



Co-Designing Autonomous Vehicle Interfaces to Mimic a Trusted Human Driver

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ABSTRACT

To increase public acceptance of autonomous vehicles (AVs), HCI researchers have explored interaction designs that foster user trust. This article introduces a novel concept: designing AV interfaces to mimic the social presence and behavioral traits of an experienced, attentive human driver, leveraging people's greater trust in such drivers over opaque automation. To investigate this idea, we conducted two co-design workshops. Using the Annotated Portfolio method, we derived design annotations from visual artifacts (e.g., prototype photos and sketches), which were analyzed alongside workshop transcripts through Reflexive Thematic Analysis (RTA). We present design guidelines for AV interfaces that embody a trustworthy human driver, including: (1) proactive multimodal communication of situational awareness; (2) use of a driving agent (robotic, virtual, vocal, or spatial); (3) gradual development of human–AV companionship; and (4) personalization to foster familiarity and trust. Methodologically, we demonstrate integrating Annotated Portfolios and RTA to generate design insights.

KEYWORDS

Autonomous vehicle; co-design; human-vehicle interaction; reflexive thematic analysis; annotated portfolio

1. Introduction

The emergence of Autonomous Vehicles (AVs) has captured significant attention within transportation and artificial intelligence research, propelled by breakthroughs in AI and sensor technologies. As AVs become more prevalent in daily life, they hold the potential to enhance road safety, alleviate traffic congestion, improve mobility access, and promote environmentally sustainable transportation solutions (Gruzauskas et al., 2018; Massar et al., 2021). Despite these technological promises, fostering public trust remains a significant challenge to the widespread adoption of AVs. In response, HCI researchers and designers are examining how interaction design can facilitate AV systems that are perceived as safe, comprehensible, and trustworthy.

Two foundational concepts have guided much of this exploration: the dynamics of trust and the notion of trust calibration. Trust dynamics refers to how users establish, sustain, or lose trust in AV systems over time (Khastgir et al., 2018), whereas trust calibration emphasizes aligning the user's level of trust with the vehicle's true capabilities and limitations (Helldin et al., 2013; Kraus et al., 2020). Misalignment in trust—either excessive reliance or undue skepticism—can compromise safety. Over-trust arises when users assign too much confidence to the AV, potentially disengaging from necessary oversight (Lee & See, 2004). In contrast, mistrust often stems from doubts about reliability, inadequate system transparency, or emotional responses to widely publicized AV-related incidents (Lohaus et al., 2024; Naiseh et al., 2025).

To mitigate these concerns, prior work has explored interface designs that help users build coherent and accurate mental models of AV functionality. A recurring insight from this research is that perceived social roles significantly influence how users interpret and trust intelligent systems (Cheng et al., 2022). Users tend to project familiar social roles—such as those of a teacher, assistant, or driver—onto autonomous systems, shaping their expectations accordingly. This raises an interesting design question: What driving behaviors or personas are most likely to elicit user trust?

We argue that the persona of an experienced and courteous human driver represents one of the most trusted social roles in driving contexts. This persona is typically associated with several key behavioral traits (Lohaus et al., 2024; Strayer et al., 2015; Verberne et al., 2012), including:

1. engaging in socially appropriate interactions with passengers;
2. demonstrating cautious and deliberate decision-making;
3. maintaining vigilance and competence in responding to road conditions;
4. avoiding distractions while driving; and
5. clearly signaling intentions and actions.

This study proposes to design AV behaviors modeled on this trusted social role. By incorporating the behaviors and communication patterns of an experienced human driver, we aim to make the AV's actions more transparent, predictable, relatable, and social. Rather than positioning the AV as a black-box machine, this design strategy emphasizes familiar social cues to reduce perceived ambiguity and foster more accurate trust calibration.

To investigate this design concept, we organized two co-design workshops involving 12 participants, including AV users and relevant stakeholders. The workshops generated a diverse range of design concepts, expressed through low-fidelity prototypes, sketches, and audio-recorded conversations. Using the Annotated Portfolio method, we created visual and textual annotations of the design artifacts. These, along with the workshop transcripts, were analyzed through Reflexive Thematic Analysis (RTA) (Seyitofülu & Ivanov, 2024). The result is a set of five thematic insights that illustrate how the trusted driver role can be embedded in AV interaction design.

2. Related work

This section reviews literature across four interconnected domains relevant to designing trust-enhancing interactions in autonomous vehicles (AVs): users' mistrust and discomfort with AVs; strategies for calibrating human–AV trust; design approaches that leverage familiar driving behaviors and social roles; and state-of-the-art AV interfaces in research and commercial contexts. This review situates our co-design study within the broader discourse on AV trust, emphasizing how interaction design can bridge the gap between machine operation and human social expectations.

2.1. The roots of mistrust: Why users hesitate to trust autonomous vehicles

As noted in the introduction, both over-trust and mistrust in autonomous vehicles (AVs) pose significant safety risks. Calibrating trust appropriately is essential for user acceptance, enhanced experience, and effective human–system collaboration (Hoff & Bashir, 2015; Lee & See, 2004; Parasuraman & Riley, 1997).

Over-trust occurs when users place excessive confidence in AV technology, potentially reducing attentiveness during critical moments (Kraus et al., 2020). Empirical studies, however, indicate that mistrust—a persistent reluctance to rely on AVs—is more common (Moye, 2024; Tyson et al., 2022). This mistrust arises from multiple interrelated factors (Abraham et al., 2017; Hong et al., 2020; Kaur & Rampersad, 2018; Ruijten et al., 2018; Seet et al., 2022), including perceptions of technical unreliability and error-proneness, psychological concerns such as lack of control and unfamiliarity, and limited personal experience with AVs. Gaps in public education, regulation, and standardized training further exacerbate users' skepticism.

These findings highlight the need for interaction strategies that extend beyond demonstrating technical competence. AV interfaces must also address users' emotional and cognitive concerns by offering interactions that are relatable, transparent, and socially intuitive. Consequently, trust-building has become a central focus in human–machine interaction (HMI) and human–robot interaction (HRI), where designers aim to mitigate mistrust by creating AV experiences that users can understand and connect with on a human level.

2.2. Design strategies for enhancing human-AV trust

Researchers have proposed several strategies to support calibrated trust in autonomous vehicles (AVs). A widely studied approach is increasing system transparency. Interfaces that clearly communicate the AV's intentions, reasoning, and operational state enhance user understanding and trust. In-vehicle agents providing consistent, expressive, and context-aware communication further strengthen confidence, particularly during control handovers (Atakishiyev et al., 2024; Lyons & Havig, n.d.; Taylor et al., 2023). User training through scenario-based modules is another effective method, helping users build accurate mental models of AV behavior, reduce anxiety, and calibrate trust (Johnson et al., 2023; Murtaza et al., 2023; Sarter et al., 1997). Adaptive feedback systems that acknowledge limitations or errors and provide clear recovery guidance can also repair and maintain trust after unexpected events (de Visser et al., 2018). Dynamic communication of system reliability constitutes a further strategy. Real-time updates on the AV's confidence in its decisions, as well as situational impacts on performance, promote realistic, informed user engagement (Hoff & Bashir, 2015).

Beyond technical measures, socially inspired interaction design aims to make AVs feel more relatable, approachable, and social. While such designs can improve trust, excessive or poorly aligned human-like behaviors may cause confusion or unmet expectations (Jensen & Khan, 2022). This design strategy is discussed further in the next section.

2.3. Enhancing human-AV trust through anthropomorphism

Anthropomorphism, from the Greek *anthropos* (human) and *morphe* (form), refers to the human tendency to attribute human-like characteristics—such as emotions, intentions, and behaviors—to non-human entities. This cognitive shortcut helps individuals interpret complex or unfamiliar systems through socially familiar frameworks (Bartneck et al., 2020). In human-computer interaction, designers often embed anthropomorphic attributes intentionally to foster relatability, emotional engagement, and user acceptance. While anthropomorphism describes a psychological tendency or user response (Epley et al., 2007), anthropomorphic design refers to deliberately implementing human-like forms—such as faces, bodies, or gestures—into interactive systems (Bartneck et al., 2020; Fong et al., 2003). In this article, we focus on anthropomorphism as it emerges in users' interpretations of AVs' social roles, emphasizing behavioral and social cues associated with trusted human drivers rather than human-like visual or physical embodiment (Breazeal, 2003; Damacharla et al., 2022).

In autonomous vehicle (AV) research, anthropomorphism in design has been explored to enhance trust and user experience. Studies show that naturalistic communication, expressive feedback, and persistent system identities can positively influence perceptions of AV reliability and predictability (Wu et al., 2023). Clear intent signaling and socially appropriate behaviors increase user confidence and comfort, while a consistent AV identity across contexts helps establish a stable, trustworthy relationship with users (Hong et al., 2021).

However, employing anthropomorphism in design is not without risks. Systems that appear human-like but act unreliably may cause confusion, discomfort, or a collapse of trust, as mismatches between form and function create unrealistic expectations and perceptions of deception (Naiseh et al., 2025). Over-trust may also occur, leading users to rely on the AV beyond its actual capabilities or disclose sensitive information. For experienced users, anthropomorphic traits can reduce technical transparency and the sense of control (Cheng et al., 2022).

Given these mixed findings, it remains unclear which anthropomorphic features consistently support trust across user demographics and driving contexts. Rather than emphasizing visual resemblance or playful personality traits, this paper proposes positioning the AV as a socially legible entity adopting the role of an experienced, attentive human driver. While individual drivers differ in personality, their social interactions share qualities—such as cautious, confident decision-making, attentiveness, and courteous behavior—that promote trust. By embedding behavioral cues aligned with these expectations, our role-based design aims to foster user trust through consistency, familiarity, and social coherence.

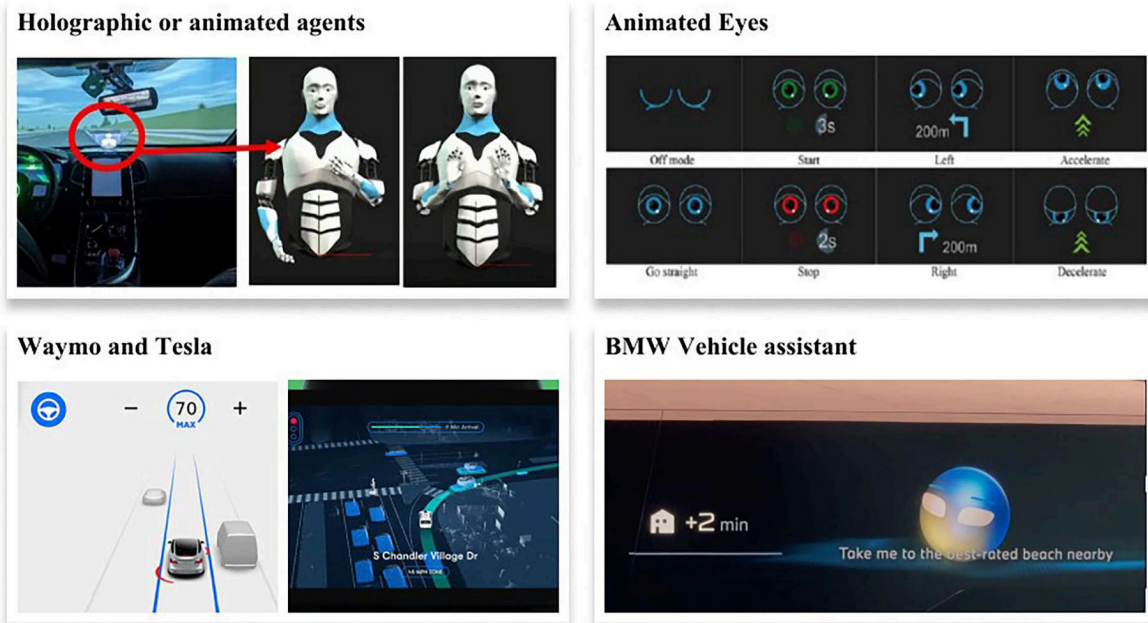


Figure 1. State-of-the-art anthropomorphism AV interface design examples.

2.4. State-of-the-art human-AV interaction: Designs informed by anthropomorphism

Recent advances in both academic and industry contexts have demonstrated increasing interest in designing autonomous vehicle (AV) interfaces that incorporate social and behavioral expressiveness, often inspired by principles of anthropomorphism. As illustrated in Figure 1, a wide range of prototypes and commercial systems have sought to humanize AV interactions by adopting more intuitive and communicative modalities.

Academic research has proposed several approaches to make AV systems more socially intelligible. These include voice-based driving assistants that communicate intentions conversationally (Park et al., 2024), holographic or animated agents conveying expressive cues through speech and motion (Lawson-Guidigbe et al., 2023), and simplified visual metaphors—such as animated eyes—that indicate attentional focus or system responsiveness during maneuvers (Niu et al., 2018). Such designs aim to bridge the interpretability gap between autonomous decision-making and user understanding.

Industry implementations reflect similar strategies. Mercedes-Benz and Toyota offer in-vehicle assistants capable of functional and casual dialogue using natural language processing (DRIVE PILOT Automated Driving, 2026; Edmunds Cars (Director), Edmunds, 2017), while BMW’s virtual agent leverages personality and expressive feedback for a relatable experience (BMW Group, 2018). Tesla and Waymo emphasize data visualization, using dynamic dashboards to convey environmental perception and decision logic in real time (Autopilot | Tesla, n.d.; Petersen Automotive Museum (Director), 2024).

These examples highlight a growing consensus that interaction style, social signaling, and perceived behavioral intent significantly influence user trust and comfort. Yet, little attention has been given to a familiar social role: the attentive, experienced human driver, whose qualities—competence, safety, and predictability—strongly shape trust. This study addresses that gap by exploring how AV interfaces can embody this trusted driver persona through behavioral and communication design, fostering stronger user confidence, improved system legibility, and a heightened sense of control.

3. Methodology

This study aims to generate intermediate-level design knowledge (Löwgren, 2013)—including annotated portfolios, design patterns, and guidelines—to support novel human-AV interaction strategies that foster trust. “Intermediate-level design knowledge,” according to Löwgren, refers to a reflective, practice-grounded form of knowledge that informs and inspires the design process and outcome. It derives

from “portfolios of design exemplars,” lies “between particular design instances and more general theories,” and thus, is “more broadly applicable than a single design” and “less abstract than theory” (Löwgren, 2013). “Annotated Portfolio” is a vehicle for conveying intermediate-level design knowledge through a collection of design exemplars in a design portfolio, “augmented with commentary that draws out design themes, patterns, and insights” (Löwgren, 2013).

Specifically, in this project, we examine how AV interfaces can reflect the communicative behaviors of an attentive, experienced human driver, providing users with a socially recognizable and trustworthy presence. To explore this concept, we conducted two co-design workshops in which participants brainstormed, discussed, and created low-fidelity prototypes of potential AV interfaces. The resulting data were analyzed using Reflexive Thematic Analysis (RTA) within the framework of intermediate-level design knowledge (Höök & Löwgren, 2012). More specifically, the Annotated Portfolio method was employed to systematically examine the visual artifacts produced. Integrating these approaches allowed us to extract design insights from both participants’ verbal contributions and their visual outputs.

3.1. Co-designing future human-AV interactions

This study’s co-design exploration is informed by previous scholarship that characterizes co-design as a collaborative creative practice embedded throughout all stages of the design process (Sanders & Stappers, 2008; Steen, 2013). Such an approach creates opportunities for participants with diverse backgrounds to contribute not only to the content being developed but also to the shaping of the process itself. This exchange helps to build mutual understanding before new ideas and artifacts are produced (Kleinsmann & Valkenburg, 2008; Steen, 2013). Our work specifically draws on Marc Steen’s interpretation of co-design as a collaborative effort grounded in both inquiry and imagination, carried out collectively by designers, users, and other stakeholders (Steen, 2013).

Aligned with this framework, the co-design workshops were structured to promote inclusive participation and open-ended exploration of AV interaction design. Participants came from diverse professional backgrounds, including industrial design, toy design, HCI, and AV interface design. Sessions began with guided group discussions that introduced the social and experiential complexities of human-AV interaction, emphasizing reflection over definitive solutions and framing the AV as a trusted human-like driver.

Following this introduction, participants collaboratively generated speculative use cases and design concepts, translating ideas into sketches, prototypes, and narrative scenarios. These outputs were presented in group critique sessions, providing opportunities for reflection, feedback, and refinement. The workshops emphasized imagination, shared interpretation, and tangible representations as key tools for envisioning future user-AV interactions.

3.2. Integrating annotated portfolio with reflexive thematic analysis (RTA) to analyze co-design outcomes

This research aims to generate intermediate-level design knowledge to guide future autonomous vehicle (AV) interaction strategies. We employed Reflexive Thematic Analysis (RTA) (Braun & Clarke, 2012; Doing reflexive TA, n.d.), guided by the theory of intermediate-level design knowledge (Höök & Löwgren, 2012), to analyze textual and visual data from the co-design workshops, including sketches, photographs of physical prototypes, and transcripts of group discussions. The RTA process necessitates a guiding theoretical framework, which, in this study, is applied to implement and explore the generation of intermediate-level design knowledge in the context of our workshop data analysis.

As described by Höök and Löwgren, intermediate-level design knowledge occupies a space between specific case studies and generalized theoretical models. Rather than making universal claims, it provides insights that are abstract enough to guide future design while remaining grounded in practice. Such knowledge can be generative—informing new design concepts—or evaluative—supporting reflection and decision-making within design processes (Höök & Löwgren, 2012).

To support visual analysis, we employed the Annotated Portfolio method, systematically reviewing participants’ sketches and prototype images and adding annotations to highlight recurring elements,

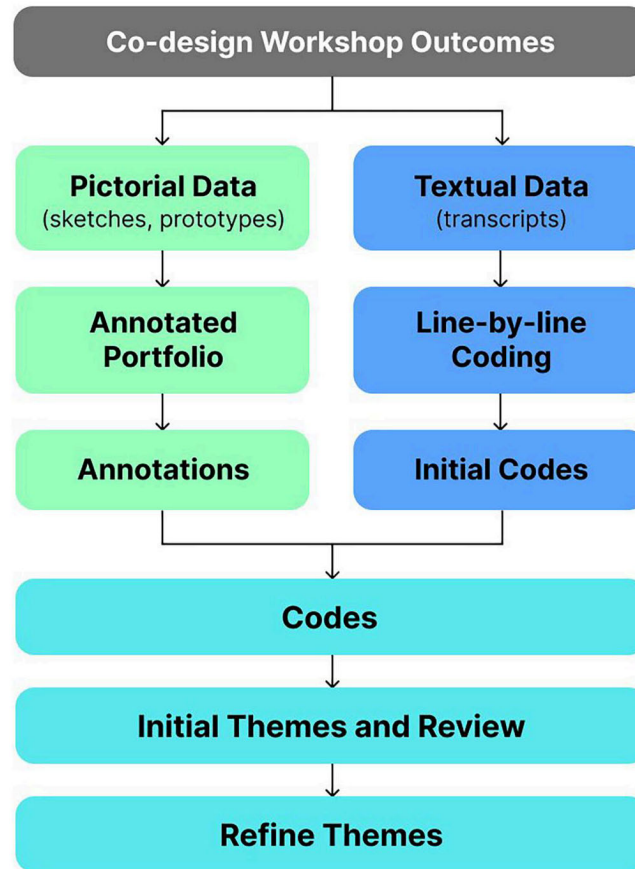


Figure 2. RTA process integrated with annotated portfolio to generate intermediate-level design knowledge.

intentions, and design rationales. These annotations surfaced latent knowledge embedded in visual artifacts and informed our thematic analysis (Gaver & Bowers, 2012; Hoggenmüller et al., 2021; Löwgren, 2013).

During RTA, we analyzed both the visual annotations and textual transcripts from interviews and group discussions, identifying patterns that revealed user values, expectations, and recurring themes related to interface behaviors, interaction strategies, and design decisions in AV contexts.

Integrating visual and textual sources produced a comprehensive framework for generating design knowledge. Figure 2 illustrates the interaction between Annotated Portfolio and RTA within this methodological structure. We suggest that this approach provides a useful model for interaction design researchers working with co-design data spanning both verbal and visual expression.

4. Participants and workshop process

4.1. Participants information

Two co-design workshops were conducted with a total of 12 participants (6 per session). Participants were recruited through flyers, email outreach, and snowball sampling. All individuals had prior exposure to various levels of AV technologies or demonstrated interest in AV design and interaction. This was assessed using a pre-workshop questionnaire that captured their experience, familiarity, and attitudes toward AV systems. Of the 12 participants, 10 were AV users (4 male, 6 female). The remaining 2 participants were both experienced AV designers, including one professional with decades of experience in the automotive and AV industry (both male). For each workshop session, there are 5 AV users and 1 AV designer among the 6 participants. Each participant received \$10 compensation for their participation in the 2-hour session.

4.2. Co-design workshop structure

The sessions started with a brief presentation highlighting recent advancements in AV interface design, offering contextual grounding and real-world examples to inform participants' exploration. Following this introduction, participants were presented with the central prompt: to imagine an AV interface that mimics the behavior of an attentive, experienced human driver, with the goal of fostering trust through socially meaningful interaction.

To initiate the ideation phase, the research team introduced a set of open-ended questions intended to challenge participant assumptions and encourage reflection on personal experiences with both human-driven and autonomous vehicles. These prompts invited comparisons between the strengths and shortcomings of traditional driving behaviors and current AV interfaces, encouraging participants to think critically about how elements from both could be combined to enable more trustworthy interactions.

After these discussions, participants transitioned into a hands-on creative phase where they generated fictional scenarios and conceptual systems through activities such as sketching, physical prototyping, and storytelling (Figure 3). A wide variety of low-fidelity materials—such as Play-Doh, paper, aluminum foil, wood sticks, and straws—were made available to support expressive and tactile forms of ideation. For those who had difficulty imagining complete systems, optional prompts were provided that focused on specific interaction moments, including entering the vehicle, starting a route, navigating, and reaching the destination. This flexible framework allowed each participant to engage with moments they found particularly relevant, emotionally charged, or problematic in current AV experiences.

The output from these sessions included a mix of physical models, illustrated narratives, and sketches of interface designs. Participants presented their creations during a group sharing session, explaining the reasoning behind their designs and describing how their concepts embodied the traits of an attentive and trustworthy human driver. This presentation phase was followed by focused group discussions in which participants provided feedback, responded to emerging patterns, and elaborated on the affective and functional qualities embedded in their ideas.

Each session was recorded using both audio and video, and all physical and visual design materials were systematically photographed for further study. Together, these recordings and artifacts formed a rich multimodal dataset that enabled deeper analysis of how social expectations and trustworthiness were imagined and expressed in speculative AV interface concepts.



Figure 3. Sketching and low-fidelity prototyping during the co-design workshops.

5. Data analysis

The outcomes of the co-design workshop were analyzed using the process illustrated in Figure 2. This section presents an example of how both textual and pictorial data were processed to derive themes, contributing to the generation of design guidelines.

The textual data, including transcripts of the workshop discussions, were analyzed using line-by-line coding with similar codes combined, which produced an initial set of codes. For instance, codes like “not too human-like,” “Prediction information,” “Explain decisions,” “Trip info and statistics,” “abstract digital agent,” and “Transparency” were identified before being used to generate themes.

On the other hand, the pictorial data—including participants’ design sketches and prototypes—were organized by individual participants’ design and accompanied by brief design summaries. Selected images were annotated to highlight key features and design ideas. These annotated images were then aggregated into an Annotated Portfolio. Below are some of the annotations and the corresponding design artifacts (from which these annotations were abstracted):

- Design 1 and 9: “Communicate environmental information instantly”
- Design 2, 5, and 8: “Transformable”
- Design 1 and 11: “Proactivity and sociality”
- Design 3, 7, and 12: “Crafted with precision”
- Design 6 and 10: “Trust evolves gradually”
- Design 4 and 7: “Reveal environmental awareness”
- Design 3 and 12: “Iron-man ‘Jarvis’ Interface”

With all the codes and annotations generated, we then cluster similar or connected codes and annotations together to generate themes. For instance, we identified the theme “different ways of conveying information transparency to boost trust in AV” (the initial version of Theme 1) by clustering the following codes together: “Prediction information,” “Explain decisions,” “Trip info and statistics,” “Transparency,” “Communicate environmental information instantly” (Design 1 and 9), “Proactivity and sociality” (Design 1 and 11), “Crafted with precision” (Design 3, 7 and 12), “Reveal environmental awareness” (Design 4 and 7), and “Iron-man ‘Jarvis’ Interface” (Design 3 and 12). The convergence of codes and annotations confirms that Theme 1 is significant, reflected both in participant discussions and the design artifacts.

6. Results

Our findings are presented across four central themes. These data sources included annotated portfolios based on participants’ sketches and prototype imagery, as well as transcripts from guided group discussions. Each theme captures recurring user expectations, patterns of interaction, and communicative behaviors that participants associated with trustworthy autonomous vehicle systems. The purpose of organizing the results in this way is to offer actionable insights for future AV interface development, grounded in principles that reflect the behavioral traits commonly attributed to experienced, attentive human drivers.

6.1. Theme 1: Proactive multimodal communication to convey situational awareness, planned behavior, and system confidence in real time as a foundation for fostering trust in AV

Participants consistently expressed a strong preference for AVs that provide real-time updates in a proactive, clear, and easily accessible manner. Across sketches, prototypes, and discussions, they emphasized that continuous, transparent communication about the vehicle’s status, planned actions, and environmental awareness is essential for fostering trust. This expectation parallels the behavior of skilled human drivers, who naturally signal their intentions through verbal or contextual cues. Many participants felt that current AV interfaces lack this communicative richness, offering feedback that is delayed, limited, or difficult to interpret.

This need was articulated explicitly during brainstorming. P7 noted, “The interface should tell the user what the car is going to do, like slowing down two miles ahead due to traffic.” P1 highlighted the value of multimodal communication: “There should be information on the front windshield—if I can’t hear well, I need to see it.” Seven additional participants echoed this sentiment, producing designs that combined visual and auditory cues through windshield or dashboard displays. Others—including P3, P5, P7, and P10—extended these ideas by proposing advanced features such as predictive risk forecasting, summarized driving history, and real-time sensor diagnostics.

These proposals were reflected in several recurring annotations:

1. Crafted with precision – describing interfaces that blend technical clarity with refined esthetics, such as P9’s “Jarvis”-style voice assistant and luxury watch-inspired heads-up displays.
2. Reveal environmental awareness – denoting map-based visualizations that highlight dynamic environmental elements to convey the AV’s perceptual focus.
3. Communicate environmental information instantly – emphasizing rapid, responsive updates during changing traffic conditions.

A notable example was P3’s concept of a large-scale real-time environmental map that visualized AV blind spots. Similar ideas appeared in sketches by P7 and P10, who designed dashboard displays layering environmental insights for improved situational understanding.

Beyond heads-up displays and map visualizations, several participants proposed more expressive, character-driven communication. P6 and P8, for example, imagined stylized agents—such as the “Giraffe” and “Sloth” (Figure 4)—delivering voice-based updates through animated, personable avatars. These concepts embodied “proactivity and sociality,” traits participants strongly associated with trust, confidence, and emotional reassurance.

In summary, this theme demonstrates how AV interfaces that communicate transparently, proactively, and through multiple senses can enhance user trust. By consistently expressing situational awareness, planned behavior, and system confidence in real time, AVs can better emulate the qualities users associate with capable and attentive human drivers.

6.2. Theme 2: Employing a driving agent (either robotic, virtual, vocal, or spatial) as the representation of the AV to effectively demonstrate a human driver’s defensive driving style

A strongly recurring theme across the co-design workshops was the expectation that autonomous vehicles should embody a defensive driving style. Participants described this style as cautious, deliberate, and smooth—communicating competence while minimizing risk. These qualities were consistently linked to their mental models of a skilled human driver, and participants emphasized that AVs demonstrating such behaviors were more likely to earn their trust.

Crucially, participants did not equate defensive driving with slowness or inefficiency. Instead, they framed it as intelligent, alert, and context-sensitive decision-making. P2 explained, “The system should drive cautiously but smoothly—like a taxi driver who knows what they’re doing.” P5 added, “If it’s merging to the right, then it should look to the right. I want someone who pays close attention, who is serious and vigilant.” To convey this level of awareness and intention, many participants envisioned interfaces featuring embodied agents—robotic, virtual, spatial, or voice-based—that could signal attentiveness through socially expressive behaviors.

Participants frequently drew parallels to how human drivers naturally communicate defensive driving through subtle gestures and movements—facing forward when driving, scanning the environment before turning, or leaning to improve visibility. Analysis of annotated portfolios (Figure 5) revealed several recurring design strategies:

1. Eye and body movement design – Participants including P2, P5, P6, P7, P8, and P12 incorporated gaze direction and head-turn cues to indicate the AV’s attentional focus during maneuvers such as lane changes. They emphasized that the driving agent—regardless of form—should maintain a forward-facing orientation while driving, even when addressing passengers, to convey vigilance.

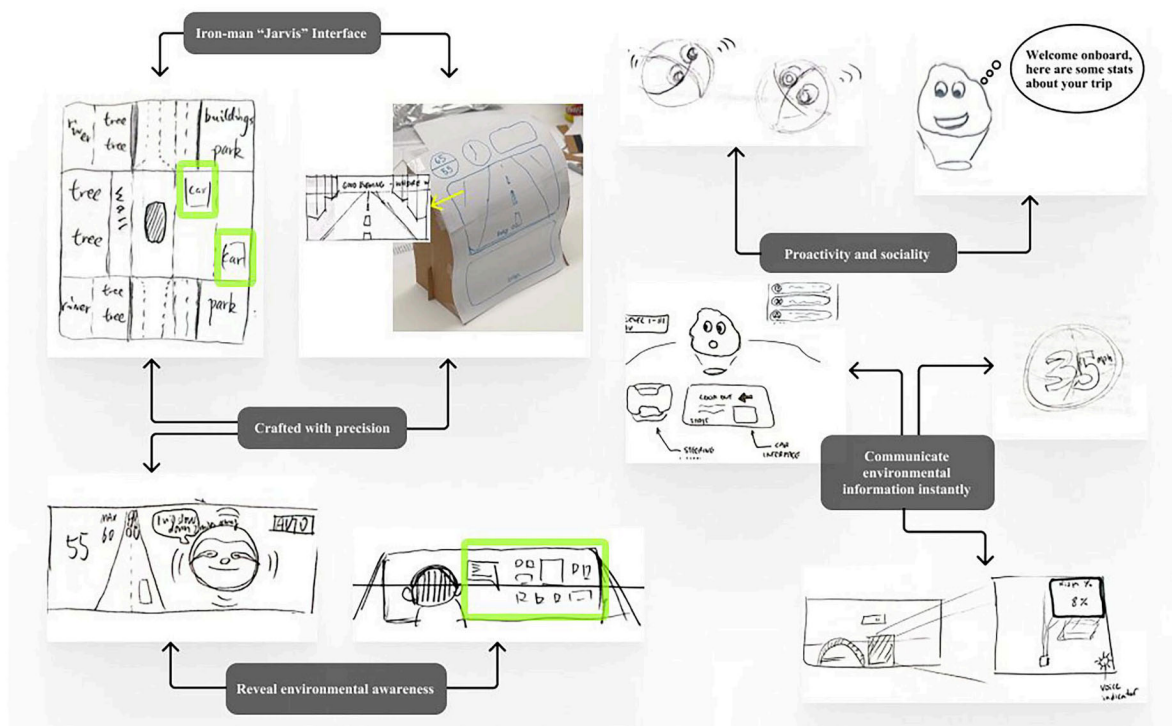


Figure 4. Exemplary annotated portfolios addressing theme 1.

2. Constant vigilance and cautious driving – P2 proposed a steering-wheel-embedded interface that expressed attentiveness through combined visual, haptic, and movement cues, including soft gaze animations, seatbelt tension feedback, and seat vibrations that simulate the embodied focus of careful drivers.
3. Emblematic design for safety – One concept introduced a digital water-tank display that remained still when the vehicle drove smoothly, offering an intuitive metaphor for stability and risk avoidance.

Overall, participants regarded defensive driving not merely as a driving style but as an embodied communication practice that AV interfaces should emulate to strengthen user trust.

In addition to visual and haptic cues, participants explored how the AV's spatial environment could function as an expressive agent. P2, P6, and P8 proposed “space agents”—non-character interface environments that respond to driving context through ambient visual feedback. Dynamic elements such as lighting shifts, dashboard movement, and subtle animations were used to convey the vehicle's attentiveness and environmental awareness. This approach was captured in the annotation: “Space agent: ambient environment for immersive experience.”

Together, these concepts highlight a desire for interfaces that do more than display information—they perform attentiveness in ways that users can intuitively perceive and trust. By leveraging movement, gaze, environmental responsiveness, and tactile feedback, such agent-like representations enable AVs to communicate driving behavior in embodied, expressive ways, reflecting the calm precision and vigilance associated with reliable human drivers.

6.3. Theme 3: Cultivating human-AV trust through gradual, evolving human-AV companionship, featuring the reassuring and calming demeanor of a driving agent

Extending the theme of embodied attentiveness, participants also reflected on how AV systems might engage users emotionally and socially—both during driving and across longer-term interactions. Rather than limiting communication to functional cues, many envisioned companion-like interfaces capable of

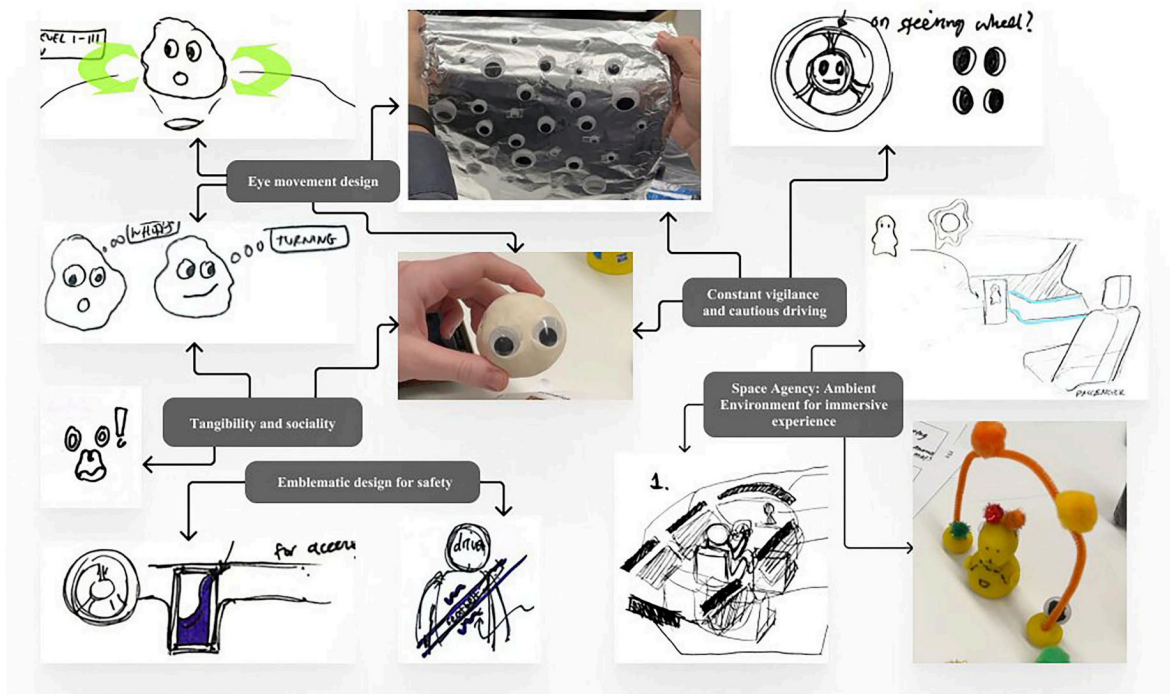


Figure 5. Exemplary annotated portfolios addressing theme 2.

greeting, reassuring, and adapting to users over time. These interactions were seen as pathways to building trust through sustained engagement, emotional expressiveness, and relational familiarity.

Across sketches and discussions, participants proposed features that emphasized emotional resonance and social presence rather than simply conveying information. P2, for example, suggested subtle facial animations (e.g., eyebrow movements) to signal emotional tone, while P5 proposed that a brief verbal cue such as “Oops” after sudden braking could acknowledge the event and soften the experience.

Half of the participants (6 of 12) incorporated greetings and farewells into their designs, signaling a desire for the AV to act as a familiar and emotionally present companion. P1 imagined the system saying, “Come, Allen, let’s start our journey,” followed by, “See you in an hour,” upon arrival, framing the AV as reliable and socially attentive. Annotated portfolios in Figure 6 captured this direction, including:

1. Embodied emotional expression: P11 created animal-inspired interface characters—such as a calm, grounded capybara—to represent different emotional and functional states.
2. Calm and composed demeanor: P3 envisioned a smiling agent offering verbal reassurances like “Leave the driving to me,” mirroring the presence of a confident human driver.

Participants also explored how these relational dynamics might extend beyond the vehicle. P3 proposed integrating the agent into smartphones or smart home assistants to maintain casual exchanges like “See you at home.” P1 preferred a minimal, voice-only version accessible via headphones, while P5 imagined an interface that matures alongside the user, shifting from playful to more professional over time as trust deepens.

Another notable concept came from P4, who designed a projected visual companion appearing beside the vehicle during nighttime pick-up and drop-off. This glowing, walking figure was intended to accompany users as they approached or exited the car, offering emotional reassurance and a sense of physical security. The idea resonated with many participants—including women and several men (P1, P5, P6, P7)—and was annotated as “Beyond the AV, always present,” emphasizing continuity in transitional moments.

Taken together, participant contributions revealed two guiding principles:

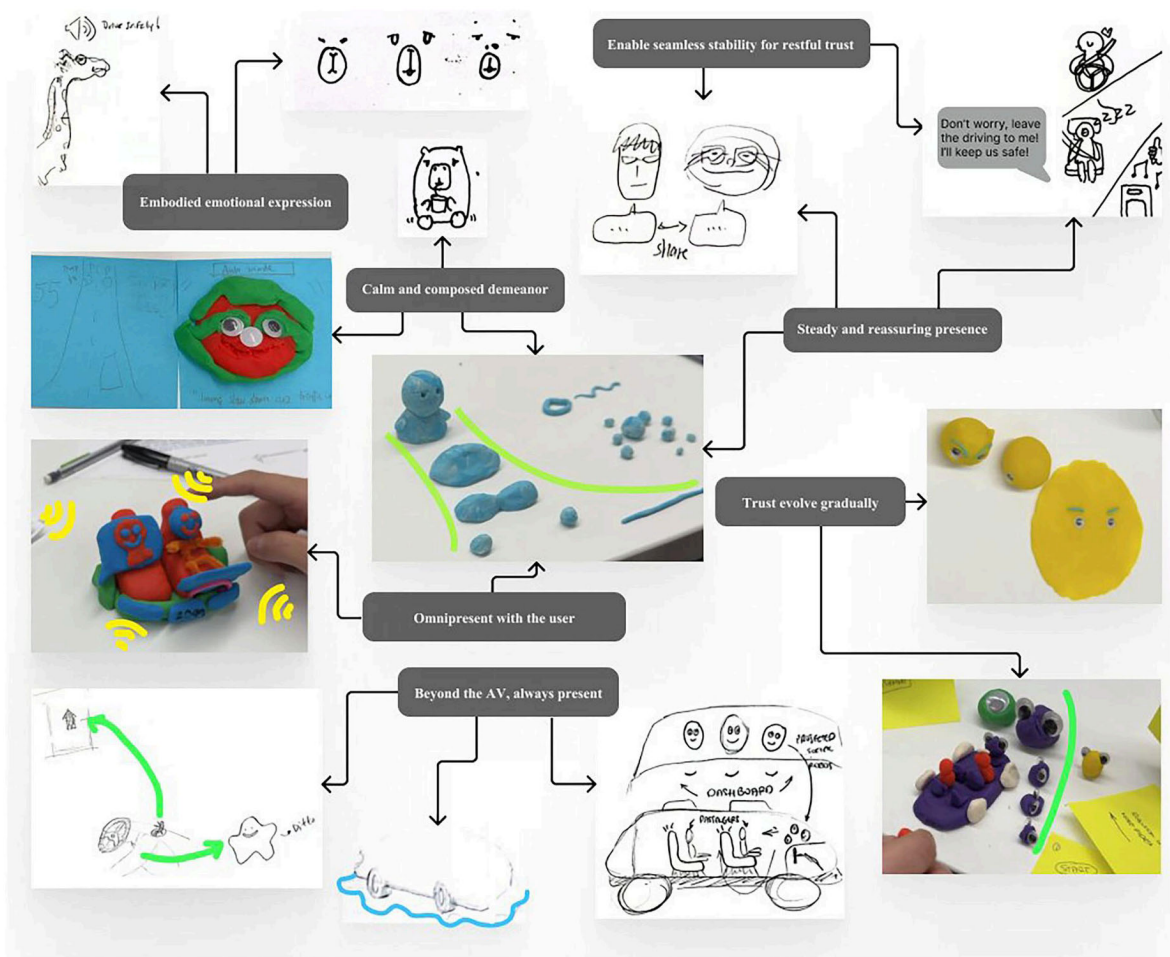


Figure 6. Exemplary annotated portfolios addressing design strategy-Emotional connections with experienced human-like driver.

1. Trust evolves gradually: Emotional connection and confidence develop through repeated, meaningful interactions over time and across contexts.
2. Beyond the AV, always present: Extending the system's presence outside the vehicle reinforces trust by creating a consistent, contextually relevant relationship.

Overall, this theme highlights how emotional expressiveness, cross-platform continuity, and social familiarity shape user perceptions of long-term trust in automated systems. Rather than replicating human behavior, participants emphasized qualities of presence, consistency, and relational warmth—reflecting how users want to feel with the AV, not merely how they operate it.

6.4. Theme 4: Enabling users to personalize their driving agents to foster familiarity and trust

A fourth major theme from the co-design workshops emphasized that trust in AV systems can be strengthened through opportunities for user customization. Participants highlighted the value of adaptable interface representations—physical, visual, spatial, or auditory—that reflect personal preferences and feel meaningful to individual users. Personalizing how the AV is represented was often described as a way to enhance comfort and better align with user expectations. For instance, P3 envisioned a system capable of fully transforming its identity based on user input: “It can transform into anyone—it can look like you, your friend, your family... or even a cat.” Two additional participants echoed this

idea, imagining companion agents whose appearance or behavior could shift each time a new user entered the vehicle.

As illustrated in the annotated portfolios (Figure 7), participants expressed a wide range of aesthetic and behavioral preferences shaped by their personal conceptions of a “trusted driver.” From these diverse proposals, several design annotations emerged:

1. **Cute and soft:** Participants in this category favored playful, cartoon-like characters with rounded forms and expressive gestures. These designs were intended to offer emotional reassurance, particularly in unfamiliar situations or for users with limited experience with AVs.
2. **Serious and mature:** Other participants preferred interfaces that conveyed technical authority and composure. These minimal or analog-inspired designs emphasized clarity, restraint, and precision—qualities interpreted as markers of competence and reliability.
3. **Time-based customizable outfit:** Some envisioned dynamic customization, where the interface adapts its appearance based on time of day, usage patterns, or user mood. P3, for example, proposed gradual shifts in appearance that reflect growing familiarity, aligning with the broader idea that trust develops over time.

Participants also proposed more personal forms of identification. Some imagined the AV adopting traits of a trusted friend or loved one, while others preferred an interface that mirrored aspects of themselves, suggesting that personal alignment and recognition could enhance trust.

Collectively, these contributions underscore the limitations of one-size-fits-all approaches to AV interface design. Participants emphasized that the ability to personalize aesthetic, behavioral, and emotional dimensions increases engagement, fosters familiarity, and ultimately strengthens trust. In this sense, Theme 4 serves as a call to design AV interfaces that are transformable, expressive, and meaningfully shaped by the user.

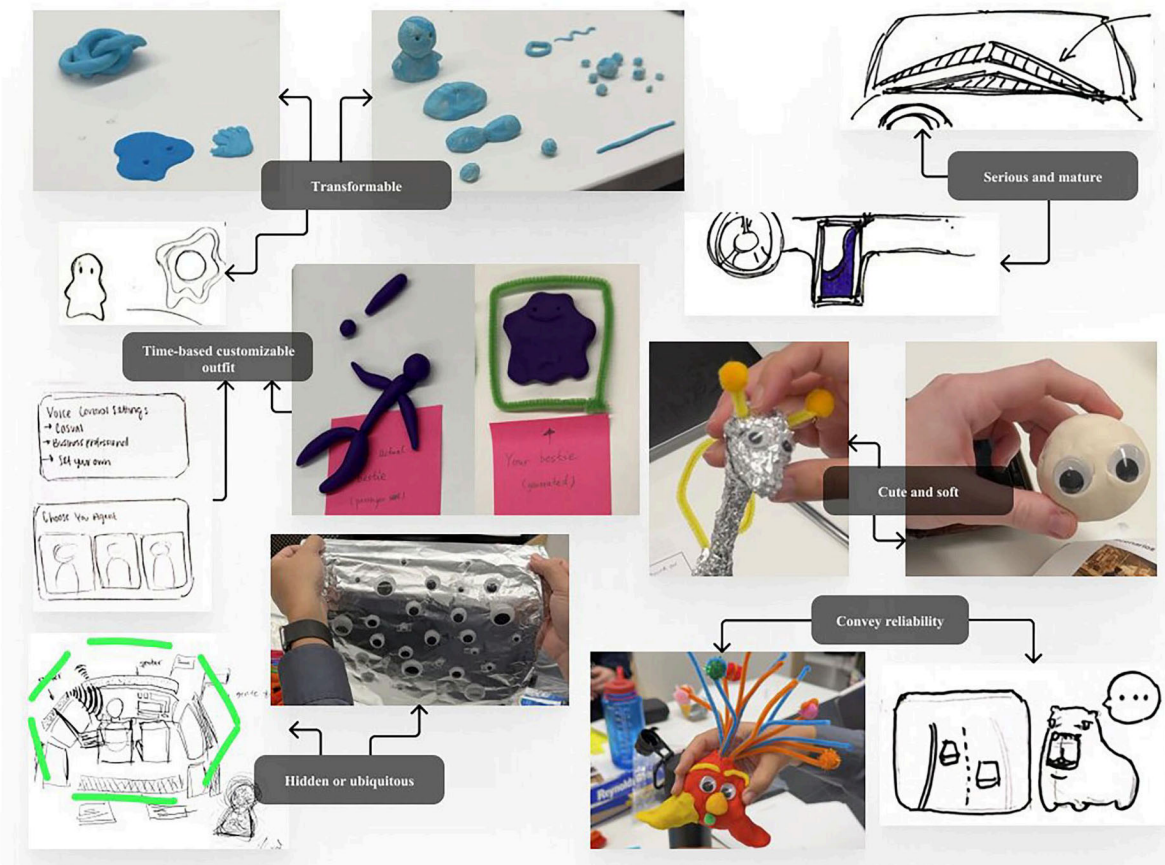


Figure 7. Exemplary annotated portfolios addressing the “personalization” design features of the driving agents.

7. Discussion

This research applied a hybrid methodological approach—combining Reflexive Thematic Analysis (RTA) with the Annotated Portfolio method—to identify four central themes related to designing AV interfaces that emulate the behaviors of experienced, attentive human drivers. These themes shed light not only on how trust can be cultivated through expressive interaction but also on concrete design strategies for developing AV systems that are both responsive and relational in nature. In the following discussion, we examine the methodological contributions of this work and introduce a design space for future exploration situated at the intersection of embodiment, expressiveness, and interaction within autonomous vehicle interfaces.

7.1. Annotations: The bridge between design artifacts and thematic insights

As described in Section 3, we used the Annotated Portfolio method to surface the embedded design reasoning within visual data, including sketches and prototype images. This method played a key role in making implicit design rationales explicit and contributed directly to the generation of themes during Reflexive Thematic Analysis (RTA).

Annotations served as a vital intermediary between the raw visual artifacts and the broader themes, enabling us to articulate how specific design details aligned with higher-level interaction goals. One example is the capybara-inspired interface depicted in Figures 5–7. While it might initially appear as a whimsical character, the annotations clarified its function in conveying environmental context, fostering companionship, and signaling emotional stability—traits that cut across Themes 1, 3, and 4. In this way, the annotation process enabled us to move from visual output to conceptual insight, capturing the rationale behind each design decision and supporting the creation of both generative and evaluative design knowledge.

7.2. A design space emerging from the intersection of four themes

Although each of the four themes highlights a distinct dimension of trust-building—ranging from transparency and expressiveness to relational continuity and personalization—they converge to form a more specific design space. This space envisions AV interfaces as socially expressive companions that foster trust by behaving in ways that are familiar, contextually sensitive, and user-aligned.

At the center of this space is the concept of a situated, embodied companion—an interface representation that communicates through various interactions (voice, visual cues, movement, spatial feedback, or environmental adaptation) and maintains presence across the different phases of the user’s journey. Such a companion would be:

- Capable of providing real-time, transparent updates;
- Demonstrative of attentiveness and defensive driving through expressive cues;
- Adaptable to evolving user preferences and needs;
- Multimodal in its output, engaging users through sound, light, motion, or haptics depending on the context.

Rather than defining a single interface form or agent type, this design space invites flexible and user-defined embodiments—ranging from screen-based avatars to ambient systems or purely auditory agents. The AV becomes a socially aware, adaptive system that modulates its expressiveness to suit both the situational context and the individual user. We propose this intersectional design space as a foundation for future research in designing trusted AV interaction.

7.3. Rethinking the driving agent: Robot, virtual entity, or space-based companion?

Throughout the workshops, participants proposed a wide spectrum of embodiments for the AV’s interactive presence. While some leaned toward conventional forms—such as screen-based agents or robotic figures—others introduced less tangible designs, including non-visual or spatially embedded systems.

For instance, P1 imagined a voice-only companion accessible through the car's audio system and user-worn headphones, entirely absent from the visual field. Other participants (P2, P4, P6, P12) explored sensorial communication through touch, light, and vibration. These concepts led to the notion of a “space agent”—a presence embedded within the vehicle interior itself, expressed through spatial cues, sensory modulation, and environmental dynamics (Wang & Green, 2019). In other words, the cabin space itself can act as a distributed, embodied interface—transforming the cabin into a socially expressive environment.

Such ideas resonate with broader directions in embodied interaction, which emphasize communication through spatial configuration, multimodal feedback, and material engagement rather than anthropomorphic designs. Designing for “space agents” introduces several compelling questions for future research:

- In what ways can designers choreograph multisensory environments to signal intent, safety, and capability?
- What interaction modalities best support long-term user comfort and trust in shared autonomous mobility contexts?
- How might user expectations and behaviors co-adapt with these systems over extended use?

We argue that this area represents a promising frontier for interaction design communities in general. The vehicle interior—when treated as both interface and expressive companion—offers new opportunities to design systems that are responsive, emotionally attuned, and capable of evolving alongside their users.

8. Conclusion

This study presented and explored a novel interaction design concept: designing Autonomous Vehicle (AV) interfaces to emulate the behaviors typically associated with trusted human drivers. The goal was to enhance user trust in AVs by enabling socially meaningful and contextually appropriate human-AV interactions. Through two co-design workshops, we generated four design guidelines with practical design suggestions and examples for this design concept.

Beyond the design insights, this work also underscores the methodological value of integrating Annotated Portfolios with Reflexive Thematic Analysis. This combined method promotes the integral interpretation of both visual artifacts and verbal reflections produced during the co-design process.

9. Limitations

First, although the identified themes and resulting design guidelines are grounded in participatory design outcomes, they have not yet undergone empirical validation. Accordingly, these guidelines should be understood as exploratory in nature and intended primarily to inform and inspire subsequent design efforts rather than to serve as prescriptive standards. Future research will involve systematic empirical studies to evaluate and refine these guidelines, as will be discussed in the future work section below.

In addition, the proposed design guidelines should not be interpreted as universal. These guidelines were primarily generated by participants who possess relative familiarity with autonomous vehicle (AV) technologies. Given the diversity of current and prospective AV user populations, establishing a universally applicable set of design guidelines is highly challenging, if not infeasible. Furthermore, the sample size of 12 participants is limited in relation to the breadth and complexity of the design space explored in this study. The participants in the co-design workshops consisted mainly of students and professors who are AV users or, at minimum, have prior knowledge of AV technologies. As a result, this limitation may be particularly pronounced for populations with little to no prior exposure to AVs.

10. Future work

Future work will involve developing functional AV interface prototypes that incorporate the identified themes (or design guidelines) and evaluating them in simulation environments, such as virtual reality

driving scenarios, to assess user trust, emotional response, and interaction efficacy under controlled and experimental conditions.

11. Contribution

Through two co-design workshops, we identified four key themes that offer interaction design strategies for creating AV interfaces that behave in ways users interpret as attentive, familiar, and trustworthy. These themes contribute to interaction design knowledge on how AV systems can express intent, model defensive driving behavior, offer emotional continuity, and adapt to user preferences.

Additionally, we introduced a methodological approach that integrates Annotated Portfolios with Reflexive Thematic Analysis. This hybrid method enabled us to analyze design-focused textual and pictorial data in a structured yet creative way, bridging visual sketches, physical prototypes, and verbal discussions. We propose this approach as a practical framework for HCI researchers and designers who work with textual and graphical co-design data and seek to derive intermediate-level design knowledge.

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Ethical approval

The co-design workshops were conducted after the IRB approval (H23416) of our home institution. All participants signed consent forms before participating in the workshops.

Author contributions

CRedit: **Huaizhuo Yang**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing; **Yixiao Wang**: Conceptualization, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing; **Tim Purdy**: Conceptualization, Supervision; **Wayne Li**: Conceptualization, Supervision; **Mengyao Li**: Conceptualization, Supervision.

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Data availability statement

The data from this study cannot be shared publicly due to ethical obligations to protect participants' privacy, as required by our IRB approval.

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