionality and their own personal activities within these tools, rather than observing their real-time use, we are able to gather understandings based on their higher-level perceptions of the process, rather than the low-level (e.g., which button starts an upload). Previous research has highlighted the importance of using user reports, instead of observations, to understand mental models [50]. This approach has been seen in previous works using illustrations to expose mental models, which highlights the user's understanding of the *process* rather than of a specific tool [58]. As with all qualitative research, engaging participants in an external activity (e.g., interview, think aloud, drawing) has some limitation on the results. However, measures were taken by the first author (an experienced qualitative researcher and ethnographer), to ensure that the data gathering was free of any confounding factors, especially those potentially varying across age groups, such as fatigue. These measures included provisions for additional breaks and careful monitoring of tasks for signs of fatigue, such as longer pauses or slow-downs in drawing. These provisions were not necessary for any of our older (or younger) participants.

Further, while the methods we have followed here are typical of qualitative research on exposing mental models [24,58], we have adjusted the study apparatus to ensure the known limitations of these types of methods are minimized in our research. In particular, the use of preprinted icons and pictorial elements ensures that participants are not held back by their potential or perceived lack of drawing skills, as they only need to visually represent their workflow around such elements. Preprinted elements have been successfully employed in other HCI-related research on exposing users' mental models [53]. Although evaluating such established methods is not the subject of our research, we can report that, based on our observations during all sessions with participants, there were no significant differences between age groups with respect to ability to use the instruments provided for the study, nor with respect to difficulties in completing the drawing tasks as instructed. All sessions were completed within the allocated time, and no adverse effects being observed.

The warm up used digital music or video streaming as example of digital storage as it is similar to, but not overlapping with, pictures, which is supported by previous works [5]. During the warm up, the researcher would prompt the user to write and, if necessary, provide suggestions of what to write based on what they were describing. The researcher asked the participant to confirm that they accurately represented their explanations. After the warm up, the researcher did not contribute to what was written and only prompted the participant generally without suggesting what or how to do so.

In the first section of the study, the participant was asked to describe and illustrate their understanding of the general process of adding, storing, and deleting pictures for the three categories (physical, database, and narrative), which were counterbalanced for order between participants. To do this, they chose their most familiar tool based on current or past use. In the case where the user had no personal experience with a given category, they were asked to describe a predetermined default tool as they understood it from what they had seen from friends, family, or media. The chosen defaults were based on cultural prevalence and were Facebook for narrative, Dropbox for database, and photo albums for physical.

They were prompted first with a general request, for example, "Could you show how pictures are stored on Facebook?" and "Where are those pictures stored?". As needed, the researcher would further prompt the user to provide details without explicitly asking them to write specific information on the whiteboard. They would remind the participant to use the whiteboard only generally. After the participant shared the general process of storage, they were asked about how the same tool managed adding and deleting pictures.

The second section asked participants to describe their perceptions and opinions of digital and physical picture storage (also counterbalanced between participants) through their experiences specifically with their own pictures, rather than their general understanding of a tool. In this section, we did not distinguish between database and narrative digital tools as we wanted to focus on their experiences and activities with their own

pictures. This documented the duplication of pictures in between narrative and database tools. For a particular set of pictures (e.g., an album on Facebook, a box of printed pictures), participants illustrated all the places they were stored, how they looked for and added new pictures to the set, and who had access (including to any copies or backups). With this fresh in their minds, and illustrated on the whiteboard, they were then prompted to share their concerns and risks for these particular pictures as well as the upsides and downsides of their storage.

The order of categories was counterbalanced within each section; narrative, database, and physical for the first, and digital and physical for the second. We also counterbalanced between the sessions so that every combination of orders was covered, and there was at least one older and one younger participant for each possible order. The study concluded with a short interview into their opinions on generational differences in use and the future of these tools, both physical and digital, as well as a short debrief.

4 FINDINGS

Our findings are presented below, first we explain the analysis of our data, with particular emphasis on how the processes described and illustrated by each participant were merged to form combined high-level mental models of use. We then describe these combined models for both age groups and the three categories of tools and their implications. This is followed by detailed findings into users' preferences and concerns for various methods of picture storage. Finally, we review participants' views of the future of picture storage.

4.1 Data Analysis

The interviews were transcribed, and both transcripts and participants' drawn models were analyzed using inductive thematic analysis [7], as is typical for such qualitative work and especially for understanding mental models [24]. Following the typical thematic analysis method, codes describing entities, actions, and participants' expressed opinions were iteratively generated from transcripts and drawings using inductive coding by the lead researcher. The codes were further analyzed and clustered. A theme was then identified for each of these interconnected clusters (with each theme in this thematic map directly supporting one of our findings). The coding scheme, coded documents, and thematic map were reviewed by a researcher not involved on the project to confirm that they are meaningful as well as for internal consistency. Both the lead researcher and the researcher reviewing the codes have significant experience with thematic analysis of qualitative data collected from socio-technical studies.

All the findings in this section reflect users' thought processes (that is, their mental models) of their different tools for picture storage and may not, even do not, reflect the reality of the functionality and use of these tools. Each general finding is given an identifier (e.g., **HL1: 3-Step Process**) that we use to refer back in the discussion section. Findings are grouped by each subsection found below: those for high-level mental models are identified with HL, low-level with LL, and looking ahead with LA.

4.1.2 Creating Combined Models of Use

The processes described and illustrated in the first section of the study were coded for the different identified tasks, such as take a picture, open app or website, and transfer pictures between devices. These were grouped into common task categories (both between tools and participants), again using thematic analysis (see table 3).

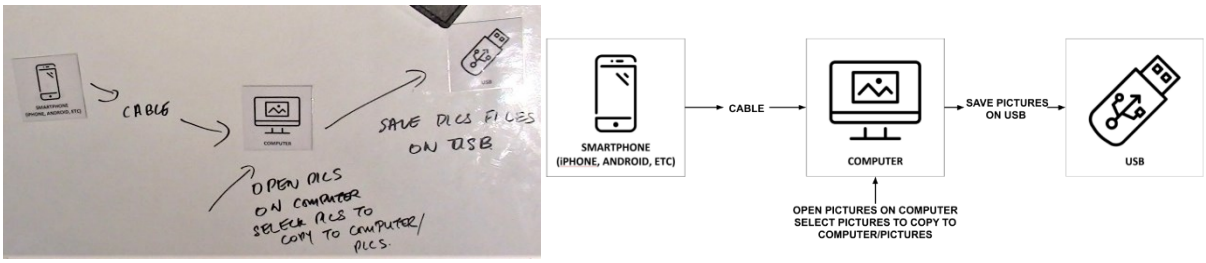

Figure 2. OA11 illustration of database process (left) and formalized model (right)

Table 3. Definitions of tasks for combined mental models

Category	Description	Symbol
Creating and moving pictures	Take or receive picture(s)	Take Pic
	Transfer picture(s) between devices	Transfer
	Print or develop picture	Print
Navigation	Open app or software	Open App
	Navigate to new page	Navigate
	Display or show pictures	Show Pic
Curation and editing	Curate pictures	Curate
	Sort pictures	Sort
	Write caption	Caption
	Edit a picture	Edit
Loading	Upload	Upload
	Post or Add	Add
	Stored on device or app	Stored

Some very uncommon tasks (only included by one or two participants) are not represented in the task categories. These categories to create combined mental models, providing models representative of each picture storage category for both age groups. This provides a visualization of the overlap between users' models in order to highlight the differences and similarities between categories and ages. Other works exposing mental models with illustrations have used similar techniques to identify common themes and trends, such as grouping models into major types [24,58], and creating a combined model of different all participants' models [16,55], though none of these works explained in detail the process used to create their combined models. The combined models can be seen in figure 3 for OAs and figure 4 for YAs.

For example, looking at OA11's database process: *"I take pictures or people send me on WhatsApp... I hook on the cable and go get onto my computer. And then... usually my phone will show up on the "E" or "F" or whatever... Then I will upload the images to my computer... I open up pictures on my computer... I will select pictures to copy to the computer. Back to my page in the pictures drive page... I try to organize it, I try and say if I know where... everything is on my computer then I will... do a back up on my thumb drive."* Figure 2 shows the accompanying

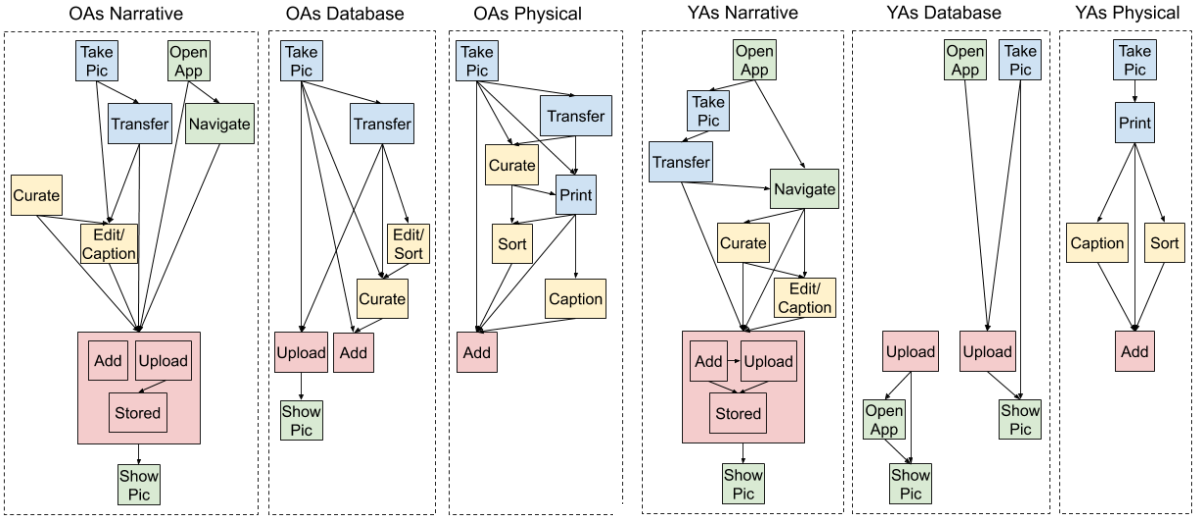

Figure 3. Older Adults' combined models for Narrative, Database, and Physical storage

Figure 4. Younger Adults' combined models for Narrative, Database, and Physical storage

illustration. This process was coded as: Take or receive pictures, Transfer pictures between devices, Open app or software, Sort pictures, and Manual local backup. As "Manual local backup" was not described by any other participant for any process, it is ignored in the combined process. The summarized process for OA11 is: Take Pic, Transfer, Open App, Sort. However, Open App and Sort are also excluded from the combined model as they were included in only one other OA's process.

4.2 High-Level Mental Models

The three models for younger adults can be split into three larger steps (**HL1: 3-Step Process**):

1. Taking or transferring pictures and Navigation
2. Editing and Curating pictures
3. Uploading and Viewing pictures

The YA database model further found two distinct processes, one of which follows these three steps, but the other *starts* with uploading rather than ending with it (**HL2: Split DB Process**). This process was only shared by users that have automatic uploads set up on their devices, so it is the first step taken by the device rather than the last step done by the user. This was not present in any older adults' models.

The older adults' models often included these same three steps (**HL1**), but compared to those of the younger users, were more complicated and inconsistent in terms of order. Some participants presented Editing and Curating pictures as the first or last step, rather than an intermediate step. Additionally, loading tasks were never the start of a process.

Younger adults also present more distinctions between database and narrative tools (**HL3: DB/N Distinction**). Posting or adding a picture is common in narrative models ($N_Y = 9$), but not at all present in the database model. Additionally, there are more curation tasks ($N_Y = 12$), namely editing or writing a caption ($N_Y = 4$), for narrative tools than seen for database ($N_Y = 2$). These activities had little difference between older adults' database and narrative models. Actively navigating to a page is also more common in narrative processes ($N_Y = 6$) than in database ($N_Y = 1$). OAs rarely included navigation tasks, though only for narrative processes ($N_O = 2$).

From this, we see that database tools are seen as more static or passive, with automatic uploads and limited manual interaction, like captioning or navigation narrative tools, however, which are presented to a public audience, are more interactive; pictures are edited, posts are added. OAs showed no strong divide in these areas, suggesting that they see tools in both categories as more general and not fitting into distinct roles as they do for YAs.

Generally, the lack of a consistent, recognizable process between older participants is likely due to lower levels of digital literacy and confidence. OAs also feel pressure to learn more abut the tools they use ($N_O = 4$, $N_Y = 0$), and other, mostly older, participants feel they do not know enough about what the tools can do ($N_O = 6$, $N_Y = 2$) (**HL4: Pressure to Learn**). External pressures to adopt and tools' lack of presented process for OAs to follow may cause confusion and inconsistencies for these users.

These models reveal that there is generally more consensus to YAs' understanding and use of picture tools than seen with older users. The inconsistencies in older adults' processes could stem from misunderstanding the technology or from adapting existing processes to fit onto new tools as best as possible. This is especially likely for narrative tools as two thirds of older users either had never had a social media account or had not used social media for some time.

4.2.1 Picture Deletion

None of the participant models included removing pictures as a step (with the exception of Snapchat, as described by YA11 and YA15, which automatically deletes pictures). When prompted on deletion, older users are also more skeptical of services' handling of privacy and deletion than younger users (**HL5: Skeptical of Deletion**), as has been seen before [51]. While nearly all older users believed that deleted pictures may be kept by the service (e.g., Facebook) after they had deleted it ($N_O = 11$), younger users either said pictures were immediately and completely deleted or were unsure and could not say whether deletion was permanent ($N_Y =$

10). This may by a result of older adults being more aware of their lack of technical knowledge, and so they assume there is something they do not know or understand.

Only two younger participants (and no OAs) believed that both database and narrative digital storage would be completely deleted, compared to 11 participants, almost half of all users, who thought deletion on any tool was incomplete or was not sure whether deletion would be complete in both database and narrative ($N_O = 6$, $N_Y = 5$).

The large majority of participants believed digital deletion to be incomplete in some way. All OAs were skeptical of deletion for at least one of the categories, and all but one (OA10, who was not a current user of narrative tools) was wary of deletion on narrative tools. Approximately two thirds of YAs said that at least some aspect of digital deletion to be incomplete ($N_Y = 10$). Incomplete deletion was most often attributed to a SMN keeping the pictures longer than implied ($N_O = 7$, $N_Y = 6$).

Four OAs said database deletion was complete and one said it was incomplete or was unsure. For narrative, no OAs said it was complete and five said it was incomplete or was unsure. YAs show more mixed results, with slightly more finding narrative to delete completely over database. See table 4 for detailed counts. This shows that database storage is generally seen as having a more permanent deletion than narrative, and that OAs are more skeptical of deletion that YAs across the board.

Table 4. Deletion across digital tools for OAs and YAs

Pop.	Deletion	DB	Narr.	Both
OAs	Complete	4	0	0
	Incomplete/Unsure	1	5	6
YAs	Complete	3	5	2
	Incomplete/Unsure	2	3	5

Some users stated that their concerns for picture storage came from outside sources, such as news articles ($N_O = 2$, $N_Y = 3$). Perhaps because SMNs are believed to keep pictures for their own uses, which is the subject of many news articles (e.g., [18]), clouds do not seem to present this same risk for misuse of data.

4.3 Low-Level Mental Models

The low-level mental models, developed from the second half of the interview, focused on what motivated use of chosen tools (i.e., over other options) and user awareness of their own storage and organization. To understand what motivated tool selection and use, participants were asked to share what could put their pictures at risk for both their digital and physical storage. They were also asked to identify their upsides and downsides for each tool. Risks were separated from downsides, though they likely overlap, to distinguish between difficulties in using tools (downsides) and aspects that threatened the safety of their pictures (risks). This highlights issues around digital permanence and cultural ideas around protecting personal pictures. To understand how participants were aware of their own picture storage, we asked them to explain how they would look for or find a particular picture and how they would add a picture into existing storage (e.g., received as a gift).

The risks, upsides, and downsides show clear delineations between physical and digital picture storage (**LL1: Physical/Digital Divided**), with very little overlap between responses (seen in tables 5, 6, and 7). Risks are further divided into physical risks for physical pictures (e.g., destroyed in a fire) and social risks for digital pictures (e.g., stolen and used by others) (**LL2: Digital Risks are Social**). Noticeably fewer downsides were identified than upsides or risks. Participants often qualified their downsides, if there were any, as seen by OA1, *"Not really. I mean I guess you leave yourself open to criticism"*, YA8, *"I guess maybe just spending money"*, and OA10, *"I can't say there's anything I don't like. Not really"*. We speculate that a possible explanation for this might be that participants may be hesitant to identify downsides of picture tools because they did not want to imply that they do not enjoy their family pictures and viewing them. That is, they wanted to ensure the

Table 5. Upsides of Picture Storage

Upsides	Digital		Physical	
	OA	YA	OA	YA
Friendly format	0	0	9	4
Nostalgic look/feel	0	0	1	8
Enjoyable process	0	0	4	3
Memory trigger	0	0	1	6
Tangibility	0	0	5	1
Feels more personal	0	1	2	3
Ease of access	3	1	3	4
Easy to share	6	6	0	0
Keep in touch passively	2	4	0	0
Sharing over distances	3	2	0	0

Table 6. Downsides of Picture Storage

Downsides	Digital		Physical	
	OA	YA	OA	YA
Lack of access	0	0	3	4
Damage	0	0	2	5
Too much effort	0	0	4	1
Too much space	1	2	3	2
Misuse by others	2	2	0	0

researcher knew they appreciated their pictures, so they did not offer many downsides to the tools that gave them access.

The two age groups agreed on the major upsides of digital tools (easy to share, passively keeping in touch with family and friends, and distance sharing), but differed on physical upsides. Older users enjoy the tangible aspect of albums and the interactions they support ($N_O = 9$, $N_Y = 4$), whereas younger users find albums to be nostalgic and better trigger their memories ($N_O = 2$, $N_Y = 9$) (**LL3: Physical; Differing Perspectives**). This is likely simply because albums are mostly seen as artefacts from younger users' childhoods, but older adults usually have spent time making albums for their own families and children.

Of the few provided downsides, there was some agreement between ages for physical storage, the main concerns being that physical pictures can only be accessed in one place and take up a lot of space. However, older adults are more concerned about the effort involved ($N_O = 5$, $N_Y = 1$), while younger users are more concerned about the potential for damaging pictures ($N_O = 2$, $N_Y = 5$). This, again, is likely because younger users are not familiar with the work involved with albums as they have not had the chance to create and maintain many themselves, if any.

The downsides of digital storage showed very little consensus between users. Most common were misuse by others (also a common risk, as we discuss below), bad design or technical limitations, and taking up too much space in a device. Taking up space was the only overlapping concern between physical and digital tools, showing at least some common difficulties in all available options. Four users, all OAs, found no downsides to their digital tools. Three participants found no downsides to physical tools: one YA and two OAs (one of whom also found no digital downsides). Generally, physical storage was seen as too precious to dislike. As OA9 said, *"I can't say I don't like anything about a photo album. They're all pleasant memories."* (**LL4: Lack of Downsides**)

4.3.1 Physical and Social Risks to Pictures

The risks identified by users split into two groups: physical risks that threaten the existence of their pictures, and social risks which put their reputation in jeopardy. See table 7 for the most common social and physical risks. All participants identified at least one risk to physical pictures. Only three participants ($N_O = 1$, $N_Y = 2$) could not identify any risk for digital tools. In total, OAs identified nearly twice as many physical risks than YAs ($N_O = 60$, $N_Y = 33$), and the reverse was true for social risks; YAs found twice as many as OAs ($N_O = 10$, $N_Y = 20$). YAs did identify damage to pictures as a downside of physical pictures but did not see it as a risk. OAs may find more physical risks because they are likely more familiar (directly or indirectly) with property risks, like fire or flood. This shows a strong generational divide and that younger users may be more sure of their digital pictures' security.

Table 7. Risks of Picture Storage

Risks	Digital		Physical	
	OA	YA	OA	YA
Fire	0	1	9	5
Water	0	0	6	5
Other damage	0	0	4	7
Age	0	0	3	6
Discarded accidentally	2	0	5	0
Stolen	1	0	2	2
Pictures lost	3	1	4	3
Accessed by others	3	6	0	0
Misused by others	4	4	0	0
Device breaks	4	0	0	0
Other social risk	1	3	0	0

The social/physical divide also aligns nearly perfectly with the risks identified for physical and digital tools; physical risks for physical tools and social risks for digital. No one contributed a social risk to their physical pictures. Half of OAs identified a few physical risks to digital pictures, and only one YA. Additionally, most users (except for one OA and two YAs) identified either social risks or physical risks for digital storage, but not both. This demonstrates a clear separation in users' mental models of picture storage: picture risks are seen as only physical or only social, regardless of tool.

Although no one identified it as a risk, several users brought up that storing *"risqué pictures"* (OA12) or *"'private' things"* (YA11) would create more need for concern around privacy and access to pictures ($N_O = 3$, $N_Y = 2$). These participants all brought this up independently and were adamant that they did not use these tools for this purpose themselves. These users are aware of social risks, but see them as unimportant unless a user chooses to put themself at risk, such as by posting something private online, which they would not.

This social and physical divide of risks shows how strong the separation between our physical and digital pictures is. Even for the same risk, for example lost storage, the result of the risk was seen to be different for the two settings. For example, OA1 said both *"If you lose your iPhone, someone gets it then it would be a risk."* and *"probably could get lost … then you could lose all that for sure"*. The same result, no more access to your pictures, has a social risk in the digital space, and a physical risk in the physical space.

Some participants also found that digital pictures had less worth than physical, since they were so easily made and deleted, as YA3 shared, *"You never think or worry about losing [digital pictures] so in a sense it's not as precious to you. Whereas the photos I'm thinking … 'I need to protect them future fires' … They're more precious to me. There's a danger of losing it."*. This lower value may cause the lowered concern for the physical well-being of digital pictures. This was contrasted by the idea that physical pictures are *"real live pictures"* as described by OA1 ($N_O = 5$, $N_Y = 2$), that is, something with more substance (literally and culturally) than digital pictures.

4.3.2 Adding and Searching for Pictures

Adding pictures, both digitally and physically, was explained very briefly by most younger participants as, in the words of YA10 *"I just put it in there."* ($N_O = 1$, $N_Y = 9$). Other common responses were similarly general: some would simply add it to an existing gap ($N_O = 4$, $N_Y = 3$), and others would not add at all ($N_O = 3$, $N_Y = 1$). These responses show that adding is not seen as a process for picture storage, digitally or physically. This may have been because we asked specifically about adding a single picture, which implies that the organization is already present. It also points to the need to balance the effort of maintaining these collections with ease of use and the more enjoyable aspects of picture interaction.

Searching for pictures was supported by very similar activities between physical and digital spaces. Going through pictures in order (by scrolling or flipping through pages) was suggested by almost every user (N_O = 11, N_Y = 12) for both physical and digital storage. Most older users described the first step of searching as a mental one, such as remembering which album would contain the right time period for a picture, but this was not common for younger users. Similarly, most older users expressed using time as an anchor to find a picture (N_O = 9). For example, OA12 explained, *"If I have a rough idea of the date, I would find it."* In contrast, younger users had a less structured approach to finding pictures, either through the page-by-page process mentioned above or through trial and error. YA15 said he would simply *"open up all the albums."*

This mismatch may be due to the prevalent tools of the generations. Older users were required to provide their own high-level organization (e.g., albums) whereas younger users have rarely made their own albums and base their understanding of pictures on systems that sort automatically by metadata and do not easily support more detailed manual organization. This contrasts with user conceptions as seen in LA1 below.

4.4 Looking Ahead

When asked to compare their own usage to that of older users (for YAs) or younger users (for OAs), there were several points of agreement between the groups. Younger adults were seen to be more organized with their pictures than older (N_O = 3, N_Y = 8) (**LA1: YAs More Organized**). This is likely because most modern picture storage is digital, and OAs are less familiar and confident with these tools, as was found by both groups (N_O = 4, N_Y = 6) (**LA2: OAs Lack Confidence**).

Most users believed that paper pictures would become less common in the future, but YAs saw their nostalgic value were sure they would always have some pictures (N_Y = 12). YA10 said, *"People like me will still print them out and store them"*. Though users were also concerned that printing is becoming less accessible (N_O = 3, N_Y = 3), as OA1 said, *"It's getting harder and harder to make a physical photo. That's my concern, that it is a technology that is becoming obsolete"*. Some users also noticed a parallel between physical and digital pictures and physical and digital books in that the introduction of a digital alternative caused some to believe that the analog version would die out, but this has not been the case (N_O = 4, N_Y = 1) (**LA3: Continued Need for Physical**).

In terms of digital tools, most users could not imagine what might change in the future. Some OAs (N_O = 3) imagined tools that seem to draw from science fiction, such as being able to enter a holographic picture projection. Others expected to see general improvements to the technology, such as device performance (N_O = 3, N_Y = 1) or to picture quality (N_O = 2).

This lack of clarity on potential future directions may be influenced by inconsistent tools created without a thorough understanding of user needs and by the unnatural narrative/database divide. Users cannot imagine what might come next because they were not able to imagine what has come so far and it does not match their expectations, especially with regards to privacy and usability (**LA4: Picture Future Unclear**).

5 DISCUSSION

The study described in this paper revealed several differences in mental models across age groups with respect to perceptions of how photo cloud storage and cloud services operate. These differences, representing the key findings of our research, are highlighted in table 8, alongside implications for designers and service providers to take into consideration when trying to increase older adults' adoption of photo cloud services. We further discuss how our findings connect to the prior body of work in this area, actionable considerations that designers may consider, and how other application areas can benefit from these findings.

5.1 Reflections on Current Body of Knowledge

Younger adults' consistent high-level process, distinction between narrative and database processes, and split understanding of the database process (based on upload method) clearly demonstrate their familiarity with available tools and their respective purposes. Older adults, however, show a clearer idea of their own picture collections as a whole and are more concerned with continued security and availability of pictures online along

Table 8. Implications of Major Findings

Finding	Implications
HL1: 3-Step Process OAs: No general process consensus YAs: Follow 3 general steps for all tools	YAs' consistent process demonstrates their more detailed and accepted mental models for picture storage compared to OAs.
HL2: Split DB Process OAs: DB always ends with upload YAs: Upload to DB either last or first	This reflects the move towards automatic uploads over manual backups. This mental model reflects that (upload first, rather than last), but only with YAs. OAs still see upload as a final step, even when upload is automatic.
HL3: DB/N Distinction OAs: DB/N seen as similar general tools YAs: Separate processes for DB/N	YAs see database and narrative tools as separate and for separate purposes (e.g., storing vs. sharing pictures), while OAs tend to group them together as related tools without large differences in use or functionality.
HL4: Pressure to Learn OAs: Pressure to learn and use new tech YAs: Seem and feel more confident	Though these tools are seen as fun and social, OAs still feel pressure to learn and use them, just as for other areas of technology, suggesting it is more due to lack of understanding than fear of making mistakes, as in online banking.
HL5: Skeptical of Deletion OAs: Skeptical that pictures are deleted YAs: Not concerned with deletion	OAs are often more cautious, likely influenced by news coverage of privacy scandals. YAs are more relaxed, possibly as they filter which pictures to post or are more aware of privacy settings or options like private accounts.
LL1: Physical/Digital Divided OAs/YAs: Upsides, downsides, and risks had little to no overlap for DB/N	Digital picture tools are completely separated from physical options across age groups confirming that they inhabit distinct social spaces. While digital pictures may take over, they are not filling the same role as physical ones.
LL2: Digital Risks are Social OAs/YAs: Digital risk poses social threat, or social result to a physical threat	Across ages, digital pictures exist in such a different space than physical that they are not concerned with losing these pictures, except if it affects how people see them (e.g., if pictures are stolen for a malevolent purpose).
LL3: Phys. Differing Perspectives OAs: Offers tangibility and simplicity YAs: Offers nostalgia and memories	This generational divide shows how YAs see physical pictures as something older generations have and something to look back on, while OAs still consider it the default for picture storage.
LL4: Lack of Downsides OAs/YAs: Very few downsides shared, uncomfortable suggesting any at all	Pictures are seen as too important to dislike, though we see some common issues, like storage space (physically and digitally).
LA1: YAs More Organized OAs: Cannot keep up with work of new tools YAs: Seem more organized, use new features	OAs struggle to keep up and see YAs as more organized, likely due to YAs' adoption of new automatic options, such as facial recognition. However, YAs remain similarly unorganized in physical storage, or even less so.
LA2: OAs Lack Confidence OAs: Feel they lack necessary confidence YAs: Learn new tools quickly easily	OAs' general lack of confidence, similar to LA1, further contributes to the struggle to keep up. This can limit adoption of new tools and features within existing tools, as they are overwhelmed and cannot add more.
LA3: Need for Physical Pictures OAs: Worry how phys. pictures can continue YAs: Sure they will have physical pictures	Users agree that physical pictures will continue, but OAs' are concerned that printing is getting more difficult, showing how digital pictures are at odds with physical, pushing out essential services, like development.
LA4: Picture Future Unclear OAs/YAs: Little to no consensus on future changes for picture storage	The inability to imagine future changes reflects how quickly storage has changed. The science fiction ideas in particular show how unclear it is and how users' needs are not reflected in these changing processes.

with general access to new physical pictures. Thus, while younger users may share a consistent process and may be more organized by taking advantage of new features, older adults have a better awareness of their pictures, despite lack of familiarity and comfort with their digital tools. This suggests the presence of a trade-off between confident use and concern for security.

Our research showed that older adults are also more aware of the gaps in their technical knowledge, seen in their overt expression of this, but also in their inconsistent processes, skeptical opinions on deletion and permanence, and much higher number of physical risks compared to younger users. Despite their skepticism towards deletion, they are not concerned about social risks for their pictures. They are aware that they should learn more about the tools they use (or could use) in order to feel more secure. While this limits their motivation to commit to using these new tools, they also feel pressured to use them, such as needing to stay connected to grandchildren as they grow up. This explains why many had limited use and largely used the most familiar option (e.g., Facebook).

Despite recognition of security concerns as a barrier to their use, they did not see this as a risk, leaning instead on familiar physical risks. This builds on previous findings on the effects of digital marginalization and older adults' barriers to adoption [38]. Such research showed that older adults' mental models of how an online service works (in this case, financial services) leads to less engagement with that service. In particular, older adults were concerned about "what happens when something goes wrong – who do I talk to?" Such concerns may not necessarily be illustrative of being risk adverse (a common older adult stereotype), but instead may simply be the result of mismatched mental models between older adults' expected way of troubleshooting a problem and the transition to online self-support that many services are experiencing. We see that mental models of digital use, especially for older adults, are divorced from existing models of physical use, which may result in challenges with respect to adoption.

Between age groups, mental models are further split between database and narrative tools. For younger adults, database is static and concrete, while narrative is interactive and social, which comes with inherent personal risks. Unlike physical storage, where narrative and database roles overlap (interactive browsing and static storage), this divide limits interaction and leads to more confusion and more tools to learn, especially for older users. Digital tools need to consider the significant overlap in our traditional methods of picture interaction, and intentionally design to combine narrative and database interactions, rather than further split them. Existing physical processes need to be considered and protected, alongside or within digital processes, rather than being pushed aside and assumed obsolete.

These differing mental models of narrative and database across age groups mirror similar differences in usage and motivations. For example, while a strong motivation to use social media (and photo sharing) for both age groups is staying connected to friends and family members, YAs have additional motivations, such as self-presentation (e.g., "selfies") [49,57]. As such, their use is driven by additional purposes not shared by older adults; an example of a narrative activity performed predominantly by YAs and much less by OAs. This in itself should not result in fundamental differences in the design of such applications; however, designers themselves (often belonging to the younger group) may act upon their own mental models when designing such services. This can lead to poor usability and lack of adoption for older adults [46].

These split mental models coincide with uncertainty in use, mostly, but not solely, for older adults. We see a consistent need for physical pictures going forward, but disagreement on the motivation for that physical presence. Potential risks are clearly divided between physical and digital spaces, implying that digital pictures are not even considered to be pictures in the same sense as physical pictures. The tools and applications available are so varied that participants feel they cannot know how it will change going forward, leaving the future of picture interactions unclear. However, there is still a consistent sense that pictures are important in all their forms. People continue to cherish pictures, especially physical ones, and were unwilling to share downsides of a tool, so they would not seem ungrateful for the pictures it stores.

By directly seeking out mental models, we can identify motivations and barriers, as past works have, but also understand what drives these to design usable interfaces adoptable across ages. The differences found between older and younger adults show the different perspectives they bring to picture interactions. These cross physical and digital spaces as well as levels of picture and technology experience, and therefore go deeper than older

adults' being less experienced or being novices compared to younger adult experts. Older adults are often curators of family picture collections and bring a large variety of experiences to new digital spaces. These shape how they interact with picture tools and need to be considered along side those of younger users.

5.2 Design Considerations

From our findings, we provide suggestions to guide the continuing design of picture tools, based on these cross-generational mental models.

Consider both narrative and database interactions together in order to create complete, usable tools. [HL1, HL3] This can be done with storage that is simple to browse by time and support the addition of some high-level manual organization, such as by events. Additionally, consider navigation through picture storage and how that affects the experience of browsing and sharing. Prior research has shown that OAs are often incorrectly perceived (by designers) to be less active content creators and more passive consumers of online services [9]. Further, if a service does not provide the functionality older adults seek in a way that relates to their experiences and expectations [30,54], they are less likely to adopt it. This highlights the importance of designers understanding older adults' mental models of seeing narrative and database interactions as overlapping activities, which may lead to lower adoption of either type as their distinct intended uses are not understood. Designing interactions that consider these functionalities together, yet maintain distinction to avoid furthering the mental model mismatch across ages, will support OAs use and better match familiar analog activities which blur the lines between database and narrative (e.g., photo albums).

Design to expose the three major steps of picture storage (taking pictures and selecting tool, editing pictures, and uploading or adding pictures) in order to align with the expectations of younger users. [HL1, HL2, HL4] This transparency would also clarify the process for older users, who could benefit from a clearly presented process to support their perceived level of technical ability. For example, HL2 shows us that OAs finalize their database picture interactions with an upload, while YAs see upload to a database as happening either at the beginning or at the end. Following Jakob Nielsen's ten-point heuristics [44] and Don Norman's gulf of execution [45], we speculate that more clearly exposing the major steps of picture storage is unlikely to "alienate" YAs from using such services. It may, however, help OAs receive confirmation that pictures have been uploaded, their last step in using cloud storage. Even in the case when upload is automatic and no longer explicitly performed, as is common in services like Google Photos and Apple iCloud, it will still reassure older adults of its completion and match the consistent shared process which ends with an upload.

Consider the risks to picture storage, both physically and socially, and how users can or should be made aware of that. [LL2, LL4] Storing family memories on a tool requires the user's trust that they will be taken care of. Visualizing the distinction between what is stored locally or on a cloud could provide the necessary clarity for users to understand how pictures are protected. This is particularly important to OAs, as their mental models of online privacy and security are often grounded in knowledge that may not be accurate, while at the same time their perceptions of threats and overall privacy/security concerns are high [6,40].

Recognize digital picture interactions as distinct from, not replacing, physical pictures. [LL3, LL4, LA3] There is no reason to believe that we will stop printing and sharing physical pictures. The nostalgic, tangible aspect of printed pictures will likely carry onto future generations, as long as printing is still feasible, but users are skeptical that printing will continue to be feasible. This is despite some digital tools, like Google Photos and Flickr, including services to print photo books from users' cloud collections. These recognize the continued need for physical access to pictures, but our research suggests there is more to be done to go beyond offering analog as a separate add-on option in order to lessen the divide between physical and digital pictures. The recognition of clear benefits of digital picture tools (sharing over distances, large storage capacity with small physical footprints, easy immediate capturing and sharing) show that digital offers new experiences with pictures. Design of digital tools should respect the role of paper pictures, and perhaps even design to support printing and physical picture interactions as an integral ~~as~~ part of the digital process.

5.3 Takeaways for Other Application Areas

Understanding older adults' mental models and how these differ from younger adults' has the potential to address many of the barriers to technology adoption [38]. This is particularly relevant to a wide range of emerging applications, many prompted by the increased affordability of smartphones and similar devices, which may be suffering from a decrease in usability as pertaining to older adults [46]. Ignoring OAs' mental models in the design phase can thus lead to significant widening of the digital divide between OAs and YAs. This was evident in our findings, with functionalities such as upload and cloud backup being clear sources of frustration.

We hope that the work presented here may provide takeaways for designers working in other related areas, particularly in terms of methods to better understand OAs' mental models and how these influence the adoption of (digital) essential services. Financial technology services for older adults is one such area where research has shown how failure to understand OAs' mental models in relation to the physical/online divide and its perception of risks (much like our findings LL1, LL3, and LL4) can lead to significant barriers to adoption [38].

Several other emerging applications may benefit from conducting research similar to ours. For example, online healthcare applications (e-health), where OAs have expressed significant concerns with respect to privacy [2,59] – similar to our findings HL1 and LL2. Another application area is that of conversational (voice) interfaces, which have been seen as potentially addressing many usability and accessibility issues for OAs [8]. Yet mismatches in OAs' mental models about conversations and how these systems function may lead to low adoption rates and usability concerns [39] that are similar to our findings HL1, HL2, and HL3 (illustrating how OAs have certain entrenched approaches for executing familiar tasks).

5.4 Limitations and Future Work

This work is the first that we know of to explore mental models of digital picture tool usage across broad-reaching categories. Future work needs to include the middle age group (40-60 years old) to better understand the complete range of how use is changing across generations. As this research scales up across generations and across other similar use cases, additional steps will also be required to match the growing scale, ensuring that data analysis is rigorous (e.g., multiple coders with cross-validation).

Research on creating formal mental models is relatively scarce compared to other topics within HCI, such as usability studies, and as such many processes for uncovering mental models are not yet independently validated. We have followed the processed outlined in [53], with the analysis additionally grounded in established qualitative research tools, including inductive thematic analysis. Future work expanding on the research presented here may look at further independent validation of these research approaches in order to better support continued formal mental models research in various HCI domains.

6 CONCLUSION

We present mental models of digital and physical picture storage, and their generational differences, to better understand motivations for use, barriers to adoption, and continuing use of these tools. Our representative samples of both older and younger picture users, all regular users of technology with varying levels of picture use between groups, provide a clearer understanding of the differences and similarities stemming from the distinct experiences and backgrounds of these age groups. The divided models illustrate how digital tools are alienating older users by separating more encompassing and familiar picture activities. Current options for digital picture interaction have not considered their roots: what we have been doing with pictures so far. Users have (often reluctantly and not easily) adapted to keep up with the changes and match their models to new applications, but what worked with physical pictures continues to draw people and is essential to personal picture experiences.

To support cross-generational users, digital picture tools need to bridge the narrative/database divide, as physical photo albums do, and include the physicality and tangibility of pictures in the larger process. Maintaining our connections with personal pictures will mean bringing together all the aspects of use: physical and digital, narrative and database, and users young and old.

ACKNOWLEDGEMENTS

This work was supported by AGE-WELL NCE Inc., a member of the Networks of Centres of Excellence (NCE), a Government of Canada program supporting research, networking, commercialization, knowledge mobilization and capacity building activities in technology and ageing to improve the quality of lives of Canadians. The authors also wish to acknowledge the sacred lands on which the University of Toronto operates. These lands are the traditional territories of the Huron-Wendat and Petun First Nations, the Seneca, the Haudenosaunee, and most recently, the Mississaugas of the Credit River. Today, the meeting place of Tkaronto is still the home to many Indigenous people from across Turtle Island, and we are grateful to have the opportunity to work in the community, on this territory.

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