# Guiding the Design of Inclusive Interactive Systems: Do Younger and Older Adults Use the Same Image-schematic Metaphors?

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The use of image-schematic metaphors is often promoted for being near-universal across user groups, suggesting that these metaphors have the potential to make novel interactive systems easy to use by both younger and older adults. This study empirically investigates this by eliciting image-schematic metaphors from the spoken language and interaction behaviors of 12 younger adults and 12 older adults undertaking tasks in a technology learning domain. For the first time, we reveal an almost-perfect overlap between image-schematic metaphors used by the younger and older groups, despite the two groups showing significant differences in prior technological knowledge. This finding provides empirical evidence for the near-universality of image-schematic metaphor use across age groups. The study also identifies 37 image-schematic metaphors shared between the two age groups in the technology learning domain to support future design of age-inclusive interactive systems.

CCS Concepts: • **Human-centered computing → HCI theory, concepts and models**; **Human computer interaction (HCI);**

Additional Key Words and Phrases: Image schema, image-schematic metaphors, interactive systems, inclusive design

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## 1 INTRODUCTION

A challenge in **human-computer interaction (HCI)** is to make interactive systems usable by the widest possible range of users, regardless of age and ability. However, accessibility considerations often lag behind the advancements made in other areas of usability and interaction design [39]. Despite the recognition that promoting the use of **information and communication technologies (ICTs)** is crucial to enabling healthy ageing and social inclusion among older adults, older adults continue to significantly fall behind their younger counterparts when it comes to adopting new technologies [99].

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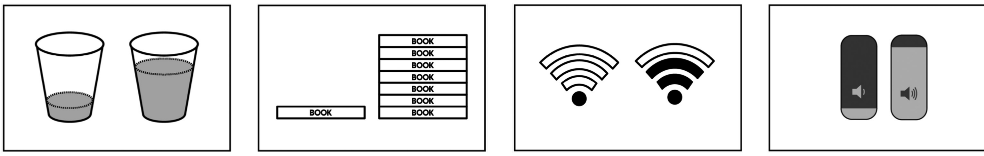



(a) (b) (c) (d)

Fig. 1. Instantiations of a universal image-schematic metaphor: "More of a *Quantity* is UP," which is a mapping between an abstract concept *Quantity* and a basic image schema UP-DOWN: Panels (a) and (b) are examples in the physical world: the water level increases as we pour more water into a cup, and the height of a pile of books increases as the number of books increases; panels (c) and (d) are examples in user interface design: the height of a WiFi icon increases as the signal gets stronger, and the control bar increases upwards as volume increases.

The group of older users (60 years of age or older, as defined by the United Nations [97]) is increasingly relevant in the field of HCI as a result of demographic shifts: by 2030, one in six individuals in the world will be 60 years of age or older [105]. As highlighted in the Senior Technology Acceptance and Adoption Model [90], a crucial factor in facilitating technology adoption among older adults is ease of learning and use. This can be achieved by leveraging prior knowledge, and prior technological knowledge can facilitate intuitive and successful use of interactive systems [13, 86]. However, younger and older people have significant differences in their prior technological knowledge [88]. This makes it difficult to design for age-inclusive ease of use if that design relies on prior technological knowledge.

An alternative idea is to leverage technology-independent prior knowledge shared by the younger and older generations to design age-inclusive interactive systems.

One form of technology-independent prior knowledge theoretically shared by younger and older adults is *image schema*, a notion that was first introduced in the area of conceptual metaphor research by Lakoff and Johnson [68]. In a later publication, Johnson [53] provided a more detailed explanation of image schema as "a recurring dynamic pattern of our perceptual interactions and motor programs that gives coherence and structure to our experience." From a very young age, we are exposed to repeated sensorimotor experiences in the physical world (e.g., the water level goes up and down, the sun rises and falls, and an apple drops from a tree). These experiences are abstracted into primitive representations (e.g., image schema UP-DOWN) and then stored underneath the threshold of consciousness. We subconsciously use these primitive representations (image schemas) to understand unfamiliar concepts that lack physical referents, the mental association between an abstract concept and an image schema is an **image-schematic metaphor (ISM)**. For example, the image schema UP-DOWN is universally used to understand the concept *Quantity*. In real life, we frequently experience co-activations of the concept *Quantity* and the image schema UP-DOWN. As we pour more water into the cup, the water level rises (for more examples see Figure 1). Instances can also be found in people's use of language (e.g., "The *Cost* of living is going UP."). These recurrent co-activations lead to the image-schematic metaphor "More of a *Quantity* is UP."

Metaphors are a well-known concept among HCI researchers and practitioners, with the term "desktop metaphor" being closely associated with the success of **graphical user interfaces (GUI)** [14]. The "desktop metaphor" is an example of a *conceptual metaphor*, which is defined as understanding a target domain using knowledge from a familiar source domain [68]. This is different from the "classical" view of a metaphor, in which a metaphor was regarded as a novel or poetic linguistic expression, and solely a matter of language [65]. In contrast, the focus of conceptual metaphors is not on language, but on how people conceptualize one domain in terms of another domain. For example, people use knowledge about a *Desktop* to understand a more abstract and vague concept *Computing System*. This gives rise to a conceptual metaphor "*Computing System* is a *Desktop*," which prompts the recognition that information and tools can be arranged on a computer in a manner similar to how they can be arranged on a desk.

An image-schematic metaphor (also known as a primary metaphor) [33, 34] is a specific sub-type of conceptual metaphor. It is a device that uses a set of basic concepts (image schemas) derived from universal physical experiences as source domains to understand other unfamiliar domains. Lakoff [66] proposed the "neural theory of metaphor," which suggests that image-schematic metaphors are formed in a universal binding mechanism where the metaphorical "mapping circuit" connects one neuronal group that represents a sensorimotor experience and another neuronal group that represents an abstract and subjective experience. According to Lakoff [66]'s theory, image-schematic metaphors should be near-universal across different age groups, since they are based on universal metaphorical structures and people's shared sensorimotor experiences. This makes image-schematic metaphors a promising tool for designing interactive systems that are easy to learn and use for both younger and older people.

Despite the prevailing arguments for the universality of image-schematic metaphors, there are other competing arguments in the literature. For example, one such argument suggests that the use and comprehension of metaphors in general are likely to decrease as people age [16, 37, 51]. Another argument suggests that users' understanding of metaphors is heavily influenced by their experiences and knowledge [30, 57, 100, 104]. These counterarguments stand in contrast to the argument that the use of image-schematic metaphors is universal across different age groups (who often differ in prior technological knowledge).

There is limited evidence that supports both the arguments and counter-arguments for the universality of image-schematic metaphors across different age groups. If a substantial overlap was found between image-schematic metaphors used by the younger and older groups, then image-schematic metaphors could be a promising tool that designers can use for designing age-inclusive interactive systems. Going further, if the overlap was found to be small, then this could redirect researchers' and designers' efforts away from the development and application of compromised design principles that are not truly "age-inclusive" and towards identifying new design principles that are more effective.

This article explores the cross-group consensus of image-schematic metaphor usage between the younger and older population by investigating if a group of younger adults and a group of older adults, who have statistically significant differences in prior technological knowledge, share the same image-schematic metaphors in the technology learning domain. In a study with 24 participants, 12 older and 12 younger, we elicit image-schematic metaphors from participants' spoken language and interaction behaviors and examine the degree of overlap between image-schematic metaphors used by the two groups. The headline result is that an almost-perfect overlap was found between image-schematic metaphors used by the younger and older groups. This highlights the potential of image-schematic metaphors as a novel method for guiding the design of age-inclusive interactive systems. The article makes the following contributions:

(1) Theoretical Contributions:
- For the first time, we reveal an almost-perfect overlap between the younger and older groups in image-schematic metaphors found in their language and interaction behaviors in the context of technology learning, despite the two age groups' differences in prior technological knowledge.
- We report that the two groups have highly similar usage patterns of image-schematic metaphors with no statistically significant differences found.

(2) Practical Contribution:
- We identify 37 shared image-schematic metaphors in the domain of technology learning, which can be used in future design of age-inclusive interactive systems.

(3) Empirical Contribution:
- We find that augmenting the established language elicitation protocol for image schematic metaphors with a behavior observation method is beneficial for the identification of image-schematic metaphors with a high prevalence across all participants.

## 2 LITERATURE REVIEW

### 2.1 Older Adults' Technology Adoption

Recent data from the UK [87] shows a significant increase in internet use among older adults over recent years. In 2020, 85.5% of adults aged 65–74 were internet users, up from 61.1% in 2013. For adults aged over 75, 54.0% of them used the internet in 2020, up from 29.1% in 2013.

Despite increasing adoption of the internet, older adults' use of newer technologies, such as smartphones and tablets, remains substantially lower in comparison to earlier technologies like PCs and mobile phones [99]. Researchers argue that older adults' slow adoption of new technologies, in comparison to younger adults, is likely to be persistent as new technologies and their user interfaces and interaction styles continue to evolve rapidly [9]. It is therefore imperative to facilitate technology adoption for people of all ages as there will always be new technologies emerging and new generations of older adults who will wish to learn to use them effectively and efficiently to fully participate in society.

Technology adoption has been extensively researched and different theoretical frameworks have emerged that convey concepts of how people understand, accept and use technology. Trajkova and Martin-Hammond [95] found that essential utility plays a crucial role in motivating older users to adopt new technologies. In STAM (Senior Technology Acceptance and Adoption Model), Renaud and Van Biljon [90] highlight that *ease of learning and use* is an important factor in older adults' technology adoption. This is because, for older adults, the difficulty they experience when learning to use new technologies is a factor in whether or not they adopt that technology [106]. Barnard et al. [9] also suggest that a high level of learnability will facilitate older adults' interactions with technology. The greater the *ease of learning and use*, the more cognitive resources will be available for task completion rather than spending time and effort finding out how a system works. We note that one of the determining factors that facilitate the ease of learning new information is *prior knowledge* [22], which refers to all the past experiences and relevant information that a person uses when engaging in a cognitive task [98].

Research on prior knowledge and product usability has shown that interactions leveraging users' prior knowledge tend to be quicker and less error-prone [10, 11, 71]. Prior knowledge with technologies (e.g., experience in using a game controller) can be applied to facilitate successful use of new technologies [13, 86], and it serves as a robust predictor of performance in various computer-based tasks [20]. In an experiment conducted by Blackler et al. [11], it was demonstrated that prior experience with similar products enabled users to more rapidly and intuitively use the interfaces of two distinct microwave ovens. However, younger and older adults are reported to differ in terms of prior technological knowledge. Rama et al. [88] suggest that the most fundamental prior technological knowledge is acquired between the ages of 10 and 25, which will essentially shape the way people interact with technologies later in life. Older adults' performance with different interfaces is influenced by a combination of cognitive decline and limited prior technological knowledge [11, 89]. Therefore, although prior technological knowledge can contribute to greater ease of learning and use, it is not a type of knowledge shared by all age groups, and can become outdated due to the rapid development of new technologies. However, prior knowledge that is technology-independent can be leveraged to improve learnability and usability for all age groups.

### 2.2 Leveraging Technology-independent Prior Knowledge

Different types of technology-independent prior knowledge have been leveraged to facilitate ease of learning and engagement with user interfaces. Some of them are thought to be highly universal, such as *Gestalt Principles* [60, 61, 81, 101], *Affordances* [31] and *Population Stereotypes* [27]. However, the use of these technology-independent forms of prior knowledge in design are challenged for various reasons in prior research [42]. For example, *Gestalt Principles* suffer from the fact that they only contribute to basic layout design. *Affordances* provide a perspective on design that does not translate into concrete design guidance. In terms of *Population Stereotypes*, there is a lack of explanations regarding their origins and only a limited number of them are documented.

*Conceptual metaphors*, another form of technology-independent prior knowledge, have been widely used as a design tool to facilitate usability in the field of HCI. A conceptual metaphor is defined as a construction that allows the comprehension of a concept (e.g., a computing system) by using knowledge of another familiar concept (e.g., a physical desktop) [68]. Prominent examples of conceptual metaphors in user interfaces are the "desktop metaphor" and the "trashcan metaphor." While many popular HCI textbooks [25, 28, 77] and guidelines [5, 82] recommend leveraging people's knowledge of the world by employing metaphors to communicate concepts and features of interactive systems, some researchers have described the reliance on metaphors as harmful. According to Nelson [84], the connections between interface metaphors and real-world objects can be so weak that they often hinder rather than aid understanding, and the visualization becomes bound to the mnemonic. The use of metaphors in interactive systems has also been challenged for lacking specificity on which part of the source domain should be mapped to the interface [2]. Unnecessary mappings between source and target domains (e.g., the texture of a physical desktop and the texture of a user interface) can complicate the system and even hamper progress. Jung et al. [56] argue that the design of digital concepts based on conceptual metaphors can be constrained by the source domain of the metaphor, since the target domain (digital concept) may possess computational capabilities that the source domain lacks.

*Image Schemas* is another form of technology-independent prior knowledge. The *Invariance Hypothesis* suggests that the cognitive typology of a conceptual metaphor is determined by image schemas [64]. In other words, an image schema is the underlying framework shared between the source domain and the target domain in a conceptual metaphor. It helps designers and researchers break a complex conceptual metaphor into simpler components to better determine which part(s) of the source domain should be mapped to the target domain. Therefore, image schemas are capable of offering designers concrete and precise guidance on how to interpret and utilize a complex metaphor. In HCI, another theory that also involves image schemas is conceptual blending, which refers to the process where one creates a novel, complex concept by metaphorically blending less complex or basic level concepts [24, 52]. The theory of conceptual blending also suggests that image schemas offer fundamental cognitive building blocks, supporting the process of reasoning about and interacting with technologies.

Meanwhile, image schemas enable subconscious knowledge transfer from a source domain that users are familiar with to a target domain that is unfamiliar to them. This subconscious transfer of knowledge is supported by prior research, which suggests that interaction models based on image schemas enhanced users' task performance while users were not consciously aware of their successful performance [75].

Not only do image schemas help designers specify meaningful mappings and enable subconscious knowledge transfer but also image schemas do not carry context-specific attributes or

Table 1. List of Common Image Schemas According to Hurtienne and Blessing [46]

| Category | Image Schemas |
|---|---|
| Basic | object, substance |
| Space | center-periphery, contact, front-back, left-right, location, near-far, path, rotation, scale, up-down |
| Containment | container, content, full-empty, in-out, surface |
| Multiplicity | collection, count-mass, linkage, matching, merging, part-whole, splitting |
| Process | cycle, iteration |
| Force | attraction, balance, blockage, compulsion, counterforce, diversion, enablement, momentum, resistance, restraint-removal, self-motion |
| Attribute | big-small, bright-dark, fast-slow, hard-soft, heavy-light, smooth-rough, straight, strong-weak, warm-cold |

relations (e.g., the texture of a desk, the smell of a trashcan) that could constrain the design and interpretations of new forms of interactions. As novel technologies emerge, new forms of interactions that take full advantage of these novel technologies are required. As a result, image-schematic metaphors are a promising alternative to conventional interface metaphors in the design of interactive systems, as they could support effective knowledge transfer from a familiar source domain to a novel technological domain, and meanwhile do not suffer from constraints imposed by the source domain.

The following section formally defines image schema and image-schematic metaphors.

### 2.3 Image Schema Theory: Fundamental Concepts

Defined as "recurring, dynamic patterns of perceptual interactions and motor programmes that give coherence and structure to our experience" by Johnson [53], image schemas are highly abstract, multimodal, and analogue representations of recurring sensorimotor experiences we encounter in the world. For example, we experience the rising and falling of water levels in a bathtub, we see an apple falling down from a tree, we climb up and down the stairs. All these recurring and similar experiences shape our understandings of an up-down image schema. Similarly, we formed the image schema path as we see an object following any trajectory through space, we formed the image schema blockage when experiencing impeded motions, and we formed the image schema center-periphery by experiencing bodily relations between the trunk and the extremities. Johnson [53] and Hampe [36] distinguished 30–40 image schemas. In later work, Hurtienne and Blessing [46] organized them into seven categories based on similarity (see Table 1).

Evidence from studies of child development shows that image schemas are basic concepts that people learn from physical experience very early in life. The formation of image schemas begins in the first year of life, according to Mandler [78, 79, 80]. Later, image schemas are instantiated and reinforced in our language (e.g., "Turn up the radio") and behaviors (e.g., we moved up on the control bar to increase the volume). Image schemas are the very early primitive concepts that infants learn, and they are used as the underlying building blocks to reason about many other concepts in the world, helping people understand and give structure to their environments [43].

### 2.4 Arguments for Universality

The mapping between an image schema and an abstract concept is called an *image-schematic metaphor* [53]. Such metaphors can be considered a subset of conceptual metaphors, and are a useful design tool, because they offer more concrete and practical guidance compared to image schemas alone. They effectively enable designers to make associations between specific image schemas and yet-to-be-designed representations of abstract concepts.

An example of an image-schematic metaphor is "*Importance* is BIG," which is a mapping between image schema BIG and an abstract concept *Importance*. According to Lakoff and Johnson [69], a child develops this mental association when they find that big objects, such as their parents, are important and capable of exerting strong forces over them and dominating their visual perception.

Another image-schematic metaphor is "*Emotional Intimacy* is CLOSENESS," which is found in people's language (e.g., "We are CLOSE to each other"). This is a mapping between the abstract concept *Emotional Intimacy* and the image schema NEAR. According to Lakoff and Johnson [69], the origin of this metaphor can be traced back to the experience of being in close physical proximity with people we are intimate with.

The research on image-schematic metaphors has led to an increased focus on the study of metaphors in the brain. Lakoff [66] proposed the concept of a"neural theory of metaphor," which suggests that individual neurons in the brain form "nodes" or neuronal groups, connected through different types of neural circuits. The "mapping circuit," which characterizes metaphors, involves two groups of nodes that correspond to the mappings. The "mapping circuit" of an image-schematic metaphor has one group of nodes representing a sensorimotor experience, and another group representing an abstract and subjective experience. Image-schematic metaphors are formed via a neural binding mechanism, where the mapping circuits connect different brain regions, enabling reasoning patterns from one region to be applied to another [67]. Kövecses [63] argues that due to the predominantly universal nature of the human body and brain, metaphorical structures based on them tend to be universal as well. This could be why some image-schematic metaphors, such as "Happiness is UP," can be observed in many unrelated languages, such as English, Chinese, and Hungarian [62].

According to Lakoff's theory [66], image-schematic metaphors should be universal, because people's metaphorical structures and basic sensorimotor experiences are universal, such as the experience of gravity and force dynamics. The universality argument suggests that image-schematic metaphors should be shared across different age groups. This makes them a promising approach for creating age-inclusive interactive systems.

### 2.5 Arguments Against Universality

The preceding arguments for the universality of image-schematic metaphors should not simply be accepted without further support. There are counter-arguments that suggest that the use of metaphors may indeed be influenced by age-related changes. An experimental investigation conducted by Byrd [16] found that older adults encountered difficulties in utilizing unfamiliar metaphors, whereas younger individuals exhibited greater proficiency in comprehending and retaining novel metaphoric expressions. Hasher and Zacks [37] describe syntactic structures that are ambiguous, such as those found in metaphors, as requiring significant working memory resources and therefore being more easily affected by age-related changes. Iskandar [51] maintains that metaphor interpretation requires mental manipulation and short-term storage of information, which are components of fluid intelligence. Such fluid intelligence is well known to decline with age [40]. These arguments suggest that the use of image-schematic metaphors, a sub-type of metaphors, might differ across different age groups.

In addition, metaphor comprehension is usually considered to be affected by differences in domain knowledge and therefore may not be widely consistent across populations [30, 100, 104]. According to Jung et al. [57], the proposition of a universal perspective afforded by image-schematic metaphors may overlook the influence of socially, culturally, and individually contextualized human experiences. Such experiences, Jung et al. [57] argue, play a significant role in shaping the interpretation and application of image-schematic metaphors, rendering them highly dependent on the experiences and knowledge of users. Since the younger and older populations usually differ in their prior technological knowledge [88], these arguments challenge the argument that image-schematic metaphors are shared across different age groups.

In summary, although there is a strong, prevailing argument favoring the universality of image-schematic metaphors, it remains unclear whether there is truly a substantial overlap between image-schematic metaphors used by younger and older adults. While image-schematic metaphors appear to be a compelling means for designers to access the shared mental model (defined as "an internal representation of a state of affairs in the external world" [54]) across different age groups, it is crucial to first explore the cross-group consensus before applying these metaphors to design. Failure to do so may perpetuate doubts about the effectiveness of this approach, motivate research efforts that are wasted, and result in compromised designs that may exclude certain groups.

To determine whether the prevailing arguments for the universality of image-schematic metaphors are correct or not, empirical investigation is required. However, for such studies to be conducted, two further topics must be understood: (1) the sources from which users' image-schematic metaphors can be identified; (2) empirical evidence for image-schematic metaphors' universality, however limited that might be. Each of these topics is reviewed in the following sections.

### 2.6 Sources of Image-schematic Metaphors

Instantiations of image-schematic metaphors can be identified in people's language and behaviors. Spoken language is the most frequently used source of image-schematic metaphor elicitation. When a user's spoken language is recorded and transcribed, image-schematic metaphors can be elicited from the transcripts. Most previous studies sourced image-schematic metaphors solely from interviews [49, 50, 74, 96, 102, 103]. Despite the popularity of sourcing image schemas from spoken language, the nature of image-schematic metaphors is conceptual rather than merely linguistic. Hurtienne [43] argues that not all aspects of sensorimotor experiences can be instantiated in language, and some image-schematic metaphors not discernible in users' language can only be found in users' behaviors.

Observation of behaviors is the most straightforward way to find image-schematic metaphors, which is to directly observe the mappings between an abstract concept and physical dimensions in user behaviors to form an image-schematic metaphor. For example, Bakker et al. [8] extract image-schematic metaphors from children's body movements when they acted out different musical samples by moving their body or an object (e.g., "*Loud Sounds* are UP"). Kess Asikhia et al. [59] elicited image-schematic metaphors from video recordings of users interacting with a product. However, observation of behaviors is not commonly used as an elicitation source, as it requires long-duration observation by trained individuals.

To form an accurate and comprehensive representation of people's mental models of a specific domain, it may not be sufficient to source image-schematic metaphors from only spoken language, even though that is the most common practice. Hurtienne [43] suggests that combining different sources would be a better solution.

### 2.7 Limited Evidence for Image-schematic Metaphors' Universality across Age Groups

Prior studies have been conducted to source image-schematic metaphors from users' spoken language and observations of their interaction behaviors. However, very few of them have involved older participants (as summarised in Table 2). Although there is a strong theoretical claim that image-schematic metaphors are shared across different age groups, empirical evidence supporting this is very limited.

Table 2. Previous Elicitation Studies That Involved Older Participants

| Publication | Source of ISM | Participants of Extraction | Overlap between younger and older groups regarding ISM usage |
|---|---|---|---|
| Hurtienne and Langdon (2010) | Single source: Spoken language | 10 participants (aged 26–84) | Not reported |
| Hurtienne et al. (2015) | Single source: Spoken language | 8 older participants (aged 57–86) | Not reported (younger participants not included) |
| Winkler et al. (2016) | Single source: Spoken language | 5 younger (aged 22–23); 5 older (aged 54–61) | Not reported |
| Tscharn (2018) -Study 1 | Single source: Spoken language | 21 younger (aged 18–27); 20 older (aged 50–86) | Substantial overlap (69.70%) in spoken language |
| Tscharn (2018) -Study 2 | Single source: Spoken language | 5 younger (aged 22–23); 5 older (aged 54–61) | Substantial overlap (69.88%) in spoken language |

In the context of central heating controls, Hurtienne and Langdon [50] extracted image-schematic metaphors from the spoken language of 10 participants aged 26–84. However, this study did not report a comparison between image-schematic metaphors used by younger and older groups.

Two other studies are similar. First, Hurtienne et al. [49] extracted image-schematic metaphors from the spoken language of eight participants aged 57–86 (no younger participants were involved in image-schematic metaphor extraction), Second, Winkler et al. [103] extracted image-schematic metaphors from the spoken language of five younger (aged 22–23) and five older (aged 54–61) participants. In both studies, it was not reported whether the same image-schematic metaphors were used by the younger and older groups.

Tscharn [96] conducted two empirical studies in the domain of online banking, and for the first time, reports the overlap between image-schematic metaphors found in younger and older adults' spoken language. In the first study, image-schematic metaphors were elicited from structured interviews about online banking of 21 younger participants (aged 18–27) and 20 older participants (aged 50–86). A substantial overlap of 69.70% was found between image-schematic metaphors used by the two age groups. In the second study, contextual interviews in the context of between-cars social communications and entertainments were conducted among 5 younger participants (aged 22–23) and 5 older participants (aged 54–61). The overlap was 66.88%.

However, the methodological drawback of the two studies conducted by Tscharn [96] was that image-schematic metaphors were only sourced from user utterances. This approach could only capture a fraction of younger and older adults' mental models (see Section 2.6 of the present article).

## 3 EXAMINING IMAGE-SCHEMATIC METAPHOR OVERLAP IN YOUNGER AND OLDER ADULTS

Motivated by a lack of empirical evidence, we designed and conducted two studies to investigate the degree of overlap between image-schematic metaphors used by younger and older adults, which could indicate whether image-schematic metaphors are a useful foundation for the design of age-inclusive interactive systems. To overcome the limitations associated with solely relying on verbal utterances, we elicited image-schematic metaphors from recording not only what the participants said but also how they behaved. To do this, we created a structured interview with a set of standardized questions to elicit metaphors from spoken language, and designed four interactive

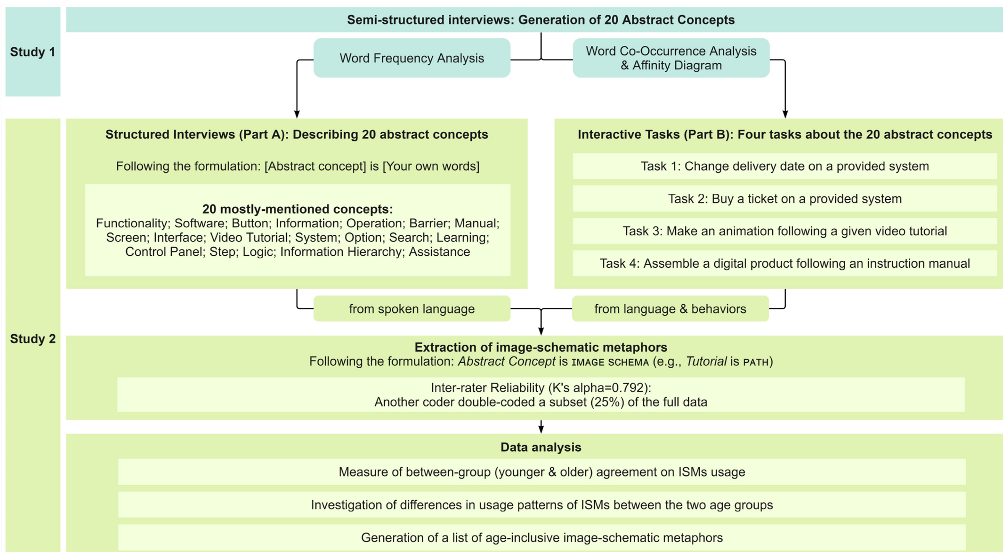



Fig. 2. Overview of the research process.

tasks to derive metaphors from behaviours. It is important to note that in this study, behaviors refer to gestures and actions, and do not include tone of voice and facial expressions.

We designed this research project to answer the following research questions:

**RQ1:** Is there a substantial overlap between image-schematic metaphors used by younger and older adults?
**RQ2:** How do the usage patterns of image-schematic metaphors differ between younger and older adults?
**RQ3:** What image-schematic metaphors are shared between the two age groups?
**RQ4:** How will the choice of image-schematic metaphors elicitation source (language and behaviors) impact the characteristics of image-schematic metaphors identified?

Our research project begins with Study 1 (see Section 4), a semantic analysis in which we identify prevalent concepts and central themes that are used to design the tasks of Study 2 that follows. Study 2 adopted the *Exploratory Design* (QUAL → quan), one of the four main types of mixed methods research approaches [19]. The Exploratory Design begins with a qualitative phase in which researchers collect qualitative data, identify emergent categories or themes from the qualitative data, and then progresses to a quantitative phase in which researchers examine the prevalence of these themes within different samples [19, 83]. Because the design begins qualitatively, a greater emphasis is typically placed on the qualitative data [19]; for this reason, we used sampling methods suitable for a qualitative study (discussed later).

For an overview of the study process see Figure 2.

## 4 STUDY 1: COLLECTION OF ABSTRACT CONCEPTS IN TECHNOLOGY LEARNING DOMAIN

We have chosen *technology learning* (learning and using unfamiliar technologies) as the domain of interest for our investigation, as it comprises several abstract concepts that lack concrete physical or conceptual referents. This characteristic of the domain encourages the use of image-schematic

Table 3. Most-frequently Mentioned Concepts Identified from Transcribed Interviews where Participants Answered Questions about Their Experiences of Learning and Using Unfamiliar Digital Systems

| **Most frequently mentioned concepts** | **Word occurrence** |
|---|---|
| Functionality | 112 |
| Button | 52 |
| Software | 52 |
| Information | 50 |
| Problem | 46 |
| Operation | 38 |
| Barrier | 36 |
| Search | 36 |
| Screen | 31 |
| Instruction Manual | 31 |
| Option | 27 |
| Video Tutorial | 26 |
| Interface | 26 |
| Step | 21 |
| System | 20 |
| Learning | 19 |
| Control Panel | 19 |
| Logic | 13 |
| Information Hierarchy | 12 |
| Assistance | 11 |

structures to comprehend these abstract concepts, rendering it an ideal domain to investigate the use of image-schematic metaphors across age groups. We conducted Study 1 to collect a set of the most commonly used abstract concepts in the domain of technology learning.

## 4.1 Participants

In Study 1, three younger participants (one female) were included, aged 26, 26, 29 (Mean = 27, SD = 1.73). Similarly, three older participants (one female) were included, aged 61, 63, 65 (Mean = 63, SD = 2). Younger adults were postgraduate students. Older adults were recruited via direct contact. All participants had a undergraduate degree. All participants gave consent for their interviews to be audio recorded. Ethical approval for this study was obtained from our University.

## 4.2 Procedure

Six participants completed semi-structured interviews conducted one-on-one, and lasting between 60 and 90 min. Participants answered questions (see Appendix A.1) about their experiences of learning and using unfamiliar digital systems of four different types: mobile applications (e.g., Teams app), desktop applications (e.g., Solidworks), integrated products (unified products designed as an integration of various products or services; e.g., smart thermostats) and public devices (e.g., ATMs). The interviews were audio-recorded and then transcribed.

## 4.3 Results

*4.3.1 Most Recurrent Nouns.* We applied a word frequency analysis to the resultant text corpus, excluding words such as adverbs, adjectives, and modal verbs, and focusing solely on the most recurrent nouns. These nouns were then ranked by their frequency of occurrence in the interviews, and the leading 20 nouns were chosen as the target concepts (see Table 3).

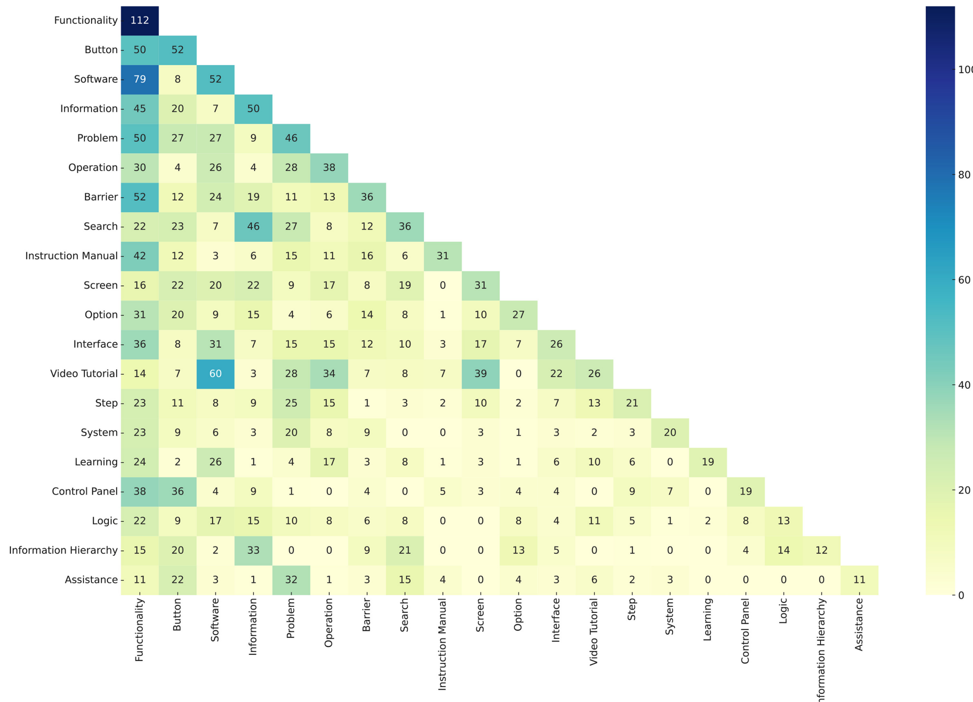



Fig. 3. Word-word co-occurrence matrix. The co-occurrence value of a word pair $A$ and $B$ was calculated by multiplying the occurrences of $A$ in a sentence with the occurrences of $B$ in that same sentence.

Some of the chosen concepts are abstract, because they do not have a concrete or physical presence, such as *Logic* and *Information Hierarchy*. Others are abstract because the connection between the input and output is not transparent, such as *Button*, *Screen*, and *Control Panel*. For the first group of concepts, there is no physical entity to refer to; for the second group of concepts, it is difficult for users to explain and reason about these concepts merely based on their physical states. For example, a *Button* represents an interactive mechanism that can invoke a series of computational operations; a *Screen* refers to the data or information rendered on a computer at one time (e.g., "Pressing F1 will display a help screen"); a *Control Panel* refers to the portion of a computing display that represents its controls. All 20 chosen concepts are considered abstract in the senses outlined above, which makes them suitable as the target domain within a metaphor.

*4.3.2 Central Themes and Satellite Concepts.* Figure 3 shows the word-word co-occurrence for the 20 most frequently mentioned concepts. For any given pair of words ($A$ and $B$), the co-occurrence value was determined by multiplying the occurrences of $A$ in a sentence with the occurrences of $B$ in that same sentence. The overall co-occurrence value for any specific pair of words was calculated by summing the co-occurrence values from all sentences where they appear together.

Analyzing word co-occurrence, we observed that the concepts *Functionality*, *Software*, *Information*, and *Problem* each had strong associations with a specific set of related satellite concepts, forming four distinct groupings (see Table 4). Consequently, we designated these four concepts as central themes. For each central theme, we identified a set of satellite concepts that frequently co-occurred with them, all having a co-occurrence value exceeding 20. Although the concept

Table 4. Central Themes and Their Related Satellite Concepts

| Central Themes | Related Satellite Concepts |
|---|---|
| Information | Search (46), Functionality (45), Information Hierarchy (33), Screen (22), Button (20) |
| Problem | Functionality (50), Assistance (32), Video Tutorial (28), Operation (28), Search (27), Button (27), Software (27), Step (25), System (20) |
| Software | Functionality (79), Video Tutorial (60), Interface (31), Problem (27), Learning (26), Operation (26), Barrier (24), Screen (20) |
| Functionality | Software (79), Barrier (52), Button (50), Problem (50), Information (45), Instruction Manual (42), Control Panel (38), Interface (36), Option (31), Operation (30), Learning (24), System (23), Step (23), Search (22), Logic (22) |

The co-occurrence value between a satellite concept and a central theme is presented as (*n*).

*Button* also showed consistent co-occurrences with other concepts, we did not select it as a central theme due to its strong association with and easy integration into the other four central themes.

## 5 STUDY 2: ELICITATION OF IMAGE-SCHEMATIC METAPHORS

The tasks of Study 2 were developed using the findings of Study 1. Study 2 consisted of a structured interview (Part A) and four interactive tasks (Part B), aiming to elicit image-schematic metaphors in younger and older adults' language and interaction behaviors (actions and gestures). The structured interview was designed using the 20 most frequently mentioned concepts individually, and the four interactive tasks were designed based on the four central themes grouped with their satellite concepts.

### 5.1 Participants

As discussed in Section 3, we used qualitative sampling methods in Study 2. In qualitative research, the determination of sample size is often guided by the principle of saturation [32]. Some researchers have operationalized saturation as consensus, and proposed evidence-based recommendations on sample size through their own empirical analysis. Romney et al. [91] developed the *Cultural Consensus Model*, suggesting that each culture possesses a shared view of the world, which leads to a "cultural consensus." While the level of consensus on various topics might differ, it is believed that there exists a finite set of ways of classifying elements in the cultural information pool. Romney et al. [91] suggest that in familiar domains where participants have homogeneously high expertise, it is possible to establish a cultural consensus relying on a small sample size (as few as four participants). Image schemas represent a domain of basic cognitive constructs developed early in infancy and continually reinforced throughout a person's life. We might therefore expect that individuals in any demographic group will possess a consistently high level of expertise regarding image schemas. According to the *Cultural Consensus Model*, any demographic group can only use a finite set of methods to categorize these image schemas. These methods are the consensual set of image-schematic metaphors. Using the *Cultural Consensus Model*, Atran et al. [7] estimate a minimum sample size, indicating that in some of their studies, as few as 10 participants were sufficient to reliably establish a consensus. Additionally, Guest et al. [35] operationalize saturation for studies that employ non-probabilistic sampling methods and suggest that saturation occurs within the first 12 interviews. This also aligns with having 12 participants in each age group in the qualitative phase of Study 2. Following these arguments, in our study we expected to establish consensus in the two groups with 12 participants in each group (see Table 15 for confirmation that consensus was indeed reached in both age groups).

In the qualitative phase of Study 2, sample size refers to the number of participants (participants). However, it is argued that the sample size concept does not necessarily refer to the number of participants when analyzing observational or linguistic data (number of events/themes coded) [76]. The "samples" that the quantitative analysis of Study 2 was actually addressing, were a large number of themes coded from the qualitative data (637 themes in total; 319 for the younger group and 318 for the younger group). We argue that the large number of coded instances constitutes an appropriate sample size for the quantitative analysis conducted in Study 2.

In Study 2, we employed a *Matched Sampling* method, which refers to recruiting individuals that belong to different groups (e.g., older adults and younger adults) but who are matched on other variables (e.g., language, educational attainments) [93]. The sampling thresholds were 20–35 years old for the younger group and 60–75 for the older group. There were 12 English-speaking younger participants, six female and six male. The younger participants in this study were between the ages of 21 and 34 (Mean = 25.92, SD = 3.55). Four of them had a undergraduate degree and the rest had a postgraduate degree. Each younger participant was matched with an older participant with the same educational attainment level. Younger participants were recruited through a mailing list distributed to members of a large university in the UK. There were 12 English-speaking younger older participants, seven female and five male. The older participants in this study were between the ages of 62 and 75 (Mean = 70.21, SD = 4.04). Four of them had a undergraduate degree and the rest had a postgraduate degree. Older participants were recruited from U3AC, a charity that organizes educational activities for people who are not or no longer in full-time employment. None of the participants had experienced severe cognitive decline or sensory impairment. Ethical approval for this study was obtained from our University.

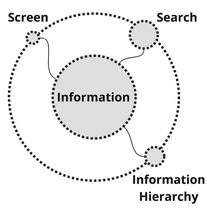
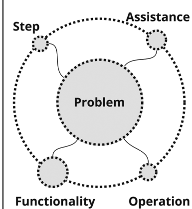
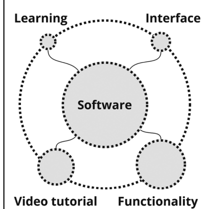
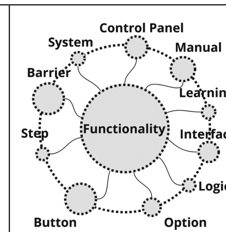
## 5.2 Procedure

*5.2.1 Measures of Prior Technological Knowledge.* Before Study 2 started, all 24 participants completed a questionnaire that measured their prior technological knowledge. We measured participants' prior experience with technology as exposure level and competency level [47]. Exposure level was measured on two dimensions, exposure to general technologies and to unfamiliar technologies. Competency was measured on two levels, competency in using general technologies and learning to use unfamiliar technologies.

At the exposure (general technologies) level, participants reported how often they had used the 12 common technologies shown on the questionnaire in everyday life, and how often they had performed 18 common digital tasks in the past year on a five-point Likert scale (from "never" (1) to "almost everyday" (5), range of total score: 30–150). At the exposure (unfamiliar technology) level, participants reported how often they had learned to use unfamiliar systems on 12 technologies presented on a five-point Likert scale (from "never" (0) to "almost everyday" (4), range of total score: 0–48); and they reported in a checklist that contained five technology learning related tasks they had used in their lives (range of total score: 0–5).

At the competency (general technologies) level, we used the **Computer Proficiency Questionnaire (CPQ)** [15] to measure participants' competence in performing 33 common digital tasks on a five-point Likert scale (from "never tried" (0) to "very easily" (4), range of total score: 0–132). This measurement was adapted from the CPQ, which is suitable for individuals with varying levels of proficiency, ranging from non-computer users to highly skilled users. At the competency (unfamiliar technologies) level, we used a single-item test where participants were asked to self-evaluate their proficiency in learning new technologies on a seven-point Likert scale (from "very poor" (−3) to "very good" (3)). Prior research suggests that using a seven-point Likert scale is more sensitive and reliable for a single-item test compared to using fewer response options [26, 94].

Table 5. Four Interactive Tasks in Part B

| | | | | |
|---|---|---|---|---|
| Groupings |   |   |   |   |
| Use Case | Search for information to solve problems when using unfamiliar systems. | Seek assistance from people around you when using unfamiliar systems. | Watch video tutorials to learn how to complete an unfamiliar task on a software. | Read instruction manuals to learn how to use an unfamiliar system. |
| Concepts | Information, Search, Information Hierarchy, Screen. | Problem, Assistance, Operation, Step, Functionality. | Software, Video Tutorial, Interface, Functionality, Learning. | Functionality, Manual, Button, Step, Learning, Interface, Control Panel, System, Barrier, Option, Logic. |
| Tasks | Task 1: On a provided delivery app, participants are required to:<br><br>(a) change delivery date of a parcel. | Task 2: On a provided train ticketing system, participants are required to:<br><br>(a) buy a ticket;<br>(b) check departure time and platform;<br>(c) top up a railcard. | Task 3: Following a provided video tutorial, participants are required to:<br><br>(a) make a toggle switch animation in PowerPoint. | Task 4: Based on an instruction manual, participants are required to:<br><br>(a) assemble a mobile phone stabilizer;<br>(b) complete four subtasks on the devices, including "start video recording," "burst shooting," "zoom in/out," "switch between front and back cameras." |

In the figures shown in the *Groupings* row, the biggest central circle represents the central theme of this grouping, while the surrounding smaller circles represent its satellite concepts. The radius of each satellite circle represents the co-occurrence value between this satellite concept and the central theme: larger circles indicate more frequent co-occurrences with the central theme.

*5.2.2 Part A: Structured Interviews.* There is a possibility that in semi-structured interviews, the experimenter's language could impact how participants understand these concepts and their word production [96]. In order not to bias participants in this way, we conducted structured interviews in Part A of Study 2, each participant described the 20 concepts identified in Study 1 in their own words, by answering a standardized question, "What do you think is [abstract concept]?" All interviews were audio-recorded, transcribed and later used as a source (spoken language) for image-schematic metaphor extraction.

*5.2.3 Part B: Interactive Tasks.* The results of Study 1 provided four groupings, each comprising a central concepts and their related satellite concepts, all with a co-occurrence value exceeding 20 (see Table 4). Using the four groupings shown above as a foundation, we brainstormed a set of four use cases that covered all 20 chosen concepts, which informed the design of the four interactive tasks in Part B (see Table 5).

The aim of the interactive tasks was to investigate how people comprehend concepts related to technology learning. To make sure participants were actually learning to use these systems during task completion, the systems used in the tasks needed to be unfamiliar to the participants of both age groups. The first author designed and implemented the novel digital systems used in this study to ensure the tasks were never encountered by any of the participants in their previous experience. These materials included a parcel delivery application, a train ticketing system and a video tutorial on how to make a toggle switch animation in PowerPoint.

Participants completed three interactive tasks on digital systems provided by the first author and one task based on a smartphone gimbal (DJI OM 4). None of the participants had any prior experience using this product. When completing the four tasks, participants were asked to think aloud [72].

(1) Task 1: Participants were required to change the delivery date of a parcel on a delivery application designed by the first author (see Figure 4). Since the "changing delivery date" option was designed to be hidden, the participants either explored the whole system to find out how to complete the task or used the "search" function in the system to find instructions on changing the delivery date.
(2) Task 2: Participants were required to buy a train ticket from one city to another, download an E-ticket, check departure time and platform information and then top up £25 to their railcard, on a rail ticketing system designed by the first author (see Figures 5 and 6). To investigate how people seek assistance and tackle problems when using unfamiliar systems, ways to complete these sub-tasks in the rail ticketing system (e.g., how to download an E-ticket, where to find the reference number, the entrance to "top-up" ) were designed to be unclear and hidden. Participants talked to the experimenter for clarification and assistance when encountering obstacles.
(3) Task 3: Participants were provided with a video tutorial made by the first author (see Figure 7) on how to create a toggle switch animation in PowerPoint and were required to make the animation following the tutorial. Each participant was equipped with two monitors and had the flexibility to arrange the monitors in any ways they preferred, as well as to adjust the size and position of both the video tutorial and the task window.
(4) Task 4: Participants were provided with a digital gimbal (see Figure 8) and an instruction manual. Based on the manual, participants assembled the gimbal and completed the four sub-tasks on the control panel of the digital gimbal, including "start/stop video recording," "burst shooting," "zoom in/out," and "switch between front/back cameras."

All interactive tasks were video-recorded, with a camera capturing participants' behaviors and a microphone capturing their utterances when completing these interactive tasks. We used an interaction analysis approach [55] to code participants' think-aloud verbal expressions and behaviors including gestures and actions from the video recordings (see Table 6). The software used for video analysis was Dovetail.[1]

## 5.3 Coding Methods

*5.3.1 Coding Process.* To standardize the coding process, we compiled a coding guideline for image-schematic metaphors according to the ISCAT database [48], a database that contains image schemas' definitions and their instantiations in language and user interfaces. Our coding guideline consisted of two components: the definitions of image schemas along with a set of signaling words, and distinct coding procedures (see Tables 7 and 8) that were employed for Part A (interviews) and Part B (interactive tasks). Both coders (the first author and the other coder) referred to the same coding guideline during their independent coding. The software used for coding was Dovetail.[2]

[1] https://dovetail.com/
[2] https://dovetail.com/

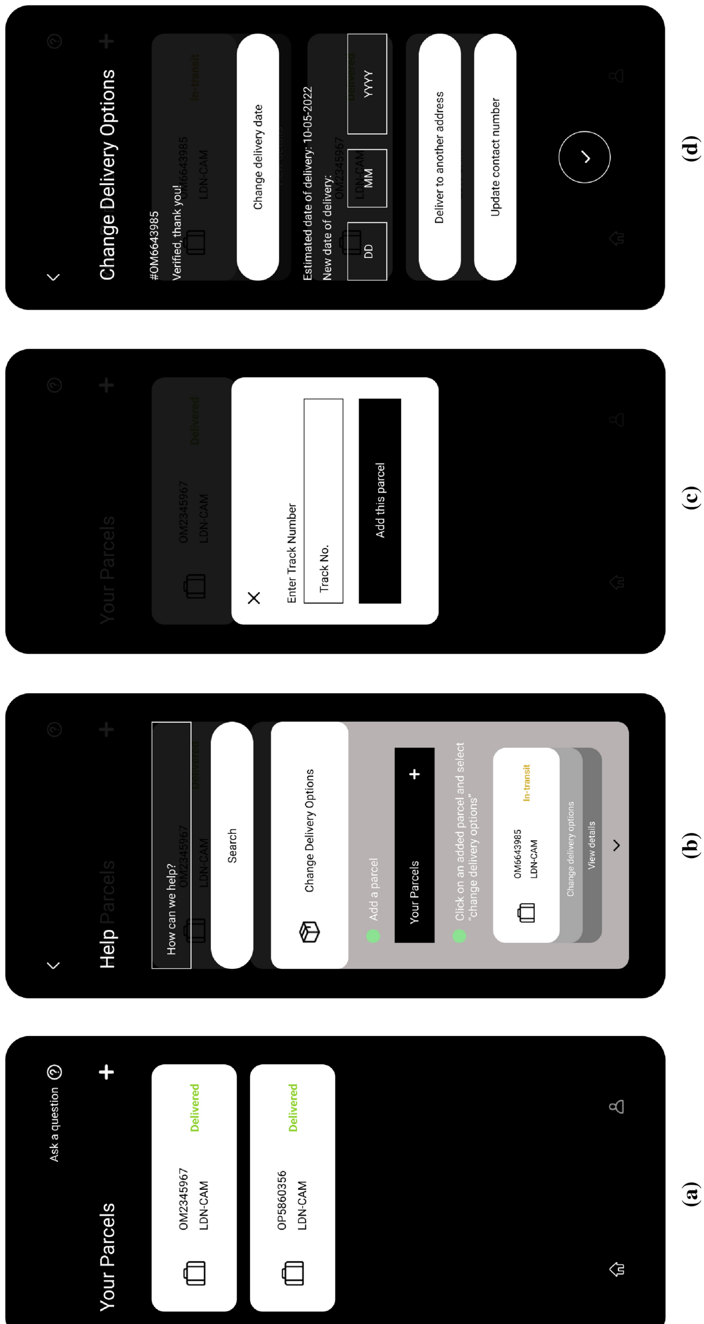
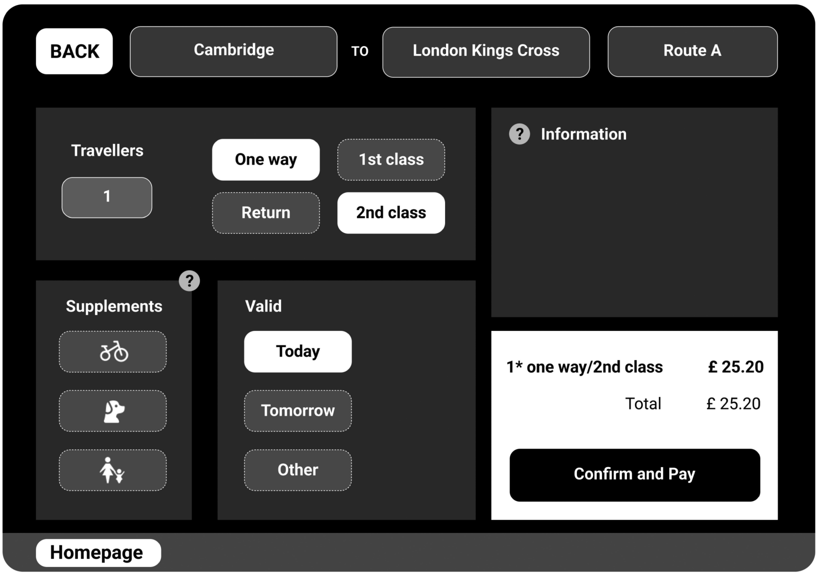
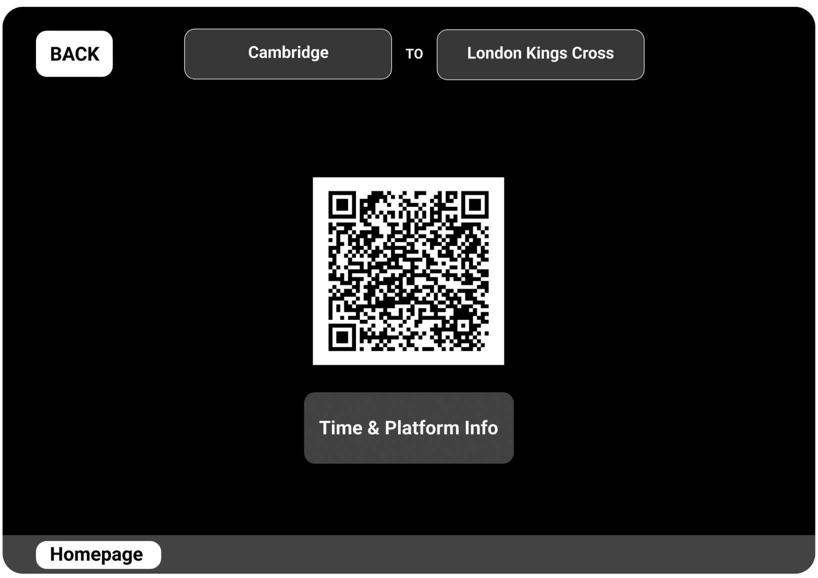



Fig. 4. Screenshots of the delivery application: (a) the "search" function; (b) adding a parcel; (c, d) changing delivery date.



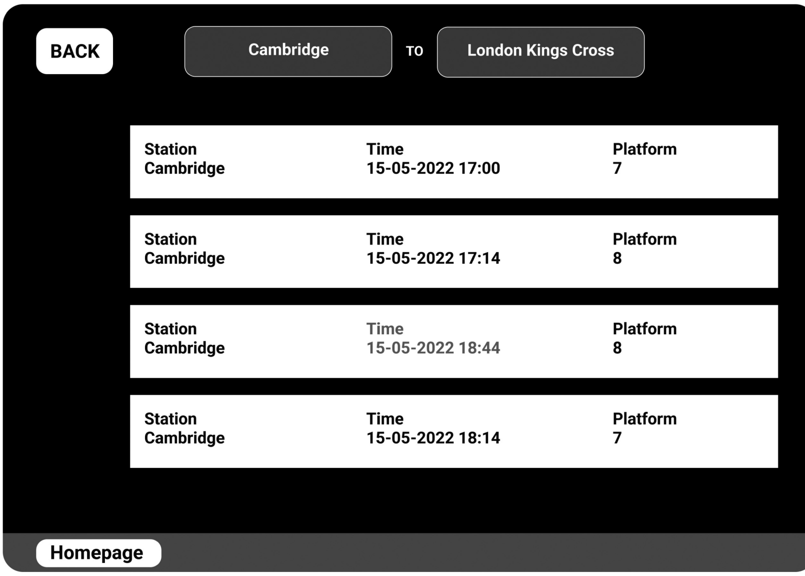

(a)



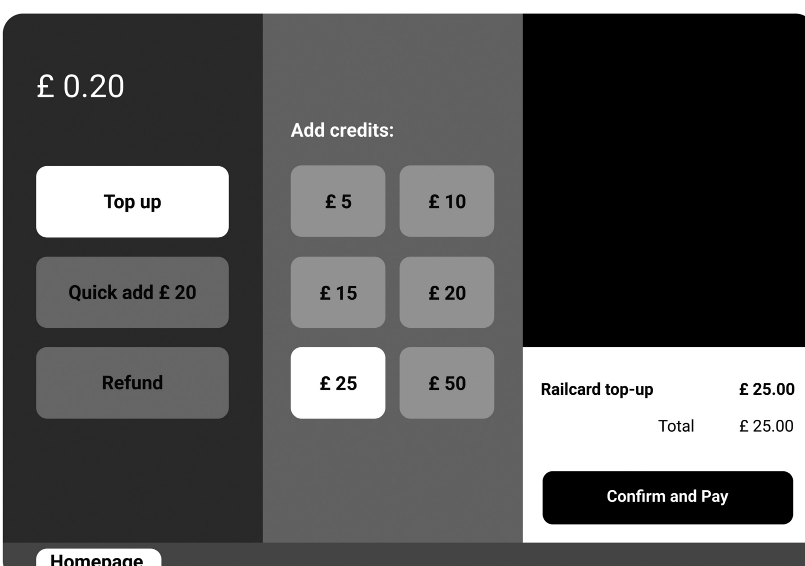

(b)

Fig. 5. Screenshots of the rail ticketing application: (a) buying a ticket; (b) getting an E-ticket.

To elicit image-schematic metaphors from the transcribed interviews in Part A, the coders went through the transcripts first, identifying possible lexical units that indicated an image schema and a target concept, then identified which property or relational structure of the target concept was mapped to the image schema tagged. This formulated a mapping between "an attribute/relational structure of a target concept" and an image schema, which was an image-schematic metaphor.




(a)




(b)

Fig. 6. Screenshots of the rail ticketing application: (a) checking departure time and platform; (b) topping up a railcard.

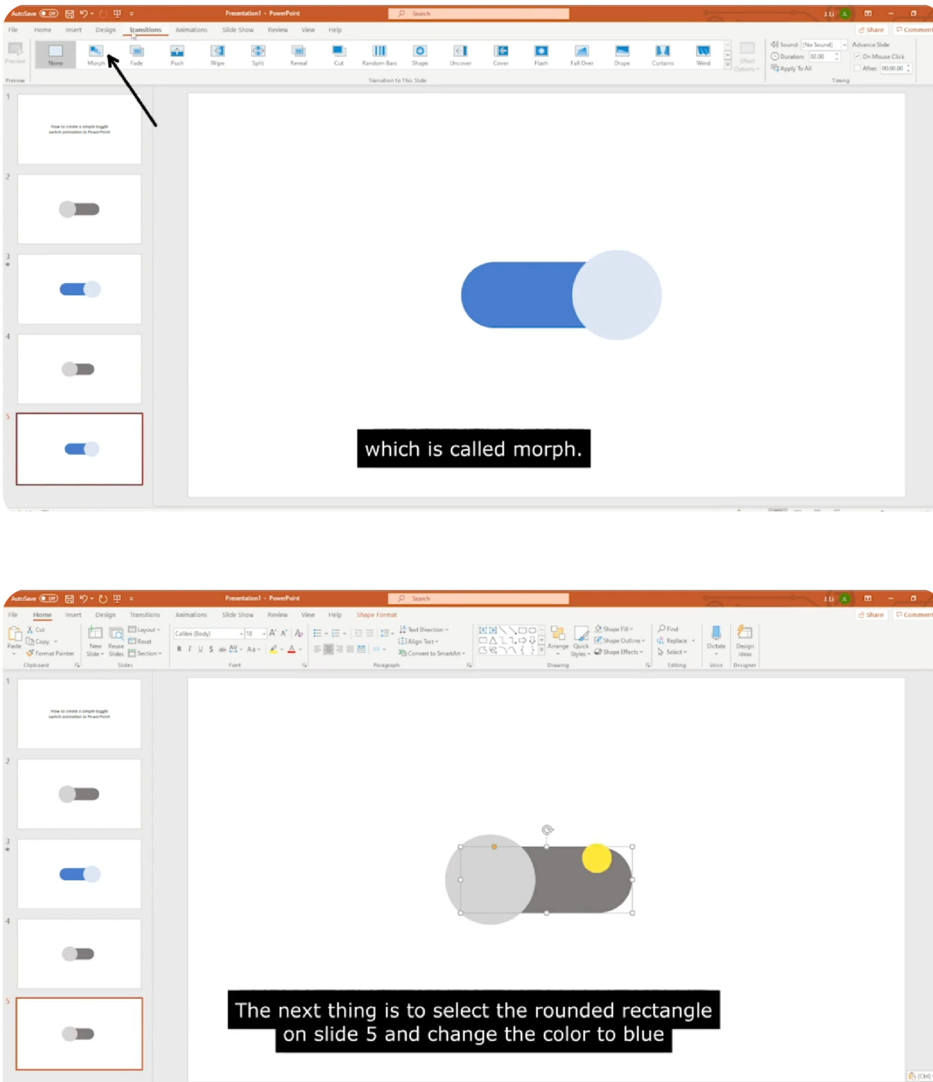



Fig. 7. Screenshots of the video tutorial made by the first author, on making a toggle switch animation in PowerPoint.

Table 7 presents an example of how an image-schematic metaphor was identified in transcribed interviews.

For interactive tasks (Part B), there were two elicitation sources, including transcribed verbal data and behaviors coded from the video recordings. The two elicitation sources were coded separately following the process shown in Table 8.

5.3.2 *Double Coding.* Based on the above-mentioned coding guideline, the first author of this work coded the entire dataset. Thereafter, inter-coder agreement analysis was conducted. The

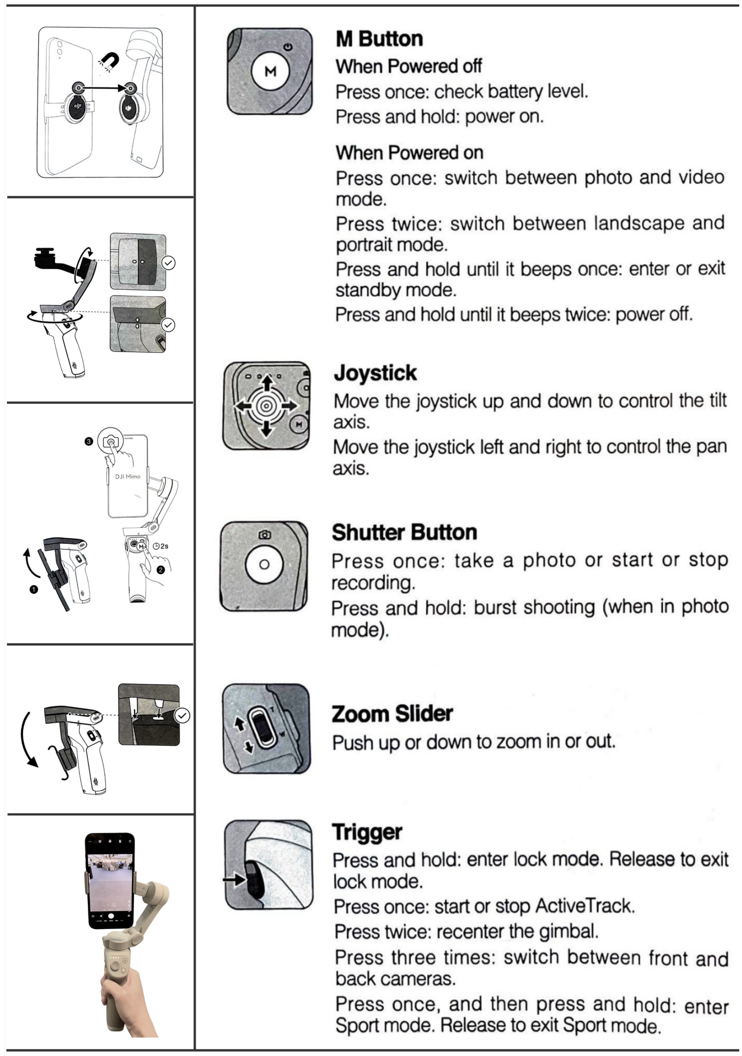



Fig. 8. Digital gimbal and instruction manual used in task 4. The instruction manual showed diagrams about assembly steps on the left and how to interact with buttons on the control panel of the digital gimbal.

Table 6. Coding User Interactions from the Video Records of Four Interactive Tasks

| **Actor** | **Verbal Expressions** | **Behaviors** (gestures and actions) |
|---|---|---|
| Participant 1 (Task 3: 0:31-0:38) | (No verbal data collected) | Placed the video tutorial on the right side and centered the task screen. |
| Participant 2 (Task 2: 7:28-7:59) | Is it the one in the middle? No. The second is not right either. How about this one? No. Oh it is the one at the corner! | Clicked on all three buttons in the center of the interface from top to bottom, then clicked the correct button at the bottom right corner. |

Table 7. Coding Process for Transcribed Interviews (in Part A of Study 2)

| **Source** | **Quote** | **Coding Process** | |
|---|---|---|---|
| Interviews | "*Interface* is the link between human beings and the things that they need to operate in the world." | **Step 1**: Identify image schema based on definitions and signaling words.<br>- Definition: "The LINKAGE image-schema consists of two or more entities which are connected with each other by means of a linking device of some kind [44]."<br>- Signaling words: connect, tie, link | *Interface* is the **link** (LINKAGE) between human beings and the things that they need to operate in the world. |
| | | **Step 2**: Identify target concept. | ***Interface*** is the link between human beings and the things that they need to operate in the world. |
| | | **Step 3**: Identify which property or relational structure of the target concept is mapped to the image schema. | The form of *Interface* is LINKAGE |

second coder was a PhD student with experience in coding qualitative data, who was provided with the same coding guideline, a tutorial on the definitions of image schemas and the extraction process, and a practice session supervised by the first author. During the practice session, the second coder was provided with 30 sample instances and was required to code these instances with image schemas.

Since having both coders process the entire dataset would be effortful and time-consuming, Armstrong et al. [6] suggest that calculating inter-coder agreement value for a representative 25% of a dataset is sufficient to evaluate coding reliability. The first author of this work independently coded the entire dataset, and then the second coder independently coded 25% of the instances coded by the first author.

To ensure the subset was representative of the entire dataset, we randomly sampled 25% of the instances coded with each of the six image schema categories that made up the full dataset. For example, 25% of instances coded with image schemas that belong to the SPACE category were be sampled. The same sampling method was applied to the other five image schema categories. In total, 160 instances were sampled in the double-coding dataset. This dataset contained the exact word sequence and its location in the transcripts.

Cohen's Kappa [70] is an established measure for the inter-coder agreement between two coders. This is most often used for a pre-defined set of data that is entirely coded by all coders (i.e., there is no missing data). However, in this study, word areas were relatively loosely defined, so not all coders tagged or analyzed the exact same words. Hayes and Krippendorff [38] argue that most reliability measures are not applicable in situations where a large number of elements could be potentially tagged. When not all extractors elicited ISMs from all possible locations, Krippendorff's alpha is regarded as more robust, because it bases its calculations on disagreements. The formula is

Table 8. Coding Process for Interactive Tasks (in Part B of Study 2)

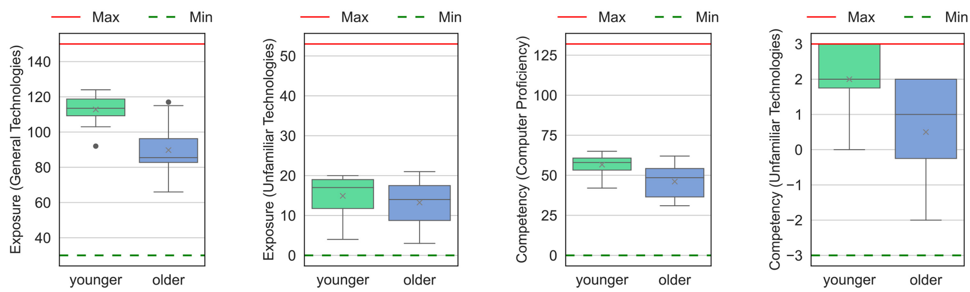
| Source | Quote | Coding Process | |
|---|---|---|---|
| **Example 1**: Upward movement on *Button* is BIGGER | | | |
| Think-aloud verbal expressions | Okay I think this is the button for zooming in and out on the camera. But what am I going to do with it? | **Step 1**: Identify image schema based on definitions and signaling words. | Okay I think this is the button for **zooming in and out** (BIG-SMALL). |
| | | **Step 2**: Identify target concept. | Okay I think this is the ***Button*** for zooming in and out. |
| | | **Step 3**: Identify which property or relational structure of the target concept is mapped to the image schema. | No obvious link found. |
| Behaviors | When provided with a button that can be clicked/pressed/held and moved towards multiple directions, the user moved their finger upward on the button's responsive area to zoom in and downward to zoom out. | **Step 1**: Identify image schema based on definitions. | BIG-SMALL |
| | | **Step 2**: Identify target concept. | *Button* |
| | | **Step 3**: Identify which property or relational structure of the target concept is mapped to the image schema. | Upward movement on *Button* is BIGGER |
| **Example 2**: Important *Information* is CENTER | | | |
| Think-aloud verbal expressions | Is it the one in the middle? No. The second is not right either. How about this one? No. Oh it is the one at the corner! | **Step 1**: Identify image schema based on definitions and signaling words. | None |
| | | **Step 2**: Identify target concept. | *Information Hierarchy* |
| | | **Step 3**: Identify which property or relational structure of the target concept is mapped to the image schema. | No obvious link found. |
| Behaviors | Clicked on all three buttons in the center of the interface from top to bottom, then clicked the button at the bottom right corner. | **Step 1**: Identify image schema based on definitions. | CENTER-PERIPHERY |
| | | **Step 2**: Identify target concept. | *Information Hierarchy* |
| | | **Step 3**: Identify which property or relational structure of the target concept is mapped to the image schema. | Important *Information* is CENTER |

$$\alpha = 1 - \frac{D_o}{D_e},$$

where $D_o$ represents the observed disagreement within the units of analysis and $D_e$ represents the predicted disagreement when coding is based on chance. The results were interpreted based on Kappa value interpretation [70]: a poor agreement would be indicated by a negative value; a slight agreement (0–0.20); a fair agreement (0.21–0.40); a moderate agreement (0.41–0.60); a substantial agreement (0.61–0.80); an almost-perfect agreement (0.81–1).

## 5.4 Results

All data was checked against assumptions for the statistical tests used.




(a) Exposure-GT* (b) Exposure-UT (c) Competency-GT* (d) Competency-UT*

Fig. 9. (a) Distribution of exposure to general technologies; (b) distribution of exposure to unfamiliar technologies; (c) distribution of competency in using general technologies; (d) distribution of competency in learning to use unfamiliar technologies. The box plots show the median (the horizontal line), the mean ("×"), the first and third quartile (the box) and the minimum and maximum (the whiskers). The circle signs ("o") indicate outliers. The asterisks on plot titles indicate the dimensions that show a statistically significant difference ($p \leq 0.05$). The red sold line indicates the possible max value on the y axis and the green dashed line indicates the possible min value.

Table 9. Kruskal-Wallis Test Results on Four Dimensions of Prior Technological Knowledge in Terms of Age

| Dimension | N | Mean Score | df | $\chi^2$ | $p$ | $\eta^2$ |
|---|---|---|---|---|---|---|
| **Exposure** (general technologies) | Older: 12<br>Younger: 12 | Older: 89.75<br>Younger: 112.83 | 1 | 9.9138 | 0.0016* | 0.4310 |
| **Exposure** (unfamiliar technologies) | Older: 12<br>Younger: 12 | Older: 13.25<br>Younger: 14.92 | 1 | 0.6155 | 0.4327 | 0.0268 |
| **Competency** (general technologies) | Older: 12<br>Younger: 12 | Older: 46.08<br>Younger: 56.67 | 1 | 5.7634 | 0.0164* | 0.2506 |
| **Competency** (unfamiliar technologies) | Older: 12<br>Younger: 12 | Older: 0.50<br>Younger: 2.00 | 1 | 6.6087 | 0.0101* | 0.2873 |

Mean scores obtained by both age groups on the four dimensions were shown in the table. The asterisks ("*") on $p$ values indicate that on these dimensions the differences between the two groups' scores are statistically significant ($p \leq 0.05$). A large effect size is represented by $\eta^2 \geq 0.14$.

*5.4.1 Prior Technological Knowledge.* We measured the prior technological knowledge of the two age groups on four dimensions and summarize this in box plots (Figure 9).

We performed the Kruskal-Wallis tests on four measured dimensions of prior technological knowledge (see Table 9). The results showed that younger and older adults differed significantly in three of the four measured dimensions. However, no significant difference was found in their exposures to unfamiliar technology. Values on most dimensions were significantly higher for the younger group. It is also possible to analyze the correlations between different measured dimensions within each age group (e.g., testing whether exposure and competency are correlated). However, in the interest of cleanness, we did not include additional analyses due to their limited relevance to the primary objective, which focuses on comparing the levels of prior technological knowledge between the two age groups. Future research could perform such correlation analyses using the publicly available data from this study.

*5.4.2 Inter-coder Agreement.* The second coder independently coded the subset. After the second coder had finished, we exported both the first author's and the second coder's coding

Table 10. Usage Frequency of Image Schemas Categories (e.g., among All the Image Schemas Used by Older Adults, 39.62% of them Fell Under the Category of Space)

| Image Schema Category | Older Adults | Younger Adults | All Participants |
|---|---|---|---|
| Space (e.g., up-down) | 39.62% | 36.68% | 38.15% |
| Force (e.g., blockage) | 32.08% | 21.32% | 26.69% |
| Multiplicity (e.g., part-whole) | 18.24% | 22.57% | 20.41% |
| Attribute (e.g., big-small) | 4.72% | 10.03% | 7.38% |
| Containment (e.g., container) | 5.03% | 8.46% | 6.75% |
| Process (e.g., cycle) | 0.31% | 0.94% | 0.63% |

results from Dovetail[3] and aggregated them into one dataset. The first author slightly edited and summarised the identified image-schematic metaphors by removing spelling errors and minimal differences (e.g., Upward movement on buttons is big, and Moving buttons up is big). The aggregated dataset consisting of both coders' coding results was then imported into Atlas.ti[4] to calculate inter-coder agreement.

The inter-coder agreement analysis revealed a Kripendorff's alpha of 0.792 (no missing value; 325 decisions; observed disagreement: 0.207; expected disagreement: 0.995), which was a substantial agreement. The inter-coder agreement value was comparable to that of earlier research focusing on the extraction process of image-schematic metaphors from language [42, 96]. Rather than discarding the set of image-schematic metaphors that were in disagreement, we used the inter-coder agreement value of a representative subset to assess the fairness and accuracy of the first author's coding against the established image schema definitions. Now with an achieved high level of inter-coder agreement, we affirmed the feasibility of proceeding with data analysis using the first author's coding results on the entire dataset.

The first author identified 319 instances in younger participants' transcribed language and coded behaviors. It is important to note that these 319 instances did not represent 319 unique image-schematic metaphors due to possible duplicates of a single image-schematic metaphor at different locations. Specifically, 51 instances were image-schematic metaphors that were only found once in the data, while the remaining instances contained metaphors that were coded in multiple locations. In terms of older participants, 318 instances were coded and 42 of them appeared only once in the data.

### *5.4.3 Cross-group Consensus.*

*Highly Correlated Distributions of Image Schemas.* Image schemas from the category Space, Force and Multiplicity were used most often by both younger and older groups, followed by Containment, Attribute and Process (see Table 10). The only difference was that for the older group, category Force ranked second (rather than third, for the younger group) and Multiplicity ranked third (rather than second) (see Table 10).

The two age groups showed similar patterns in terms of the distribution of image schemas used. When considering image schemas that had at least one instantiation, we found a high correlation between the distributions of image schemas in the two age groups ($r$ (22) = 0.92, $p$ <0.001), as shown in Figure 10. For a limited number of image schemas, we observed remarkable differences in their usage frequency between the two age groups. The older group used more blockage and enablement, and the younger group used more bright-dark, in-out and big-small.

[3]https://dovetail.com/
[4]https://atlasti.com/

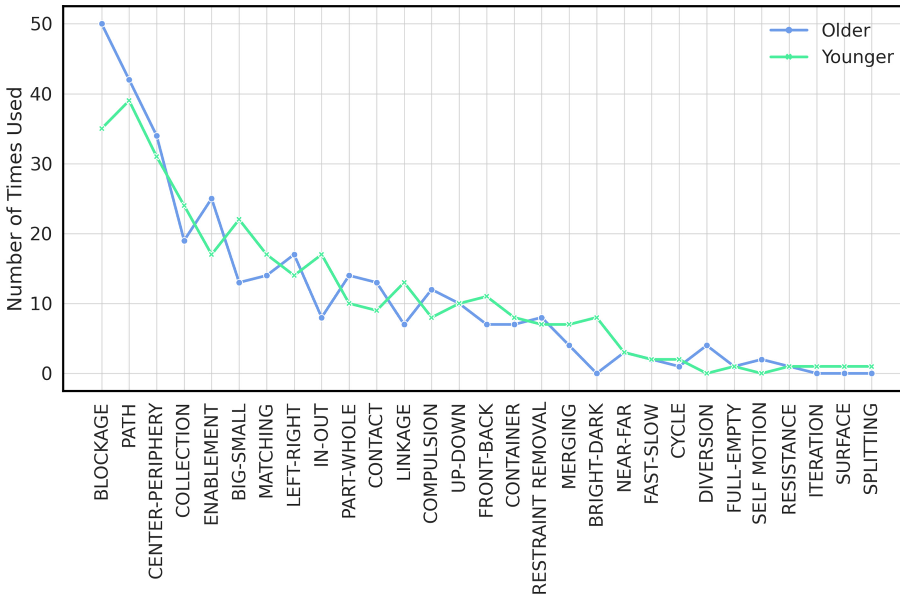



Fig. 10. Usage frequency of image schemas for both age groups.

*Almost-perfect Overlap of Image-schematic Metaphors.* This study extracted image-schematic metaphors from both spoken language and observation of behaviors. Although there were many ways to describe and understand these concepts (ISM-related or purely literal), we discovered similar image-schematic metaphors in the two age groups' language and behaviors, and found an almost-perfect overlap between image-schematic metaphors used by the two groups.

According to what Löffler et al. [73] suggest, we considered image-schematic metaphors with no fewer than two instances. Each participant could map a concept to any image schemas. However, repeated mappings between the same concept and the same image schema by one participant was considered a single instance.

For each concept, we calculated the *Observed Overlap* between the two age groups by dividing the total count of instances of shared metaphors by the overall count of metaphor instances recorded, using the following formula:

$$O = \sum_{C(M_i) \subseteq C(M)} \frac{C(M_i)}{C(M)},$$

where $C(M)$ is the count of all metaphor instances observed for a concept, and $C(M_i)$ is the total count of instances of a shared metaphor $i$. For example, for the concept "*System*," we collected $C(M) = 27$ image-schematic metaphors instances, of which 16 are "The structure of *System* is COLLECTION," used by both age groups; nine of them are "The structure of *System* is MERGING (different parts)," used by both age groups; two of them are "The form of *System* is CYCLE," only used by the younger group, i.e.,

$$C(M_1) = 16, C(M_2) = 9,$$

$$O = \frac{C(M_1)}{C(M)} + \frac{C(M_2)}{C(M)} = \frac{16}{27} + \frac{9}{27} = 0.93.$$

The study employed Cohen's Kappa score [70] to interpret the degree of overlap between the two age groups regarding image-schematic metaphors usage. This is because both overlap and Cohen's kappa score are related to how much two raters (or groups) concur in their categorizations. The formula for Cohen's kappa is

$$\kappa = \frac{p_o - p_e}{1 - p_e},$$

where $p_o$ represents the observed agreement, and $p_e$ represents the expected probability of chance agreement. Due to the extensive range of categories available for understanding a concept through any image schema, the chance agreement is significantly low, resulting in the Kappa score being close to the observed agreement. In this case, the observed agreement was an estimation of the actual agreement value. This allowed us to regard the *Observed Overlap* as a reasonable estimate of the actual degree of overlap.

Tables 12 and 13 present the overlap between image-schematic metaphors used by the two groups for each concept. The overall degree of overlap between both groups was calculated by taking the average of the 20 concepts' overlap values. An almost-perfect overlap of 0.83 (SD = 0.20) was found between image-schematic metaphors used by younger and older groups in their language and behavior.

Moreover, the most popular image-schematic metaphors were strongly shared between the two groups. For 17 of the 20 concepts, the most frequently used image-schematic metaphor was the same for both age groups. For the rest of the 20 concepts, the most frequently used image-schematic metaphor for one age group was the second-ranking image-schematic metaphor for the other age group.

*Interpretations of Some Less Direct Metaphors.* There are some image-schematic metaphors with a closer metaphorical distance or a less direct metaphorical mapping between the image schema and the target domain, which might be more difficult to interpret as a "metaphor" compared to the more direct ones. For example, "The form of *Barrier* is BLOCKAGE" might seem tautological, since every *Barrier* seems to be a physical blockage. However, unlike how we usually interpret the literal term "blockage," the image schema BLOCKAGE refers to a force dynamic in which "a force or a movement is physically or metaphorically stopped or redirected by an obstacle" [45]. As a result, this mapping is not tautological, since the image schema BLOCKAGE specifically refers to a force dynamic while a *Barrier* does not. Another less direct example is "Upward movement on *Button* is BIGGER." This image-schematic metaphor was identified in task 4 where users were asked to manipulate a button that can be pressed, held, clicked, or moved towards multiple directions to trigger the function of zooming in or out. The purpose of this sub-task was to investigate what relational structure or property of a *Button* would be mapped to the image schema BIG-SMALL. Specifically, all users moved their fingers upward on the *Button*'s responsive area to zoom in (BIG), and moved downward on the *Button*'s responsive area to zoom out (SMALL). The interpretation of this metaphor can be complicated by the fact that the observed behavior (upward movement on a *Button*) contained an image schema UP, so its mapping to BIG also revealed the relationship between two image schemas (UP and BIG). However, given that the objective of this research is to investigate the mappings between "the property/relational structure of an *Abstract Concept*" and an IMAGE SCHEMA, the observed behavior was coded as "Upward movement on *Button* is BIGGER." Table 11 provides interpretations for some of these less direct metaphors.

#### 5.4.4 *Differences in Usage Pattern.*

*Numbers of Different Image-schematic Metaphors that the Two Age Groups Relied on.* We measured how many different image-schematic metaphors were used by the two age groups to

Table 11. Interpretations of Some Less Direct Image-schematic Metaphors

| Image-schematic Metaphor | Interpretation |
|---|---|
| The form of *Barrier* is BLOCKAGE | The form of a barrier is a blocking force that stops or redirects an action attempted by a user. |
| Upward movement on *Button* is BIGGER | An upward movement within the responsive area of a button results in an increase in the size of specific system elements. |
| *Button* exerts COMPULSION to the system | Users compel a system to execute certain functions by pressing a button. |

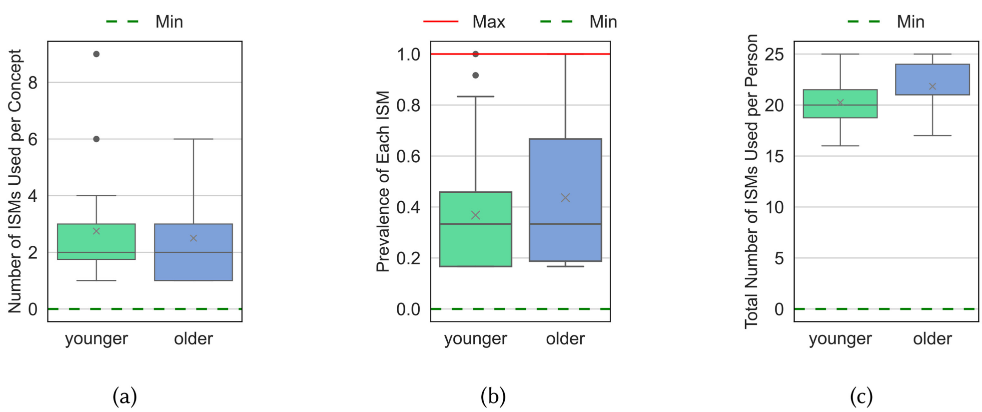



Fig. 11. Distribution of (a) number of image-schematic metaphors used by the two age groups per concept; (b) distribution of prevalence value of each image-schematic metaphor used by the two age groups; (c) total number of image-schematic metaphors used by the two age groups to comprehend the 20 concepts. The box plots show the median (the horizontal line), the mean ("×"), the first and third quartile (the box) and the minimum and maximum (the whiskers). The circle signs ("o") indicate outliers. The red sold line indicates the possible max value on the y axis and the green dashed line indicates the possible min value.

comprehend each concept and summarized the distributions in box plot as shown in Figure 11(a). The older group used 50 different image-schematic metaphors in total to describe the 20 concepts in the domain of technology learning. The mean number of different image-schematic metaphors used by the older group to comprehend one concept was 2.5 (SD = 1.50). While the younger group used 55 different image-schematic metaphors to describe the 20 concepts. The mean number of different image-schematic metaphors used by the younger group to comprehend one concept was 2.75 (SD = 1.94). The older group used slightly fewer types of image-schematic metaphors to comprehend concepts in the target domain compared to the younger group, but a Kruskal-Wallis test at a significance level of $\alpha = 0.05$ showed that the difference was not statistically significant ($\chi^2$ $(1, N = 40) = 0.1029$, $p = 0.7484$, $\eta^2 = 0.0026$).

*Average Prevalence Values of Image-schematic Metaphors.* Within both age groups, various image-schematic metaphors were employed by different individuals. Each image-schematic metaphor has a prevalence value within one age group, determined by calculating the percentage of group members who use it. For instance, if a metaphor is used by 70% of the younger group, then its prevalence within this group is 70%. We took the prevalence values of all image-schematic metaphors used

Table 12. Overlap between Age Groups in Metaphor Usage

| **Concept 1–10** | **Group** | **Instances** | **Shared ISMs** | **Total ISMs** | **Overlap** |
|---|---|---|---|---|---|
| *Functionality* | Older | Mismatch between *Functionality* and *Button* is BLOCKAGE (2)* | 6 | 10 | 0.60 |
| | | *Functionality* is ENABLEMENT to its users (2) | | | |
| | Younger | Mismatch between *Functionality* and *Button* is BLOCKAGE (4)* | | | |
| | | The form of *Functionality* is PATH (2) | | | |
| *Software* | Older | *Software* is ENABLEMENT to its users(3)* | 5 | 14 | 0.36 |
| | | The structure of *Software* is COLLECTION (3) | | | |
| | | The position of *Software* is DOWN (2) | | | |
| | Younger | *Software* is ENABLEMENT to its users (2)* | | | |
| | | The form of *Software* is LINKAGE (2) | | | |
| | | The position of *Software* is UP (2) | | | |
| *Button* | Older | Upward movement on *Button* is BIGGER (12)* | 48 | 57 | 0.84 |
| | | *Button* exerts COMPULSION to the system (10)* | | | |
| | | Mismatch between *Functionality* and *Button* is BLOCKAGE (2)* | | | |
| | | Information on *Button* and *Manual* is MATCHING (2) | | | |
| | Younger | Upward movement on *Button* is BIGGER (12)* | | | |
| | | *Button* exerts COMPULSION to the system (8)* | | | |
| | | Mismatch between *Functionality* and *Button* is BLOCKAGE (4)* | | | |
| | | The position of a key *Button* is FRONT (3) | | | |
| | | The function of a *Button* is LINKAGE (2) | | | |
| | | Important *Button* is BRIGHT (2) | | | |
| *Information* | Older | Extraneous *Information* is BLOCKAGE (4)* | 9 | 15 | 0.60 |
| | | *Information* is ENABLEMENT to its receiver (2) | | | |
| | Younger | Extraneous *Information* is BLOCKAGE (5)* | | | |
| | | The position of *Information* is OUT (4) | | | |
| *Problem* | Older | The form of *Problem* is BLOCKAGE (8)* | 14 | 14 | 1 |
| | Younger | The form of *Problem* is BLOCKAGE (6)* | | | |
| *Operation* | Older | The form of *Operation* is PATH (7)* | 13 | 15 | 0.87 |
| | Younger | The form of *Operation* is PATH (6)* | | | |
| | Younger | The structure of *Operation* is COLLECTION (2) | | | |
| *Barrier* | Older | The form of *Barrier* is BLOCKAGE (10)* | 20 | 20 | 1 |
| | Younger | The form of *Barrier* is BLOCKAGE (10)* | | | |
| *Manual* | Older | The position of *Manual* is CENTER-Task is PERIPHERY (7)* | 37 | 39 | 0.95 |
| | | The position of *Manual* is LEFT-Task is RIGHT (6)* | | | |
| | | The position of *Manual* is PERIPHERY-Task is CENTER (5)* | | | |
| | | The structure of *Manual* is COLLECTION (2)* | | | |
| | | The form of *Manual* is BLOCKAGE (2) | | | |
| | Younger | The position of *Manual* is CENTER-Task is PERIPHERY (9)* | | | |
| | | The structure of *Manual* is COLLECTION (4)* | | | |
| | | The position of *Manual* is LEFT-Task is RIGHT (2)* | | | |
| | | The position of *Manual* is PERIPHERY-Task is CENTER (2)* | | | |
| *Screen* | Older | The function of *Screen* is enabling CONTACT (3)* | 5 | 5 | 1 |
| | Younger | The function of *Screen* is enabling CONTACT (2)* | | | |
| *Interface* | Older | The function of *Interface* is enabling CONTACT (8)* | 26 | 26 | 1 |
| | | Different *Interfaces* is BLOCKAGE to task completion (4)* | | | |
| | | The form of *Interface* is LINKAGE (2)* | | | |
| | Younger | The function of *Interface* is enabling CONTACT (5)* | | | |
| | | The form of *Interface* is LINKAGE (5)* | | | |
| | | Different *Interfaces* is BLOCKAGE to task completion (2)* | | | |

The number of usage instances for each image-schematic metaphor is presented as (*n*). Image-schematic metaphors used by both younger and older groups are marked with an asterisk. For example, in the younger group, "*Software* is ENABLEMENT to its users (2)*" means that this image-schematic metaphor had two usage instances in the younger group and it was also used by the older group. Numbers in the column "Shared ISMs" show the count of instances of ISMs that are used by both age groups. Numbers in the column "Total ISMs" shows the total count of ISM usage instances found in the two age groups. In each image-schematic metaphor, the *Abstract Concept* is Italicized.

Table 13. Overlap between Age Groups in Metaphor Usage

| Concept 11–20 | Group | Instances | Shared ISMs | Total ISMs | Overlap |
|---|---|---|---|---|---|
| *Video Tutorial* | Older | The position of *Video Tutorial* is FAR-Task is NEAR (11)*<br>The position of *Video Tutorial* is PERIPHERY-Task is CENTER (11)*<br>The position of *Video Tutorial* is LEFT-Task is RIGHT (8)*<br>The form of *Video Tutorial* is PATH (6)*<br>The position of *Video Tutorial* is RIGHT - Task is LEFT (3)*<br>The motion of *Video Tutorial* is SELF MOTION (2) | 63 | 78 | 0.81 |
| | Younger | The position of *Video Tutorial* is PERIPHERY-Task is CENTER (8)*<br>The position of *Video Tutorial* is RIGHT-Task is LEFT (5)*<br>The position of *Video Tutorial* is LEFT-Task is RIGHT (5)*<br>The form of *Video Tutorial* is COLLECTION (4)<br>The form of *Video Tutorial* is PATH (4)*<br>The size of *Video Tutorial* is SMALL-Task is BIG (3)<br>The size of *Video Tutorial* is BIG-Task is SMALL (3)<br>The position of *Video Tutorial* is BACK-Task is FRONT (3)<br>The position of *Video Tutorial* is FAR-Task is NEAR (2)* | | | |
| *System* | Older | The structure of *System* is COLLECTION (6)*<br>The structure of *System* is MERGING (different parts) (2)* | 25 | 27 | 0.93 |
| | Younger | The structure of *System* is COLLECTION (10)*<br>The structure of *System* is MERGING (different parts) (7)*<br>The form of *System* is CYCLE (2) | | | |
| *Option* | Older | Providing *Option* is ENABLEMENT to users (3)* | 5 | 8 | 0.63 |
| | Younger | The form of *Option* is PATH (3)<br>Providing *Option* is ENABLEMENT to users (2)* | | | |
| *Search* | Older | The form of *Search* is PATH (4)*<br>*Search* is DIVERSION from ongoing task (3) | 7 | 10 | 0.70 |
| | Younger | The form of *Search* is PATH (3)* | | | |
| *Learning* | Older | *Learning* is MATCHING (with examples) (11)*<br>The form of *Learning* is taking IN (new things)(6)*<br>The form of *Learning* is PATH (5)* | 41 | 41 | 1 |
| | Younger | *Learning* is MATCHING (with examples) (11)*<br>The form of *Learning* is taking IN (new things) (5)*<br>The form of *Learning* is PATH (4)* | | | |
| *Control Panel* | Older | The form of *Control Panel* is COLLECTION (3)*<br>The function of *Control Panel* is enabling CONTACT (2) | 6 | 11 | 0.55 |
| | Younger | The form of *Control Panel* is COLLECTION (3)*<br>The position of *Control Panel* is CENTER (3) | | | |
| *Step* | Older | Missing *Step* is BLOCKAGE (11)*<br>The form of *Step* is PART (9)*<br>The form of *Step* is PATH (4)* | 35 | 35 | 1 |
| | Younger | The form of *Step* is PART (7)*<br>Missing *Step* is BLOCKAGE (2)*<br>The form of *Step* is PATH (2)* | | | |
| *Logic* | Older | The form of *Logic* is PATH (9)* | 15 | 15 | 1 |
| | Younger | The form of *Logic* is PATH (6)* | | | |
| *Information Hierarchy* | Older | Important *Information* is CENTER (12)*<br>General *Information* is UP-Detailed *Information* is DOWN (4)*<br>The position of Hidden *Information* is DOWN (3)*<br>The form of *Information Hierarchy* is PATH (3)<br>*Information Hierarchy* is ENABLEMENT to users (2) | 34 | 41 | 0.83 |
| | Younger | Important *Information* is CENTER (9)*<br>General *Information* is UP-Detailed *Information* is DOWN (4)*<br>The position of Hidden *Information* is DOWN (2)*<br>Important *Information* is BRIGHT (2) | | | |
| *Assistance* | Older | *Assistance* is RESTRAINT REMOVAL for users (8)*<br>*Assistance* is ENABLEMENT to users (3)* | 23 | 23 | 1 |
| | Younger | *Assistance* is ENABLEMENT to users (7)*<br>*Assistance* is RESTRAINT REMOVAL for users (5)* | | | |

The number of usage instances for each image-schematic metaphor is presented as (*n*). Image-schematic metaphors used by both younger and older groups are marked with an asterisk. For example, in the old group, "The structure of *System* is COLLECTION (6)*" means that this image-schematic metaphor had six usage instances in the older group and it was also used by the younger group. Numbers in the column "Shared ISMs" show the count of instances of ISMs that are used by both age groups. Numbers in the column "Total ISMs" shows the total count of ISM usage instances found in the two age groups. In each image-schematic metaphor, the *Abstract Concept* is Italicized.

within an age group and calculated their average. The resultant average prevalence served as an indicator of each age group's consensus towards metaphor usage. A higher average prevalence suggests a more uniform engagement with these metaphors within the age group. Figure 11(b) showed the distributions of prevalence values of image-schematic metaphors in the two age groups. In the older group, the used image-schematic metaphors demonstrated an average prevalence value of 0.44 (SD = 0.27). In the younger group, the used image-schematic metaphors demonstrated an average prevalence value of 0.37 (SD = 0.22). The average prevalence of used image-schematic metaphors in the older group was higher than that in the younger group, but a Kruskal-Wallis test at a significance level of $\alpha = 0.05$ showed that the difference was not statistically significant ($\chi^2$ (1, $N = 105$) = 1.1886, $p = 0.2756$, $\eta^2 = 0.0114$).

*Total Numbers of Image-schematic Metaphors Each Participant Used in This Study.* On an individual level, the mean number of image-schematic metaphors used by each older participant in this study is 21.83 (SD = 2.44); the mean number of image-schematic metaphors used by each younger participant is 20.25 (SD = 2.60). The distributions were shown in Figure 11(c). An older participant on average used more image-schematic metaphors in the domain of technology learning, but a Kruskal-Wallis test at a significance level of $\alpha = 0.05$ showed that the difference was not statistically significant ($\chi^2$ (1, $N = 24$) = 2.6966, $p = 0.1006$, $\eta^2 = 0.1172$).

On the three dimensions of usage pattern we measured, no statistically significant difference was found between the two age groups.

*5.4.5 Image-schematic Metaphors with High Prevalence.* This study identified 37 image-schematic metaphors used by both age groups, as detailed in Table 15. This table also outlines the prevalence of these metaphors across all 24 participants, within both the younger and older groups. A prevalence value ranging from 0.61 to 1 within a group signifies a substantial level of agreement among group members regarding the decision of using this metaphor. Hence, a metaphor demonstrating a prevalence value between 0.61 and 1 in a user group is considered to be commonly adopted. There were 10 image-schematic metaphors with a high prevalence (0.61–1) among all 24 participants, as shown in Table 14.

*5.4.6 Sources of Image-schematic Metaphors.* As shown in Table 15, among the 10 image-schematic metaphors with high prevalence across all participants, five of them were extracted only from observation of behaviors, including "Upward movement on *Button* is BIGGER," "*Learning* is MATCHING (with examples)," "Important *Information* is CENTER," "The position of *Video Tutorial* is PERIPHERY - Task is CENTER," and "The position of *Manual* is CENTER—Task is PERIPHERY." One of them appeared in both participants' language and behaviors, which is "*Button* exerts COMPULSION to the system." Four of them were extracted only from language, including "The form of *Barrier* is BLOCKAGE," "The form of *Step* is PART," "The structure of *System* is COLLECTION," "The form of *Logic* is PATH." We identified 6 of the 10 image-schematic metaphors with high prevalence from observation of behaviors, and half of these 10 metaphors were found only in observation of behaviors.

Among all 37 shared image-schematic metaphors shown in Table 15, we found that 13 of them were identified only from observation of behaviors, 20 of them were identified only from spoken language, and four of them were found in both spoken language and observation of behaviors.

## 6 DISCUSSION

By analyzing the obtained data, we elicited image-schematic metaphors from younger and older adults' language and behaviors in the context of technology learning, and find an almost-perfect overlap between metaphors used by the two age groups. Thus, image schemas can potentially be

Table 14. Interpretations of Image-schematic Metaphors with a High Prevalence (0.61–1) Across All Participants

| Image-schematic Metaphor | Interpretation |
|---|---|
| Upward movement on *Button* is BIGGER | An upward movement within the responsive area of a button results in an increase in the size of specific system elements. |
| *Learning* is MATCHING (with examples) | Users learn by matching their actions to what the instructions indicate. |
| Important *Information* is CENTER | Important information should be located at the center. |
| The position of *Video Tutorial* is PERIPHERY - Task is CENTER | Video Tutorial should be located at the periphery. |
| The position of *Manual* is CENTER - Task is PERIPHERY | Instruction manual should be located at the center. |
| *Button* exerts COMPULSION to the system | Users compel a system to execute certain functions by pressing a button. |
| The form of *Barrier* is BLOCKAGE | The form of a barrier is a blocking force that stops an action attempted by a user. |
| The form of *Step* is PART | The form of a step is presented as one part of a whole with parts arranged in a particular fashion. |
| The structure of *System* is COLLECTION | A system is structured as a collection that consists of several objects that are similar, autonomous, and neighboring each other in space. |
| The form of *Logic* is PATH | The form of logic is a path that consists of a starting point, an end-point, and a sequence of contiguous locations connecting the starting point with the end-point. |

In each image-schematic metaphor, the *Abstract Concept* is italicized.

leveraged as a form of age-inclusive prior knowledge to make digital technologies easy to learn and use for both younger and older users. In our study, the two age groups showed highly similar usage patterns of image-schematic metaphors with no statistically significant differences found. Despite the similarity, we observe that the older group demonstrated a slightly more uniform engagement with image-schematic metaphors compared to the younger group. To guide future design, this study provided a set of shared image-schematic metaphors relevant to the technology learning domain. Our empirical analysis offered insights on the design of protocols for eliciting image-schematic metaphors; augmenting the established language elicitation protocol with a behavior observation method is recommended in the interest of identifying highly prevalent image-schematic metaphors. This section elaborates on these findings and contextualizes the opportunities for employing the image schema method in the design of age-inclusive interactive systems.

### 6.1 High Cross-group Consensus

The two age groups showed highly similar patterns in the distributions of image schemas they used. This finding is consistent with what Johnson [53] predicted. Remarkable differences in usage frequency between age groups were only seen for a small number of image schemas. BLOCKAGE was used more frequently by the older group, potentially because they encountered more obstacles when learning technologies compared to their younger counterparts. This might correspond with older adults using more ENABLEMENT, which usually emerges at the absence or removal of BLOCKAGE. The younger group used more IN-OUT, BRIGHT-DARK, and BIG-SMALL, possibly as a result of the widespread usage of these image schemas as design languages in everyday interactive systems. The younger group can be more familiar with these image schemas as they were found to be more exposed to general technologies.

For both age groups alike, in the context of technology learning, the most frequently used image schema category was SPACE. This finding highlights an interesting divergence from prior studies.

Table 15. List of Shared Image-schematic Metaphors

| Prevalence-Overall | Shared Image-schematic Metaphors | Context | Source | Prevalence-Older | Prevalence-Younger |
|---|---|---|---|---|---|
| 100.00%* | Upward movement on *Button* is BIGGER* | Task 4 | B | 100.00% | 100.00% |
| 91.67%* | *Learning* is MATCHING (with examples)* | Task 3, 4 | B | 91.67% | 91.67% |
| 87.50%* | Important *Information* is CENTER* | Task 2 | B | 100.00% | 75.00% |
| 83.33%* | The form of *Barrier* is BLOCKAGE* | Interviews | L | 83.33% | 83.33% |
| 79.17%* | The position of *Video Tutorial* is PERIPHERY - Task is CENTER* | Task 3 | B | 91.67% | 66.67% |
| 75.00%* | *Button* exerts COMPULSION to the system* | Interviews; Task 4 | L, B | 83.33% | 66.67% |
| 66.67%* | The form of *Step* is PART* | Interviews | L | 75.00% | 58.33% |
| 66.67%* | The position of *Manual* is CENTER - Task is PERIPHERY* | Task 4 | B | 58.33% | 75.00% |
| 66.67%* | The structure of *System* is COLLECTION* | Interviews | L | 50.00% | 83.33% |
| 62.50%* | The form of *Logic* is PATH* | Interviews | L | 75.00% | 50.00% |
| 58.33% | The form of *Problem* is BLOCKAGE | Interviews; Task 2 | L, B | 66.67% | 50.00% |
| 54.17% | The form of *Operation* is PATH | Interviews; Task 2 | L | 58.33% | 50.00% |
| 54.17% | The position of *Video Tutorial* is LEFT - Task is RIGHT | Task 3 | B | 66.67% | 41.67% |
| 54.17% | The position of *Video Tutorial* is FAR - Task is NEAR | Task 3 | B | 91.67% | 16.67% |
| 54.17% | Missing *Step* is BLOCKAGE | Task 3, 4 | L, B | 91.67% | 16.67% |
| 54.17% | The function of *Interface* is enabling CONTACT | Interviews | L | 66.67% | 41.67% |
| 54.17% | *Assistance* is RESTRAINT REMOVAL for users | Task 2 | B | 66.67% | 41.67% |
| 45.83% | *Learning* is taking IN (new things) | Interviews | L | 50.00% | 41.67% |
| 41.67% | The form of *Video Tutorial* is PATH | Interviews; Task 3 | L | 50.00% | 33.33% |
| 41.67% | *Assistance* is ENABLEMENT to users | Interviews; Task 2 | L | 25.00% | 58.33% |
| 37.50% | The structure of *System* is MERGING (different parts) | Interviews | L | 16.67% | 58.33% |
| 37.50% | Extraneous *Information* is BLOCKAGE | Task 1 | L | 33.33% | 41.67% |
| 33.33% | General *Information* is UP - Detailed *Information* is DOWN | Interviews; Task 4 | L | 33.33% | 33.33% |
| 33.33% | The position of *Video Tutorial* is RIGHT - Task is LEFT | Task 3 | B | 25.00% | 41.67% |
| 33.33% | The position of *Manual* is LEFT - Task is RIGHT | Task 4 | B | 50.00% | 16.67% |
| 29.17% | The position of *Manual* is PERIPHERY - Task is CENTER | Task 4 | B | 41.67% | 16.67% |
| 29.17% | The form of *Interface* is LINKAGE | Interviews | L | 16.67% | 41.67% |
| 29.17% | The form of *Search* is PATH | Interviews | L | 33.33% | 25.00% |
| 25.00% | The form of *Step* is PATH | Interviews | L | 33.33% | 16.67% |
| 25.00% | The structure of *Manual* is COLLECTION | Interviews | L | 16.67% | 33.33% |
| 25.00% | Different *Interfaces* is BLOCKAGE to task completion | Task 3, 4 | L, B | 33.33% | 16.67% |
| 25.00% | Mismatch between *Functionality* and *Button* is BLOCKAGE | Task 4 | B | 16.67% | 33.33% |
| 25.00% | The structure of *Control Panel* is COLLECTION | Interviews | L | 25.00% | 25.00% |
| 20.83% | The position of Hidden *Information* is DOWN | Task 1 | B | 25.00% | 16.67% |
| 20.83% | *Software* is ENABLEMENT to its users | Interviews | L | 25.00% | 16.67% |
| 20.83% | The function of *Screen* is enabling CONTACT | Interviews | L | 25.00% | 16.67% |
| 20.83% | Providing *Option* is ENABLEMENT to users | Interviews;Task 1, 2, 4 | L | 25.00% | 16.67% |

Image-schematic metaphors with a high prevalence across all participants were marked with an asterisk(*). In the "Source" column, "L" means this metaphor was found in language, and "B" means this metaphors was found in interaction behaviors. In each image-schematic metaphor, the *Abstract Concept* is Italicized.

Cafaro et al. [17] suggest that the majority of image schemas employed by mixed-ability workers are within the FORCE category, and Blackler et al. [12] find that a feature's appearance was more important than its location in fostering correct and intuitive use. However, our finding is in line with previous work suggesting that spatial image-schematic metaphors may be easier to understand [3] and Antle et al.'s [4] recommendations about focusing on SPACE image schemas in informal learning settings. Our finding is also supported by research that investigates the contribution of spatial image schemas in abstract reasoning. It aligns with Hummel and Holyoak's [41] findings that spatial image schemas play a significant role in reasoning via transitive inference and Gattis's [29] suggestion that the comprehension of all types of relations involves spatial schemas. We argue that the SPACE image-schematic structures could be the most preferred cognitive structure for both age groups to comprehend unfamiliar concepts when learning new technologies. When representing new concepts in novel interactions or interfaces unfamiliar to users, it could be beneficial for designers to prioritise image schemas in the SPACE category to construct their design. For example, placing an important button at the CENTER of the view (using image schema CENTER in the SPACE category) could be more efficient than making it BRIGHTER in color (using image schema BRIGHT in the ATTRIBUTE category).

The two age groups demonstrated an almost-perfect overlap in terms of image-schematic metaphors found in their spoken language and behaviors. Our findings are similar to those of Tscharn [96], who observed a substantial agreement between younger and older individuals in the use of image-schematic metaphors in their spoken language in the context of online banking. However, our study used a more comprehensive set of image-schematic metaphors derived from a combined source (language and observation of behaviors), which resulted in a higher level of overlap. Moreover, the application domain in which we conducted our investigation was different to that used in the study conducted by Tscharn [96], suggesting high cross-group consensus in image-schematic metaphors usage across various domains. To further substantiate the theory, replication of this study in different domains would be desirable.

However, our results contrast with arguments in the literature proposing that people may face a decline in their ability of using and comprehending metaphors as they age due to age-related decline in working memory resource and fluid intelligence [16, 37, 51]. In our study, no significant difference was found between the total number of image-schematic metaphors used by an older participant and a younger participant. On average, older participants even used slightly more image-schematic metaphors than younger participants. Furthermore, the almost-perfect overlap observed between image-schematic metaphors employed by both age groups suggests that older adults use image schemas to generate metaphorical extensions in a manner that is highly similar to their younger counterparts. Our study did not detect any decline in the ability to use image-schematic metaphors associated with aging. A possible explanation is that while image-schematic metaphors are a specific type of conceptual metaphor, they do not appear to consume working memory resources to the same extent as most other conceptual metaphors. According to Mandler [80], image schemas are stored in long-term memory below the level of conscious awareness, and their activation occurs at the subconscious level, requiring minimal cognitive effort. Therefore, activating the use of an image-schematic metaphor can be less cognitively demanding than invoking a typical conceptual metaphor. Our study did not explicitly incorporate fluid intelligence as a variable; rather, we used age as a proxy. Future research should explore whether the use of image-schematic metaphors is indeed less sensitive to differences in fluid intelligence than the use of conventional conceptual metaphors.

Contrary to a suggestion in Jung et al. [57], this study did not find that differences in individual experiences significantly impacted the use of image-schematic metaphors. Overall, the two age groups with significantly different technological experience showed very high agreement in their use of image-schematic metaphors. We only detected very limited instances when the two groups disagreed on some of their image-schematic conception of a certain concept. For example, to comprehend concept "*Software*," both age groups agreed to use the metaphor "*Software* is ENABLEMENT to its users." But a small number of the younger participants also used "The position of *Software* is UP and "*Software* is CONTACT" (e.g., "*Software* is the instructions programmed on TOP of hardware."), while some of the older participants used "The position of *Software* is DOWN" (e.g., "*Software* is the UNDERLYING instructions that enable the functionality to be delivered."). It is possible that this difference in spatial conception is related to different experiences these participants have with *Software*. While the majority of metaphors are shared between two groups, a very small number of non-shared metaphors may be influenced by other factors, such as personal experiences, domain knowledge, or attentional focus, which are distinct from the shared sensorimotor experiences. An intriguing avenue for future research is to examine which types of image-schematic metaphors are solely derived from sensorimotor experiences and are capable of overriding the influence of other factors, such as cultural convention [21, 92] or individual attentional focus [21].

Overall, the younger and older groups exhibited high consensus in their use of image-schematic metaphors in the technology learning domain. Therefore, image-schematic metaphors could serve as an effective foundation for creating interactive systems that are easy to learn and use for users of all ages.

### 6.2 Usage Patterns

We investigated differences in usage patterns between the two age groups on three dimensions: types of different image-schematic metaphors they used to comprehend the target domain, prevalence value of image-schematic metaphors used by the two groups, and individual usage frequency of image-schematic metaphors. No statistically significant difference was found on any of these dimensions. The results indicate that the two groups were highly similar in terms of usage patterns. However, there are still observable differences in our sample. The older group demonstrated a slightly more uniform engagement with image-schematic metaphors compared to the younger group. Even when an older adult used more image-schematic metaphors to comprehend the target domain than a younger adult, they used fewer types of image-schematic metaphors, because more agreements occurred within the older group in terms of which metaphors to use. Although our sample shows small differences, it is likely that these differences are due to the small sample size and could be attributed to noise.

There could be other possible explanations why older people showed a slightly more uniform engagement with image-schematic metaphors compared to younger people. One possibility is that the constant encoding and retrieval of image-schematic metaphors results in greater robustness of information processing [42]. On this account, people develop a stronger, shared preference for a certain set of image-schematic metaphors as they age, because older people have spent more time repeatedly activating and reinforcing the image-schematic metaphors they have formed. Additionally, older adults may have a more stable and established way of behaving, thinking, and communicating, which could also contribute to a higher degree of uniformity in image-schematic metaphor usage. These are interesting hypotheses that could be investigated further.

### 6.3 Potentials Of Image-schematic Metaphors as a Design Tool

To support the design of age-inclusive interactive systems in the context of technology learning, this study provided a list of image-schematic metaphors shared between two age groups. We found 37 shared image-schematic metaphors, ten of them have a high prevalence value (0.61–1) among all participants (see Table 15). Integrating image-schematic metaphors with high prevalence in the design of interactive systems could be highly advantageous in enhancing learnability and usability for both younger and older users. Other image-schematic metaphors with a moderate or fair prevalence (0.21–0.60) may be used to support design decisions as alternatives or redundancies.

The set of shared image-schematic metaphors has the potential to reshape how the HCI community perceives metaphors as a design tool. We find that the image-schematic metaphors identified in this study effectively address the limitations of conventional interface metaphors. In contrast to Alty et al.'s [2] concern regarding the lack of specific metaphorical mappings, image-schematic metaphors we identified clearly and precisely demonstrate the resemblance between a characteristic of an *abstract concept* (e.g., the position of a *video tutorial*) and an image schema (e.g., PERIPHERY) without introducing any unnecessary mappings that might complicate the system design. Reacting to the issues Nelson [84] raised about the tenuous resemblance between computational concepts and real-world objects (e.g., Microsoft Bob's representation of user sign-in through the action of clicking on a door knocker), the set of shared image-schematic metaphors we identified exhibit a strong resemblance between the source and target domains. This is evidenced by these metaphors' robustness in overriding individual differences across both age groups, indicating their recognizability across a wide range of demographics. In response to the concern expressed by Jung et al. [56] about the design of digital concepts being constrained by the detailed features of their physical counterparts, the source domains (e.g., COLLECTION, PATH) in the image-schematic metaphors we identified are abstract enough to be instantiated in various ways, allowing for greater flexibility in design.

In HCI design practice, shared image-schematic metaphors identified in this study has the potential to benefit the design of interactive systems in the following ways. The set of shared image-schematic metaphors can offer concrete design guidance for different elements of an interactive system. For example, interaction techniques (e.g, Upward movement on *Button* is BIGGER), spatial organizations (e.g., The position of *Video Tutorial* is PERIPHERY—Task is CENTER), visualizations (e.g., The form of *Logic* is PATH), and information hierarchy (e.g., Hidden *Information* is DOWN). For example, "Upward movement on *Button* is BIGGER" represents an interaction behavior where users engage with a button and execute an upward movement within the responsive area of a *Button*. This behavior is expected to result in an increase in the size of specific system elements controlled by the *Button*. This overcomes a limitation of some inclusive design guidelines that offer higher-level design principles and recommendations [23, 58], which may not help designers to make lower-level design decisions.

Image-schematic metaphors related to FORCE may have a less direct application than other image-schematic metaphors. However, they can be very good at helping designers to design the relationship between two components, because FORCE image schemas typically represent the force dynamic between two entities. For example, "*Software* is ENABLEMENT to its users" can be used in the design of smart hardware that necessities some form of software interaction (e.g., scanning the QR code on the screen of a delivery robot ENABLES users to unlock the compartment and get their food orders).

Furthermore, image-schematic metaphors could be a promising method in novel interaction design. When interacting with novel technologies, all users will be novices with limited relevant prior technological knowledge to draw from. For example, users who are accustomed to mouse-and-keyboard interactions may not find their prior technological knowledge useful while learning to use an eye-gaze-based system. The integration of shared image-schematic metaphors should provide a reliable source of technology-independent prior knowledge for all users to leverage.

### 6.4 Recommendations on Elicitation Protocols

Among all shared image-schematic metaphors, 35% were found only in observation of behaviors (observational ISMs), 54% were found only in spoken language (linguistic ISMs), and 11% were found in both observation of behaviors and spoken language. For each target concept, the observational ISMs and linguistic ISMs actually complement each other rather than contradicting, as they describe different properties or relational structures within the target concept. For example, the observational ISM "The position of *Video Tutorial* is PERIPHERY" describes position and the linguistic ISM "The form of *Video Tutorial* is PATH" describes form. We demonstrate that while most shared image-schematic metaphors can be identified in spoken language, the integration of a behavior observation method can result in a more comprehensive elicitation result.

Among the highly prevalent image-schematic metaphors, 50% were found only in observation of behaviors, including "Upward movement on *Button* is BIGGER," "The position of *Manual* is CENTER," "The position of *Video Tutorial* is PERIPHERY," "*Learning* is MATCHING (with examples)," and "Important *Information* is CENTER," 40% were found only in spoken language (linguistic ISMs), and 10% were found in both observation of behaviors and spoken language. It is important to note that the above observational metaphors with a high prevalence were not due to users subjectively describing a predetermined interface design (e.g., all users referred to the *Video Tutorial* as PERIPHERY, simply because it was positioned in a corner and immovable). Instead, they were observations of users' behaviors when they were given the freedom of choice (e.g., users had the flexibility to place the *Video Tutorial* anywhere, and they chose to put it in the PERIPHERY).

We demonstrate that augmenting the language elicitation protocol with a behavior observation method was beneficial for the identification of highly prevalent image-schematic metaphors. Additionally, the image-schematic metaphors derived from the observation of behaviors are highly valuable for offering tangible directions to the design of interactive systems. These image-schematic metaphors capture spatial information that indicates how a concept and its related elements dynamically interact to constitute the whole system, and also provide insights into how someone might interact with these concepts.

While it is common practice in image-schematic metaphor elicitation studies to rely solely on spoken language as a source [49, 50, 74, 96, 102, 103], we argue that this approach has limitations, as it may capture incomplete mental representations and overlook valuable information that is only perceptible through observation of behaviors. Therefore, we suggest that interactive system design projects that elicit image-schematic metaphors for inclusive design support, should incorporate both observation of behaviors and spoken language as a combined source. This integration is intended to produce more accurate, comprehensive, and useful mental representations, without losing valuable spatial information stored in image-schematic metaphors that are only discernible in people's behaviors.

### 6.5 Limitations and Future Work

Our sample of older adults included only the "young-old" and did not cover the "old-old" [1]. It is important for future studies to expand the demographics, covering the "old-old" for a more comprehensive analysis.

In addition to age, other variables such as educational attainment and language, may impact people's use of image schematic metaphors. This research project aimed to explore whether there is a substantial overlap between younger and older adults' use of image-schematic metaphors. Hence, we must rule out any potential effects of language and educational attainment, which were not age-related. To do this, we recruited individuals using a *Matched Sampling* method [93]. All participants were English speakers. Each older participant was matched with a younger participant with the same educational attainment level. Younger and older participants in the study were all highly educated, with the majority holding a postgraduate degree and the remainder an undergraduate degree. Word production and other cognitive functions may be influenced by the participants' levels of educational attainment. As such, replication of this project among participants with varying educational levels would be desirable.

Prior research has challenged the universality of image-schematic metaphors across different cultures and languages. For instance, Casasanto et al.'s [18] corpus search results show that in English and Indonesian, the "time on a line" metaphor (e.g., long time) was significantly more frequently used than the "time in a bottle" (e.g., much time) metaphor; while in Greek and Spanish, the "time in a bottle" metaphor (e.g., much time) was more frequently used. Our study was conducted with English speakers only, so the shared image-schematic metaphors revealed in this study may lose some of their universality if applied in other cultures or languages. Replication of this project with participants across different cultures would be desirable, but we note that prior research demonstrates that the majority of metaphors are common across languages [62, 85].

We conducted Study 2 with 12 younger and 12 older participants. Rather than continuously evaluating the adequacy of the sample size throughout the study using the concept of saturation [32], we determined our sample size prior to data collection according to sample size recommendations proposed by researchers who operationalized saturation in the context of cultural consensus studies [7, 91] and interview studies that adopt non-probabilistic sampling methods [35]. We made this decision, because the conventional saturation criterion that compares every new observation to the previous analysis and only stops adding new participants till no new information or themes are observed could be extremely effortful due to the significant workload associated with image-schematic metaphor elicitation and matched sampling. Additionally, this work is investigating the proportion of shared image-schematic metaphors among all used image-schematic metaphors. A new participant could introduce new (non-shared) image-schematic metaphors and meanwhile also introduce recurring (shared) image-schematic metaphors. Hence, adding new participants might indeed continue to introduce new "information," but might not necessarily change the level of overlap. Moreover, the quantitative analysis in Study 2 addressed a large number of themes coded from qualitative data with the current sample size (637 themes in total). We believe that we have collected sufficient data to permit statistical analysis. However, replication of this project that continuously appraises the adequacy of its sample size, strictly following the saturation principle would be desirable.

In Section 5.3.2, we reported that a double-coding methodology was employed to test the reliability of our coding. One coder independently coded the entire dataset, while another coder independently coded a representative subset, comprising 25% of the data. Ideally, the entire dataset should be double coded by both coders. However, we expect the inter-coder agreement score computed for the subset to generalize to the entire dataset. This is because the subset included 25% of instances from each of the six image schema categories that make up the entire dataset, ensuring a representative sample.

## 7 CONCLUSION

This study contributes to the growing body of work that investigates the use of image schema theory in guiding the design of age-inclusive interactive systems. This is the first time that an almost perfect overlap has been demonstrated between the younger and older groups in terms of the image-schematic metaphors they use in their spoken language and interaction behaviors, despite the differences in prior technological knowledge between the two groups. The results suggest that using image-schematic metaphors as a foundation can be a valuable strategy when designing novel and age-inclusive interactive systems.

To support future design of age-inclusive interactive systems, this work has provided a set of 37 universal image-schematic metaphors in the domain of technology learning. A promising avenue of future work is to apply this set of universal image-schematic metaphors to guide system design in the domain of technology learning, and evaluate user performances across age groups. For instance, the authors' next step would be to use these universal metaphors to enhance the design of Mixed Reality interactions, and explore how the integration of these metaphors impacts how users of different ages learn and use this novel interaction technique. This is the first research targeting a comprehensive identification of universal image-schematic metaphors that could function as inclusive design guidelines in the technology learning domain. We believe the enhanced elicitation protocol presented in this work is transferable to different application areas. This could enable the identification of universal image-schematic metaphors, providing inclusive design support for interactive systems in a wide array of contexts beyond just technology learning.

Given the strong correspondence observed across age groups in this study, the proposed image-schematic metaphor approach appears well-suited to promoting the adoption of new interactive systems among both younger and older users and reducing the digital divide. In particular, when more novel interaction techniques emerge, image-schematic metaphors can be a promising alternative to obtain age-independent user inputs that are meanwhile unbiased and unconstrained by knowledge of existing interaction paradigms.

# A APPENDIX

## A.1 Interview Questions in Study 1

This interview aims to understand your experience of using the following four types of interactive systems:

### *A.1.1 Category 1: Integrated Products (e.g., Smart Thermostats, Smart Speakers).*

(1) In the category of home smart interactive products, which product do you think is particularly easy to learn and use?
(2) What do you usually use the above-mentioned product for?
(3) Please describe the process of using this product to complete a task.
(4) Is there any smart home product that you find particularly difficult to use and encounter many obstacles when you use it for the first time?
(5) What kind of difficulties did you encounter when using that product? Can you give a specific example?
(6) Were you able to come up with a solution at that time? If yes, how did you solve it?

### *A.1.2 Public Devices (e.g., Bank ATMs, Ticketing Machines).*

(1) In the category of public devices, which product do you think is particularly easy to learn and use?
(2) What do you usually use the above-mentioned device for?
(3) Please describe the process of using this device to complete a task.
(4) Is there any public device that you find particularly difficult to use and encounter many obstacles when you use it for the first time?
(5) What kind of difficulties did you encounter when using that device? Can you give a specific example?
(6) Were you able to come up with a solution at that time? If yes, how did you solve it?

### *A.1.3 Category 3: Mobile Applications (e.g., Teams App, Slack App).*

(1) In the category of moblie applications, which application do you think is particularly easy to learn and use?
(2) What do you usually use the above-mentioned product for?
(3) Please describe the process of using this system to complete a task.
(4) Is there any mobile application that you find particularly difficult to use and encounter many obstacles when you use it for the first time?
(5) What kind of difficulties did you encounter when using that product? Can you give a specific example?
(6) Were you able to come up with a solution at that time? If yes, how did you solve it?

### *A.1.4 Category 4: Desktop Applications (e.g., Solidworks).*

(1) In the category of computer software, which application do you think is particularly easy to learn and use?
(2) What do you usually use the above-mentioned application for?
(3) Please describe the process of using this product to complete a task.
(4) Is there any application that you find particularly difficult to use and encounter many obstacles when you use it for the first time?
(5) What kind of difficulties did you encounter when using that application? Can you give a specific example?
(6) Were you able to come up with a solution at that time? If yes, how did you solve it?

We have discussed your experience and obstacles you encountered in using these four categories of electronic interactive products. Next, we will discuss the following questions:

(1) Among the four types of interactive systems, which type in general do you think is the easiest to learn and use? Why?
(2) Among the four types interactive systems, which type in general do you think is the most difficult to learn and use? Why?
(3) When encountering obstacles in the use of these interactive systems, what methods do you usually take to solve these obstacles? Please give an example of the three methods you usually use and rank these methods based on your preference.

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