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Is It Time for Augmented Reality Theory?

Identifying Challenges and Pathways for Theoretical Development

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Abstract: While there has been several decades of augmented reality (AR) research in terms of psychological effects and outcomes, the level of theoretical development in the AR space has been fairly limited. The manuscript identifies several factors that contribute to this, starting from the historical definitions of AR, to how it has become an umbrella term for a wide range of technologies, and how ongoing development in AR continues to stretch that definition. By understanding some of the factors that make theoretical development difficult, this article identifies some areas of media psychology theory that would be relevant to all implementations of AR as well as some contextual theories that would only be brought in with specific implementations of AR. The manuscript then advances a framework for thinking about these differences in AR implementations and theory building, whether that is to isolate specific variables and build theory in that way, combine these variables and attempt to combine/bridge theory, or identify unique features of AR that might necessitate transforming existing media theories. This article aims to help researchers understand the current state of theorization and identify certain pathways for improving theoretical development with future studies into AR media technologies.

Keywords: augmented reality, theory, frameworks

Augmented Reality and the Current State of Theorization

Augmented reality (AR) research has been growing exponentially, but in many different areas and disciplines. Much of this research started in computer science and development, and expanded to applications in various industries/domains, and finally to users effects/media psychology. For decades, AR research was outcome driven, with a number of studies demonstrating that AR would lead to effects like task efficiency (Henderson & Feiner, 2007), emotional response (Javornik, 2016), spatial awareness (Oleksy & Wnuk, 2016), and user behavior (Dey et al., 2018). These studies, typically experimental, often compared an AR condition with non-AR legacy media, and conclude the AR media had a greater effect on attitudes, emotions, and effectiveness/efficiency (Aitamurto et al., 2022; Yang et al., 2020). The corpus of these studies were large enough that meta-analysis were conducted, showing small but noticeable effects for AR on education and learning (Garzón & Acevedo, 2019), marketing and behavioral intentions (Kumar et al., 2023), and training (Howard & Davis, 2023).

The issue is not with any specific effects study, or that we believe these meta-analyses are somehow incorrect in their assessment of macro-level effects, rather it is that the level of theorization for why and under what conditions these effects occur is still quite limited. This article first identifies a number of historical/definitional factors that contributes to this underdevelopment of AR theory, and then delves into some possible approaches for scholars to build out more AR theories.

One of the first challenges comes from the original definitions of AR and how it became this umbrella term. AR as a term came from an industry case study (Caudell & Mizell, 1992), and was not originally intended to be a technical term of art. It was then listed on a mixed reality spectrum to distinguish it from full virtual and unmediated reality (Milgram & Kishino, 1994). Azuma (1997) refined a definition that listed several criteria for AR, which it had to mix the real and the virtual, be registered in three-dimensional space, and be real-time and interactive. This criteria has become the de facto academic definition for AR. Adopting these definitions from computer science meant that the terminology was created to classify computing systems for development purposes rather than theorize about them

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(Skarbez et al., 2021). It also meant that AR is not a single technology or device, rather it is constituted by a collection of criteria.

One major issue is that there is a wide range for devices/applications that could meet the criteria for being AR, and each can be quite technologically different, create different experiences, and have very different features. This limits theorization because each implementation of AR can be different, include different variables, and are sometimes comparing incommensurate or mutually exclusive features. There are also certain topical areas or technologies that receive more theoretical development than others, whether due to availability, resources, or researcher interest. For example, a systematic review of AR research has found more research on mobile handheld AR than other types of AR (Dey et al., 2018).

The second major issue is that the term AR has now become both a definition and an organizing term for the community, which presents challenges for theoretical development. One is that the definition has become contested as the definition moved across domains of industry, marketing, and colloquial usage. There continues to be disagreements about which definitional criteria should be utilized, which applications meet the listed criteria, whether all of them need to be met, and who has the authority to declare things AR (Liao, 2016). It becomes hard to coherently theorize about AR when some people are using the term as top-down technical definition to draw boundaries around certain applications/technologies, while others are publishing individual studies that may utilize a specific AR application/device but attempting to generalize their findings to the broader umbrella term (e.g., AR leads to X).

One last complication is that while the criteria have not been updated for almost two decades, the development of certain AR technologies is widening the range/boundaries of what is technologically and commercially possible for AR. AR ranges from a standalone mobile application that tracks a 2-D marker to the latest consumer devices with high resolution pass-through, lenses/cameras, and experiences to a large-scale projection AR space that enables multiple users at once. Some components may be essential to meet the AR definition and are common across implementations, while others are being developed that are secondary characteristics that can nevertheless add to the experience of the media. Even a simple pipeline shows the myriad of modules for collecting real world scenes, creating virtual scenes, tracking/registration, display, and user interface (Figure 1). Adoption of certain devices and AR applications/capabilities has also shaped the direction of research and theorization, with some reaching mainstream adoption (e.g., Pokémon GO, Meta Quest Pro, etc.) while others are now defunct (e.g., Magic Leap, Microsoft Hololens, Layar, etc.). This means that some users may be pushing their AR adoption in unique and iterative ways, while others are more novelties or one-off experiences.

All of these factors have contributed to limited theoretical development in the AR space generally (Dey et al., 2018). With a technical definition that does not consider users, usage, or content, it is difficult for media psychologists to theorize about these implementations and find uniformity across those theorizations. While it is true that other media may also have contested definitions, there are more evident similarities between other types of media (e.g., Screen/Motion Media, Social Media, etc.) than with AR, because they can hold some form/content/usage variables constant as they test/theorize about other effects. AR on the other hand may start with different hardware and then combine a unique set of enabling technologies and features (e.g., visual graphics, gestural interfaces, haptics), Additionally, AR can be expansive and additive in terms of how real-world objects get recognized, how the content is triggered/accessed, and how users interface with it (Dargan et al., 2023).

Given the breadth, range of criteria, and variance that stems from the definition and ongoing developments, this manuscript explores how to more productively advance theorization about AR technologies. We argue that there may be some theories that will be relevant to any implementation of AR (e.g., theories of perception/attention, presence theory), so there could be a productive space to use these different capabilities of AR to theorize about how specific configurations could expand on those media theories. Secondly, we argue that there needs to be a modular understanding and integration of different media theories (some that overlap with other technologies like gaming/virtual reality), which are activated based on the specific AR implementation. Third, recognizing these differences in AR could open up new room for theorization, as different features individually and in the aggregate may create interrelationships and combinations of theories that were not evident or available before. Understanding the various permutations of theories that are relevant to the study of AR can help scholars in this area better conceptualize studies and improve theoretical development overall.

Existing Typologies of Different AR Implementations

Form Factors and Display Characteristics

Early development in AR utilized the definitions it did for development purposes, because it was mostly isolated to computer science research laboratories (Liao, 2016). It took decades of development for more distinct and commercial form factors to start taking place, whether the AR is

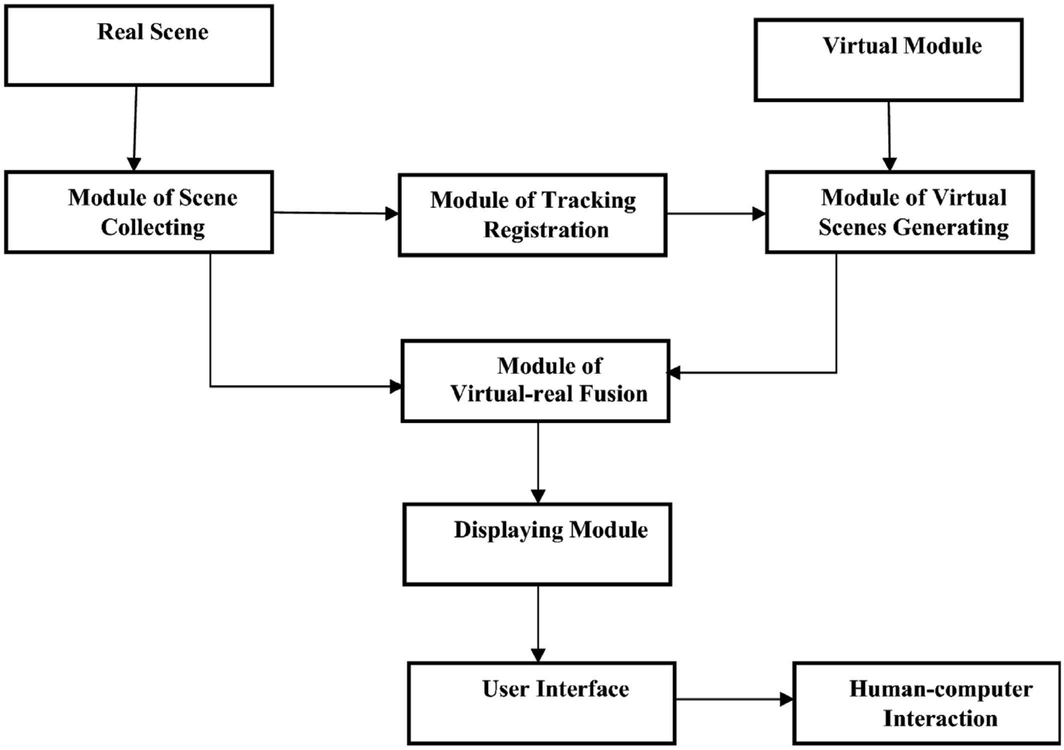

Figure 1. Pipelined framework for augmented reality system (© Dargan et al., 2023).

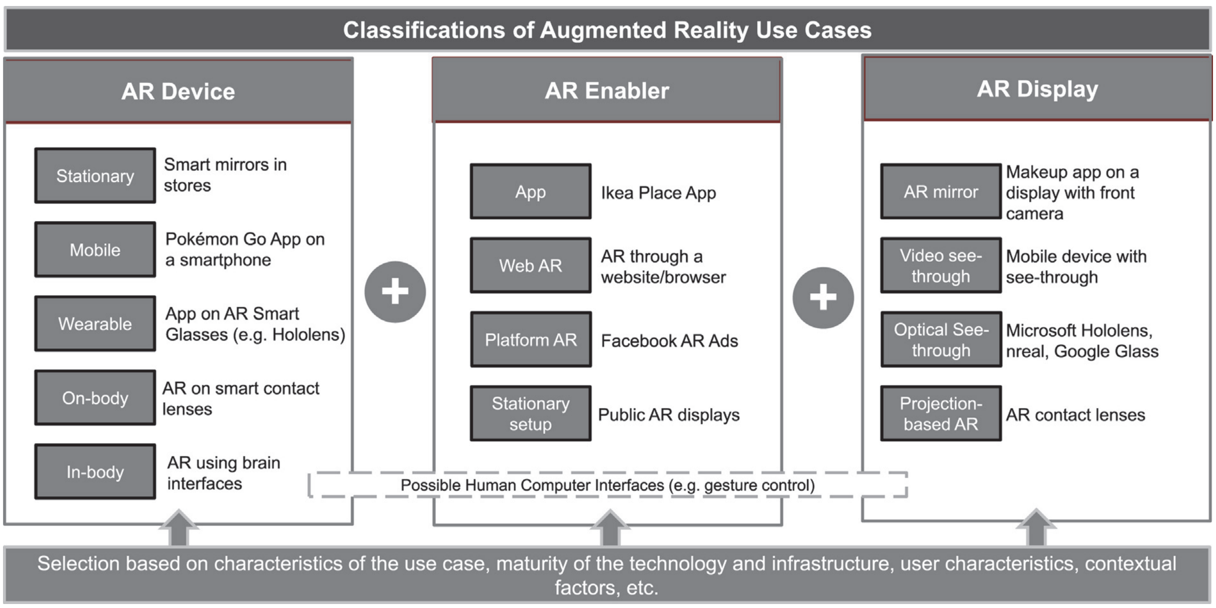

Figure 2. Classifications of augmented reality use cases (© Rauschnabel et al., 2022. Published by Elsevier Ltd. under the terms of https://creativecommons.org/licenses/by/4.0/).

stationary, mobile, wearable, enabled by web platforms, or native applications, and shown through video or optical see through (see Figure 2). These developments started to introduce differences in visual display, whether that was video see through (e.g., technology that uses images of a real scene to overlay content) or optical see through (e.g., technology that provides a direct view of the scene), even when using head-worn AR devices. Many early studies looked at mobile AR browser applications (Dey et al., 2018; Liao & Humphreys, 2015), but noted that limited screen sizes and the need to hold up a phone to access AR made the experience less rich (Liao, 2018). Some started looking at the projection-based AR systems like Microsoft HoloLens (Kalantari & Rauschnabel, 2018) and large-scale spatial interfaces (Marner et al., 2014). Depending on the hardware, the displays may be handheld or head worn, monocular or binocular, have different stereoscopic views and degrees of freedom, have differing speeds for resolution/rendering, and support a wide range of 2D, 3D, video, animation, and audio inputs/objects.

Trigger for Augmentation

Another component that is unique to AR experiences is the question of how the device activates the AR overlay (Dargan et al., 2023). While the earliest systems generated their own graphics from within the computing system (Feiner et al 1999), the advent of smartphones embedded with cameras meant that they could recognize triggers/markers to create AR, embed computer vision systems into their application for natural object recognition, and come with GPS/data signals to allow for geospatial AR in browsers. Some projection AR systems like the Hololens or Magic Leap do point cloud mapping of a space, and can project AR on top of points that are tracked (e.g., things coming out of walls, on top of tables).

The trigger/source for augmentation enables different content/display possibilities for AR experiences (Dargan et al., 2023). Geolocated content can be unrelated to the objects in the scene, whereas computer vision coming off a specific object can be tightly registered to that object and can add more on the story/visualization side. With AR, there may be some theoretical differences in who sees the AR coming out of a physical object and reacting to the scene compared to one that is only loosely hovering. There may also be different possibilities for tight AR registration to a particular trigger that are not possible with other mediums. Finally, the way that the AR is activated could affect someone's experience in their willingness to suspend disbelief for the AR media, because it is relative to our expectations and the seamlessness of the technology (Lombard & Ditton, 1997).

Input Functionality

Many new AR devices incorporate traditional button/voice/scrolling/controller inputs as well as novel systems, with some embedding motion camera systems for hand gesture tracking/recognition. The Microsoft HoloLens utilized a system that recognized an extended index finger moving up and down to click on things (called the "Airtap"), and a closed fist that opened all of the fingers was called the "Bloom" to go back to the main menu. The Apple Vision Pro utilized simple pinch motions and gestures like pinching and scrolling. Beyond gestures, some AR systems like the Apple Vision Pro utilize optic tracking to identify user eye movements as an input. Detecting eye rotation, gaze, blinks, and other eye movements can be used to select and move things in an AR headset/environment. Neural interfaces for controlling AR content have also been an emerging area of research, with many studies looking at Brain-Computer Interfaces (BCI) for AR applications in particular (Prapas et al., 2024). Interactivity is only one of the AR criteria, but the design of that has key implications for feelings of presence in AR, suspension of disbelief, and overall attitudes toward the technology itself.

Other Technological Specifications

With dozens of different AR headsets and devices released over the years, there are some other technological differences that do not change whether it is AR or not but can make a big difference in the experience. For example, one factor that could shape presence is how stereoscopic images are shown, and we have seen AR devices that are monocular (e.g., Google Glass, Vuzix M300), binocular (e.g., Apple Vision Pro; Microsoft HoloLens), and projection. Another key factor is the obtrusiveness of the medium, and here the headsets vary widely in their levels of comfort but also the seamlessness of the experience. Stimuli of the other tactile senses can occur through haptic gloves (e.g., Manus, SenseGlove, HaptX) or body suits (e.g., bHaptics, Teslasuit), and potentially accentuate the AR experience even as haptics are not a necessary condition for AR. With each of these different features and decision points, the AR device/application selected for a study and how it is implemented contains many variables, some of which are fixed and some of which can be modified. Each one may be a reason to alter the theory one chooses to analyze, or comparisons within the device/application could be ways to test those theories within a given medium.

AR Content Variables: Relationship to Space

While the form factors, enabling technologies, and types of tracking/interactivity are different, those decisions also mean that the types of content AR supports are varied and can bring its own theories to the forefront. This alone makes AR content too broad to fully categorize as a typology, but there are a few content factors to highlight that may be applicable to many AR experiences and applications.

The first is the relationship of the augmentation to space/-place, and whether the content is historically/ temporally relevant to the place in which it is experienced and observed. Some AR applications, especially those that are marker-based, may generate AR content that just floats atop the physical world with little orientation to physical surroundings. Others are geospatially oriented, and have specific relationships to the place itself, whether as a historical memory (Oleksy & Wnuk, 2016), tourism (Yin et al., 2021), crime information (Liao et al., 2020), or art/architecture (Biermann, 2018). The extent to which these augmentations are spatially relevant is important, as it relates to one's experience and construction of space and place. Several studies have utilized spatial theories from geography (Graham et al., 2013), software studies of code/space (Kitchin & Dodge, 2014), and sociology of space (Liao & Humphreys, 2015). In addition to being spatially relevant, there are other frameworks that examine the extent to which the AR is contextually integrated into the site itself (vs. just a predetermined artifact), and whether it is experientially or information-focused (Figure 3). Because by definition AR needs to be oriented to physical space, researchers have argued that the spatial/environmental context is actually a key affordance and feature of our understanding of AR as an experience (Heemsbergen et al., 2021).

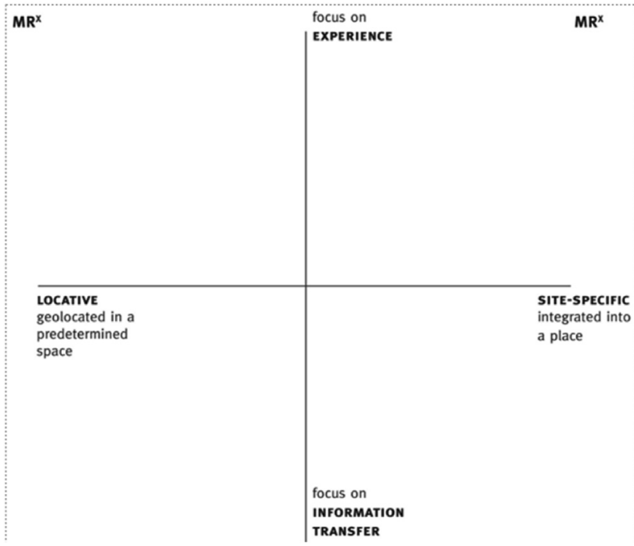

Figure 3. MR^x framework for mapping AR experiences (adopted from Rouse, R., Engberg, M., JafariNaimi, N., & Bolter, J. D. (2015). MR^x: an interdisciplinary framework for mixed reality experience design and criticism. *Digital Creativity*, *26*(3–4), 175–181, reprinted by permission of Informa UK Limited trading Taylor & Francis Gropup, https://www.tandfonline.com).

AR Content Variables: Social Interactivity and Avatars

Another consideration for AR content is how social interactions are built into these applications. Some of these AR games may represent players as avatars, and have other human-like non-player characters involved, which brings in a set of media literature and theories. The first is to consider the AR representations of one's own avatars and the antecedents or effects of using these avatars. This has received significant attention in gaming/virtual reality, so prior frameworks about avatars would certainly be applicable in AR, just with an added spatial dimension. Just as how VR may allow users to embody different avatars in immersive environments, users may also customize their avatars in AR environments.

There have been some scholars that have been trying to theorize similarities and differences between certain media across multiple dimensions. One such framework argues that one could place AR experiences on one continuum of the extent of the world that is modeled, how much the system supports certain user actions with those objects, and the coherence of the experience – operationalized by how much the virtual experience corresponds to one's expectations of reality (Figure 4).

Differences that stem from having a criteria-based definition for AR make it a uniquely challenging technology to theorize. While there are other media practices that have nebulous and contested definitions such as binge-watching (Flayelle et al., 2020; Starosta & Izydorczyk, 2020), those differences are primarily in the classification of a media practice (e.g., quantity, duration, timeframe), not in the technology that enables the practice. Similarly, while there are theories of media choice such as uses and gratifications that could potentially apply to AR broadly, those would be attempts to capture user preferences across these applications and not necessarily theorize about their effects. AR is also still in an early phase that much of the existing research has been about technological adoption of the hardware necessary to access AR (Kalantari & Rauschnabel, 2018; Rauschnabel & Ro, 2016), rather than selectively choosing between possible AR applications.

There are also a wide range of possible effect types that can stem from AR experiences, whether that is about human perception (Erickson et al., 2022), attitude (Hervás-Gómez et al., 2017), emotions (Soon, et al., 2023), behavior (Javornik, 2016), and neural/structural changes (Krugliak & Clarke, 2022). Depending on the content, the length of exposure, and the user characteristics, these effects may differ but are not being studied/theorized uniformly. One systematic review they found that 76% of AR studies were short-term exposure in experiments, and that most of these focused on issues of human perception (Dey et al., 2018). Existing AR typologies have tried to map/catalog/sort the extent of some of these dimensions, but the breadth of them is difficult to fully capture and theorize about.

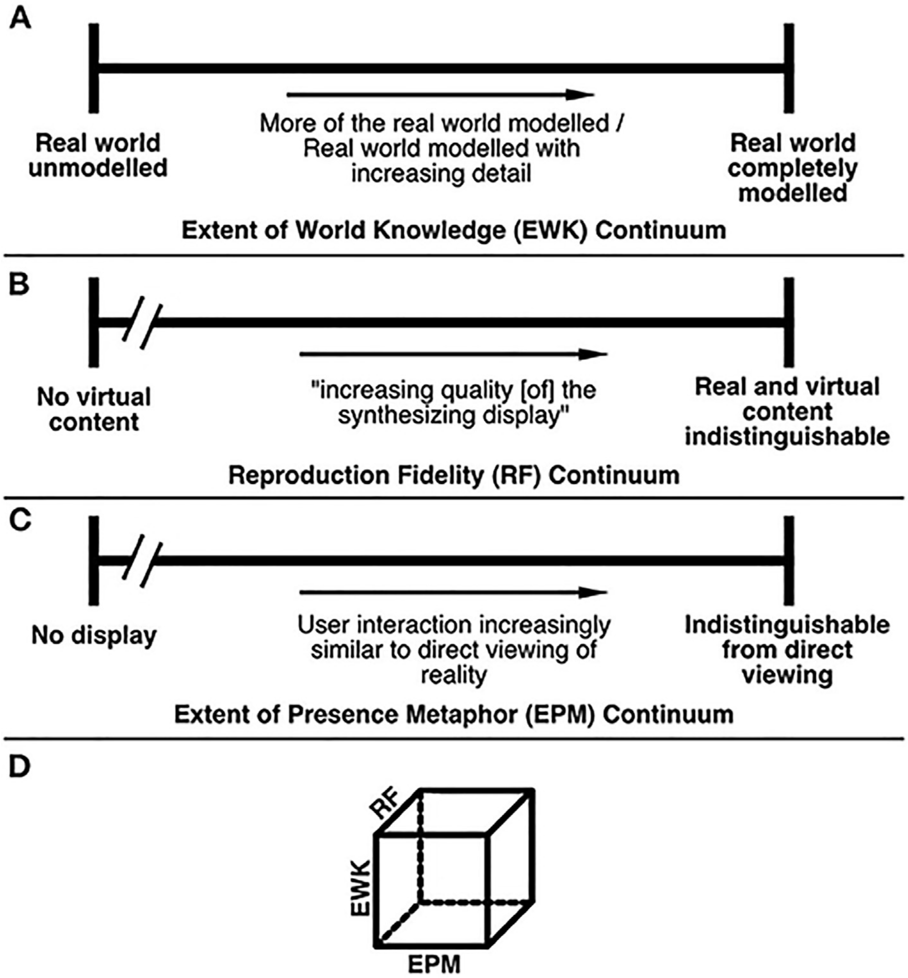

Figure 4. Revised taxonomy of MR experiences (© Skarbez et al., 2021. Open-access article distributed under the terms of the http://creativecommons.org/licenses/by/4.0/).

Utilizing General Media Psychology Theories Applicable to All AR implementations

While the section above captured the many differences in AR implementations, the fact that any AR by definition will have a 3-D representation that mixes the real and the virtual means that there will be opportunities for AR applications to extend certain theories. First is presence theory, where AR media should to some extent induce one's "perceptual illusion of non-mediation" (Lombard & Ditton, 1997, Presence explicated) (i.e., experiencing AR-generated content as if they were real). Explications of presence have identified multiple dimensions: presence as social richness, presence as realism, presence as transportation, presence as immersion, presence as social actor within the medium, and presence as medium as social actor (Lombard & Ditton, 1997). From these early conceptualizations, the development of theories of presence have evolved from the two-pole model (i.e., physical vs. virtual spaces), the three-pole model (i.e., virtual space – physical space – mental imagery space) (Biocca, 2003), and the focus-locus-sensus model (Waterworth & Waterworth, 2001) to more complicated frameworks such as the cognitive model of spatial presence (Wirth et al., 2007) and the capacity limited, cognitive constructivist (CLCC) model (Nunez, 2007). Presence theories are an attempt to make sense of all types of media in a wide range of forms and modalities, which makes it important to be connected to AR and all the different variations within AR.

Presence studies have long found that technological factors/limitations affect certain presence outcomes, where the form factor of certain media (e.g., resolution, screen size, viewing distance, etc.) will contribute to a sense of presence (Lombard et al., 2000). AR technologies may vary in how wide the field of view is and the degrees of freedom/immersion, which could allow researchers to extend our understanding of presence theories based on some of these differences and interrelationships between how

AR objects are represented alongside physical objects. The degrees and types of presence that emerge, under what conditions, and what configuration of AR implementation will lead to these effects can be theorized within our existing understanding of presence and scales, with AR extending these models (Georgiou & Kyza, 2017).

Similarly, AR can help broaden the existing theoretical debates that are occurring within media about visual perception and attention/processing. At the basic level of visual perception, adding something to one's visual sphere with AR will challenge some of our basic perception systems. While we have well-developed frameworks for how human beings process depth in physical space (Cutting & Vishton, 1995), augmentations could provide their own depth cues (e.g., occluding objects) while also diminishing the number of depth cues in a scene (e.g., ratios between objects, base height of an object, relative size, etc.). Another goal of AR may be to reveal objects covered by physical objects, or "X-ray vision." In these instances, the depth cues that are provided may be ambiguous or otherwise confusing. Some proposed solutions may be to add differing levels of transparency to the scene to delineate what is augmented and what is real, but there is still a gap in theorizing how people will process the "Superman X-Ray problem," whereby "if the user sees all depth layers of a complex environment, there will be too much information to understand the depth ordering" (Livingston et al., 2003, p. 57).

There are many theories of media attention such as Elaboration Likelihood Model (Petty, 1986), Heuristic Systematic Model (Eagly & Chaiken, 1990), and Dynamic Human-Centered Communication Systems Theory (Lang, 2006). For example, AR could be a useful application to test some of the existing debates within attention theories, specifically between those who argue for the unitary attention perspective that attention can only be deployed in a single contiguous region (Jeong & Fishbein, 2007; Murray, 2012) and those who argue for the split attention perspective that attention can be deployed in noncontiguous locations (Awh & Pashler, 2000; Muller et al., 2003). For media psychologists, the overriding goal is "general theory that encompasses all kinds of communication, [...] interpersonal communication, mass communication, human–computer interaction, human media interaction, social media, message processing, digital gaming, virtual realities, and all the types of human communication not listed here or not yet invented." (Lang, 2006, p. 60).

The variants within AR then become important tests of the boundaries of these theories, as certain conditions of AR have been found to trigger central route processing which can accentuate perceptual and persuasion effects (Jayawardena et al., 2023). In addition to higher levels of attention, the isolated viewing condition from AR may remove outside social response cues and second screen distractions, which has been an increasing factor in studying people's media viewing (Van Cauwenberge et al., 2014). At its worst, AR could be like the random blue lines in a visual scene that distract people from their primary task (Ophir et al., 2009), whereas at its best it could be designed to work with our attention systems to cue us toward the primary task and mitigate issues like in attentional blindness (Lu et al., 2012).

For general media psychology theories such as presence, perception, or attention, the ambiguity of the AR definition does not necessarily pose a challenge, because they are intended to account for a broad range of media experiences and technologies. What AR allows for is a novel context in which to explore questions of presence/perception, because by definition AR will activate some 3-D component that interacts with physical space (Azuma, 1997). Studies about AR could make important contributions to these theories as long as researchers (1) are clear about the specific operationalization of AR they are examining to make these theoretical claims and (2) understand that there may be factors/configurations of AR beyond the visual/3-D/interactive definition and criteria that play an intervening and potentially additive role to the effect, whether that is other modalities of sound/touch, the design of the application, content, and technological features/accessories.

Bringing in Theories That Are Contingent/Situational to the AR Implementation

While presence/perception frameworks may apply to all AR applications/devices, the relevance of some theories is contingent on a particular operationalization of AR. This section highlights some of the common ones that stem from certain content/technological components of AR that may be present in some (but not necessarily all) AR implementations.

Embodied Avatar Theories

While not necessary to meet Azuma's (1997) definition of AR, there can be implementations of AR that try to recreate/simulate interactions with human beings. This would draw on theories of avatars for the self and others, where researchers have proposed the proteus effect or homuncular flexibility to understand how individuals are visually represented in augmented spaces. The proteus effect indicates that individuals will likely demonstrate the expected behavior or attitudes based on their avatars' appearances or attributes (Fox & Bailenson, 2009; Ratan & Hasler, 2009; Yee et al., 2009). Homuncular flexibility refers to the idea that users have the flexibility to be adapted to novel bodies in virtual environments (Won et al., 2014). Users can not only embody humanlike avatars but also non-humanlike ones (Won et al., 2014).

Both frameworks can be applied to understand the effects of avatars in AR environments, but the continuum for AR is broader to encompass partial avatarization and body accessorization. A few studies have been theorizing about self-perception and effects after seeing and utilizing AR face filters (Fribourg et al., 2021; Javornik et al., 2022). Theories of the self-have also looked at body perception in AR and how people see versions of themselves in the mirror (Nimcharoen et al., 2018). There are also ways that AR could uniquely merge or accentuate faces and other body parts, such that theories of aging and self-continuity may become uniquely relevant (Hershfield, 2011).

User Interaction/Haptics

AR by definition includes interactivity, and an individual can thus experience an embodied interaction, processing and acting through the devices, augmented content, and real environment at the same time (Dourish, 2004). This embodied interaction can occur with inputs/feedback through button, voice, controller, gesture, eye tracking, vibration, and tactile/haptic, which can help us understand how particular affordances lead to certain effects/behavior and how individuals engage with AR content in meaningful ways. Because interactivity is one of the Azuma (1997) criteria but only loosely defined, the theory of interactive media effects (TIME) would be something that could explain/predict certain outcomes (Sundar et al., 2015). The TIME model suggests that affordances of media interfaces can activate psychological mechanisms via two routes. The cue route highlights that certain modalities, agency, and navigability of interfaces can trigger cognitive heuristics (i.e., mental shortcuts). The action route suggests that certain interface/motivational attributes can then explain users' actual behavioral responses to these interfaces. With AR, there may be a way that users interface with the device that is either aligned with and supporting the interactivity of the AR content, or existing separately/independently of the AR interaction, which complicates the actualization and theorization of these affordances (Shin, 2022).

AR experiences can also be supplemented with gestural/haptic feedback, which works to pair the sensory experience with the physical, to more completely replicate and mirror physical embodiment and sensation (Biocca, 1997). Media psychology has long theorized that the haptic/tactile route could complicate and accentuate one's media experience, whether through enhanced presence, cognitive absorption, and/or emotional resonance (Brodie et al., 2011). The pathways by which these physical input/feedback systems start to interact may work differently than just the 3-D component of AR alone, stimulating cognitive and emotional processes that enhance memory retention and immersion (Sundar, 2008). The power of touch as a research area has also looked at tactile awareness, tactile attention, tactile arousal, and the biological/neurological substrates of touch (Gallace & Spence, 2014). Tactile feedback is not a part of the AR definition, but is increasingly becoming a significant accessory to the experience such that researchers will need to start integrating these theories into the broader AR landscape.

Computer-Mediated Social Relationship Theories

Like other technologies, the draw for many people is the applications that aid human social connection. A number of companies are working on AR shared spaces, whether for work or for socializing, that enable users to visualize themselves and interact with others in AR environments. Shared workspaces and remote AR collaboration have been a common feature for enterprise applications and devices (e.g., Microsoft HoloLens, Mesh, Campfire, etc.), and applications like *Immersed* attempt to bridge devices, create avatars, and allow users to launch teleconferencing meetings with other users. The Apple Vision Pro also facilitates social interactions through its own FaceTime app with a custom-generated "persona." When the AR supports real/simulated human interactions, then a long history of computer-mediated communication and human-machine communication theories can be used to understand users' relationships in AR spaces (Guzman, 2018). For example, the social identity model of de-individuation effects (SIDE) suggests that an anonymous environment can enhance the group influence in contexts where a shared group identity can be formed (Spears & Postmes, 2015). When studying group communication contexts in AR spaces, some theories like SIDE are worth exploring to understand the group effects of avatars and users' conformity to group norms.

In some applications, people can interact with AR agents (either real human beings or AI agents). With AI agents, the application of human-machine communication/human-computer interaction theories could be instructive. One example of this would be using the AI-powered agent Replika, which has an AR function that places a human-like avatar in users' physical space and responds to them through gestures and voice. Here, to understand individuals' social responses to AR agents, media equation has indicated that users' interactions with media technologies are "fundamentally social and natural" (Reeves & Nass, 1996, p. 5). When media technologies are designed with social cues, individuals will likely apply interpersonal social scripts to human-computer interaction and respond to these technologies in a social manner (Nass & Moon, 2000). A recent study that has applied media equation to understand users' social interactions with AR agents suggested that participants avoided sitting on a chair occupied by an augmented human-like agent (Miller et al., 2019). Other studies have found that AR agents that are programmed to respond to the physical environment (e.g., turning around to acknowledge a real object dropping) can increase one's perception of the agent as human-like and interactive (Pimentel & Vinkers, 2021).

Isolating, Combining, or Transforming AR Theory

While one might look at the variance of AR technology (e.g., form factor, sensory features, interactivity/inputs, spatial/social content, etc.) and the disparate theoretical landscape of media psychology research that are relevant to our understanding of these systems and conclude that theorization will continue to be difficult and ad hoc, our argument is that understanding this complexity is the first step and an opportunity for researchers to push out theory with AR.

The first approach might attempt to utilize some of these differences to isolate the precise features, variables, and factors with AR and each implementation to see which ones were actually related to certain effects and in what proportion. This would build on the first wave of AR research that compared AR experiences with non-AR experiences. Those findings may have found an effect, but are difficult to theorize about because each implementation of AR is really a bundle of decisions and dozens of variables compared to the absence of those variables. Parsing out different AR experiences in relation to other AR experiences could help disambiguate the real sources of these effects, the proportions of them, and help more fully build out these theories by taking advantage of novel features/differences of AR that may not be present in other types of media (e.g., real-virtual spatial relationships, partial vs. full field of view, controller/device interactivity vs. natural gesture object interactivity). Some early theorization in this area has been happening in the VR space, where researchers have looked at differences in form factor and content/spectacle to see which contribute to sensations of awe (Lin et al., 2024). There have also been similar attempts with AR and presence to determine the antecedents to presence (Lombard & Xu, 2021), or which configuration of social cues will be the most impactful in any given communication setting. Continuing to develop and test these individual components theoretically is important and increasingly possible with newer commercial AR devices, but the challenge may be that there are simply too many permutations, uses, and new developments in AR technologies to properly theorize, especially if we only analyze them unidirectional and in isolation.

Another path forward for theorization may be to try to view each implementation of AR as a combination of variables, understanding that each factor within an AR implementation may bring in its own set of media theories, and try to utilize that AR implementation to bridge and merge several media theories. This approach takes a more systems approach to theorization, which argues that none of the variables about AR implementations exist in isolation. The features of the device will affect the users' attention, interface experience and motivation to process the AR. The content of the AR will affect the perception of the device and interactivity required. For example, suppose one wanted to study how users interacted with an AR-based virtual human like Replika, where the individuals may receive Replika's messages with various cues (e.g., memes, exaggeration of tones, punctuation marks, or typing bubbles). Meanwhile, during the conversations, Replika as the augmented character may also demonstrate subtle facial expressions and body language. In this process, to understand the communication between users and Replika as a whole, researchers may need to bring in computer-mediated communication theories such as the social information processing theory to understand the accrual of interpersonal closeness with Replika. Meanwhile, these facial expressions and body language may evoke users' social presence experience, which determines how much users perceive Replika as social, communicative, and life-like. A third layer that captures this phenomenon circles back to attention allocation, which may account for how much attention and cognitive efforts individuals allocate to Replika and their own physical spaces. In this scenario, there could be a space where social information processing theory could be combined with attention theories or presence theories, through which the impression formation of Replika may be dependent upon individuals' suspension of disbelief, attention allocation, and cognitive loads. All these theories could be brought in to understand the phenomenon of interacting with an AR agent in one's physical space. This approach argues that researchers should recognize and understand the range of possible differences in AR, but then realize that each feature and choice within their AR implementation will activate a set of media theories based on the design. Taking a systems approach would aim to draw on the relevant user, device, and content theories and theorize about how AR could speak to a merging of different theoretical perspectives (see Figure 5).

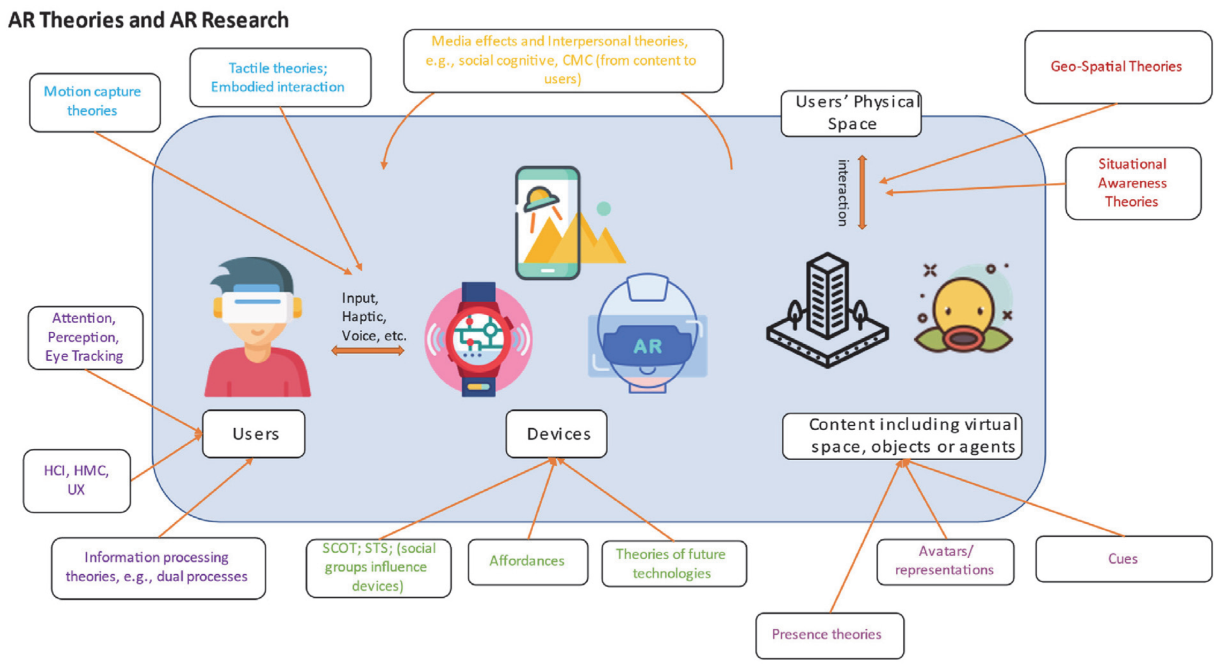

Figure 5. Integrated theories across different AR experience conditions.

The last theoretical approach scholars could take may be that there is something unique about the AR experience and interactivity that alters our existing understanding of operational media theories. For example, the first generation Apple Vision Pro utilizes eye tracking and foveated rendering to select different icons/parts of the scene, and came without a controller in favor of gestural pinches. Therefore, in order to activate that particular usage of AR, one needs to already engage in a biomechanical action of directing one's eyes (and in theory attention) to the object through their gaze and align that with their hand motions. This demonstrates how there may be transformative theorization about AR that is necessary, because this merging of biomechanical actions with interactivity could supersede other media theories (e.g., central route processing is a precondition of the experience not a byproduct), or create an operational condition that alters the assumptions/directionality of certain media psychology theories. In this example, if users are required to gaze directly at objects in order to utilize the AR, central route processing may be a feature of AR rather than a response to certain media cues. It may be that the central route processing required by the eye tracking interface is what leads to a particular response, before getting into the specifics of the AR content. This may similarly be true about other tactile inputs, spatial rendering, and other feedback, that the combination of multiple different systems of processing (e.g., visual, tactile, spatial) may override the other factors/determinants of media effects and necessitate new AR specific versions of these theories.

While this is only one example, we are already seeing how certain commercial developments in AR can limit certain physical interaction modalities (e.g., eye tracking, gesture only), which may change our orientation to that version of AR in terms of what it asks of users to operate it (Chesher, 2023). A researcher utilizing our typology and understanding this complexity could start to think about a particular implementation of AR and see how it might foreclose some possibilities and accentuate/necessitate others. Some implementations may require a more active experience than certain passive media theories, and some may fundamentally alter the orientation of the user to the media in ways that make certain media theories more salient and others less explanatory.

Conclusion

While this article identifies some of the most recent developments in the literature vis-a-vis the definition and development of the technology, it is by no means exhaustive. The goal of this piece is not to map every single place where AR may be distinct and come in different permutations, but to isolate the major factors and show how those differences matter a great deal for theorization. Rather than simply adding more research onto a contested definition of AR, this article aims to make sense of the technological criteria and how researchers could tie those back to universal theories about users' presence and attention across AR implementations, or to isolate/compare theories that stem from certain AR features. To better understand metaverse-mediated communication in the future, we hope that this article encourages AR scholars to extend theories beyond just comparing AR versus non-AR effects, but to more granular components, features, individual processes, and factors within and across AR implementations. In order to address the question of how established theories can inform AR research and vice versa, we must first consider the full gamut of technological differences, technological possibilities, and the combination/sequencing of these features in AR usage to know which possible media psychology theories need to be brought in and combined in various ways.

As a new generation of mobile applications, headsets/glasses, and spatial computing systems are bringing AR more to the mainstream, media researchers will increasingly have to consider how to understand these technologies in relation to existing media literature/theory or in the context of antecedent/related technologies. We need this baseline to build on for the next developments/adoptions in AR, whether it is extended usage, the ability to seamlessly switch across the mixed reality spectrum from AR to VR to reality and back again, and continued adoption of wearable/haptic technologies that sync with AR. The future development of AR could be as a collection of standalone devices/applications, as a feature integrated into other media (e.g., AR facial filters, Pokémon GO, etc.), or as a ubiquitous visual medium that enables all other types of media on it (e.g., Apple Vision Pro). Based on our framework of theorizing across the AR spectrum and theorizing based on specific AR implementations, we hope that the future AR media psychology researchers can start to center their theorization around AR as a specific context to make key contributions to existing theories, make the case for how to generate combined/transformative AR theories, and broaden/challenge some of what we know based on existing media psychology theorization.

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