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Abstract:

Augmented reality (AR) as an innovative technology has changed the way people use technology for interaction and communication. While researchers have studied the application of AR, research on AR as a communication medium remains scant. In this study, we investigate the effect of AR factors (namely, interaction, visual canvas/cues, and immersion) on AR-mediated communication. We apply design science research (DSR) guidelines to design, develop, and evaluate an AR artifact. We derive the design elements based on interactivity, media naturalness, and immersion theories and develop the AR artifact as a mobile app in an iterative manner. We evaluate the design product through the informed arguments and scenarios method, and the design process by assessing its conformance to DSR principles. We show that AR factors' design elements—interaction (user controls, contextual tasks, and ergonomics), visual canvas/cues (realistic 3D models, visual and audio cues, and aesthetics), and immersion (diverse components)—play a critical role in AR-mediated communication. Furthermore, high-quality product visuals and interactive user controls give users a good AR experience. From a practice perspective, AR app designers may incorporate the design process we used in our study and generate AR experiences that fully exploit AR media's communication affordance. We contribute to knowledge by using DSR guidelines for designing and developing AR as a communication medium.

Keywords: Augmented Reality, Interaction, Immersion, Visual Canvas/Cues, Communication, Design Science Research.

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1 Introduction

Augmented reality (AR) technology adds layers of virtual objects onto the real world, which gives users an illusionary experience of reality. Azuma (1997) defined AR as "an extension of the virtual world which combines both the virtual and real". AR technology has established itself as a new form of communication following its widespread adoption across the health, education, retail, manufacturing, tourism, and gaming industries. Researchers have studied AR in varied uses and contexts, such as AR in newspapers (Frohlich et al., 2017), advertisements (You et al., 2014), business presentations (Zarraonandia et al., 2014), route guides (Coovert et al., 2014), aides to senior citizens (Meneses Fernández et al., 2017), and digital shopping (McLean & Wilson, 2019). However, though researchers have applied and studied AR in several real-world phenomena, they have not yet fully explored its potential as a communication medium.

AR is a digital communication technology that supports visual, linguistic, and audio transmission. Digital communication refers to an information-transmission process via novel interventions that information and communication technologies facilitate (ICT) (Flanagin, 2020), such as email, voicemail, instant messengers, audio and video conference. ICT offers several affordances such as communication, collaboration, accessibility, speed of change, diversity, reflection, multi-modality, linearity, risk, fragility and uncertainty, immediacy, monopolization, and surveillance (Conole & Dyke, 2004) to its users. The hyperpersonal model (Walther, 1996) states that users exploit available technological affordances. For example, text and voice-based communications vary in their technological affordances to communicate and yield differing benefits. Whether ICT succeeds depends on how effectively it communicates information. However, extant research on digital communication has focused on technology rather than communication behaviors (Whittaker, 2003). The advent of AR raises new questions on how it enables communication affordances and transforms user communication. Hence, we need to study AR for its potential as a communication medium.

Azuma (2016) proposed that AR should assume its role as a new communication medium different from traditional media, such as books, movies, and even virtual reality (VR), and become more ubiquitous in consumer lives. Azuma (2016) posited: "How will we establish augmented reality as a new form of media, enabling new types of experiences that differ from established media?". To answer this overarching question, we need to assess the state of AR adoption thus far. Grzegorczyk et al. (2019) found AR attractive in the education, medicine, and tourism industries. However, because the medium conveys a significant amount of information, users could become easily overwhelmed, which could cause a bottleneck for AR adoption (Martínez et al., 2014; Ejaz et al., 2019). Furthermore, the multiple AR design tool choices further accentuate the issue (Nebeling & Speicher, 2018). These concerns underscore the challenges in AR adoption and the important role that application design plays in improving AR experiences and, thereby, its adoption.

Ashtari et al. (2020) identified eight critical barriers in creating AR applications, five of which relate to design and evaluation. Irshad and Rambli (2016) discovered several design shortcomings that impact the AR experience and proposed design guidelines for creating AR applications. Endsley et al. (2017) discussed the importance of AR application design and determined a set of design heuristics to improve application usability. Gartner (2018b) considered poor interface design as the reason for the slow AR adoption, the only exception being Pokemon Go (Gartner, 2020). Industry-designed AR applications have not met expectations on many fronts (see Table A1 in Appendix A) and, in many cases, tumbled into the uncanny valley (Mori, 1970), which describes how a sudden drop replaces the initial pleasantness and realism that one experiences when engaging with an AR application once the novelty effect wanes. Research has shown that design plays a critical role in generating novel and usable AR experiences. In this research, we design an AR application using extant theories to help in AR-mediated communication.

The media factors inherent in AR technology drive how one designs AR applications. Lister et al. (2008) identified new media factors—digital, interactive, hypertextual, virtual, networked, and simulated—and AR as the technology possessing these factors. One needs to incorporate these factors when designing an AR application design for it to succeed. Existing AR applications may offer insight into developing AR as a new communication medium. However, we feel that their creators adopted suboptimal approaches. Current AR applications have neither incorporated all these AR factors nor fully exploited them. Additionally, hardly any research has shown these factors embedded in application design. Hence, to bridge this gap, we design an AR application from the ground up, embed these AR factors with support from existing theories, evaluate the AR application, and understand what impact the factors have on communication.

Gartner (2018a) identified AR as one of the top strategic technology trends. The industry expects the global AR market to reach US$61.39 billion in 2023 up from $4.21 billion in 2017 based on a 40.29 percent compound annual growth rate (CAGR). Many see AR as a strategic technology, and the expected growth in the AR market warrants a design study. Gartner (2018a) noted that AR applications would increase user productivity and add value to how users engage with the real world. One can study AR technology from a user-technology or a user-user perspective. We focus on the former in this study (i.e., users' interaction with AR technology). Devices such as mobile phones, tablets, desktops, wearables, and non-wearables support AR technology, and a device's characteristics might influence communication with the help of AR technology. However, we do not focus on device characteristics and their potential impact on AR as a communication medium.

We follow the DSR methodology in information systems as it helps one solve design problems and advances theory (Hevner et al., 2004). Hevner and Chatterjee (2010) opined that "the fundamental principle of design science research is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artifact". DSR also helps one reduce the ad hoc nature of industry-developed solutions by creating purposeful and innovative IT artifacts through rigorous design and evaluation (Hevner et al., 2004), and IT managers can leverage it. Furthermore, DSR bridges the gap between academic and industry practices. In this research, we apply DSR to develop a novel AR artifact (applying design framework in building an AR artifact that leverages AR factors) that addresses a particular business need (an AR experience of a retail product). Researchers have applied DSR in different studies (Elia et al., 2019; Kao et al., 2016; Chang et al., 2016; Prinz et al., 2021), but, to our knowledge, ours constitutes the first to apply DSR to design an AR artifact.

Ultimately, DSR allows one to synthesize design knowledge (DK). Venable (2006) conceptualized DK in a model that comprised three simple components: 1) problem space, 2) solution space, and 3) evaluation. The problem space comprises the application context and the goodness of criteria (Vom Brocke et al., 2020). We identify the AR design features that influence communication effectiveness. One can apply these design features across multiple use contexts such as education, retail, manufacturing, games, and tourism (*space*) and supports end users' (*stakeholder*) in the present digital world (*time*). From the goodness of criteria perspective, we focus on AR factors embedded in an AR artifact that enrich the user experience (*human interaction*) and assess the AR artifact for utility, efficacy, and quality (*information value*). The solution space comprises representation and process (Vom Brocke et al., 2020). From a representation perspective, we instantiate an AR artifact (*design entity*) based on extant theories from social science and develop nascent design theory that gives explicit design prescriptions that one can use to design the AR artifact (*design theory*). From a process perspective, we use DSR iterative design-evaluate cycles (Hevner et al., 2004). We use the DSR evaluation framework to evaluate the design artifact and design process.

DK comprises design entities and design theories (Drechsler & Hevner, 2018). Vom Brocke and Maedche (2019) classified DSR research into three types based on design entities and design theories. With this research, we contribute to both design entity and design theory. The design entity refers to the AR artifact that we developed from the design processes using DSR guidelines. We produced prescriptive knowledge about designing AR artifacts that contributes to the design theory. Routine design practice applies best practices in artifact creation, and it does not create any new knowledge and, hence, does not qualify as a DSR (Hevner & Chatterjee, 2010). DSR involves creating new knowledge and understanding a design problem and its solution during the artifact-creation process (Hevner & Chatterjee, 2010). The design knowledge synthesized from this research helps bridge the gap in embedding AR factors in designing any AR artifact. Further, the design knowledge connects the problem and solution space in a specific context in which one uses AR as a communication medium.

We incorporate AR factors in designing and evaluating an AR artifact. First, we identify the AR factors from communication theories. Second, we design an AR artifact that espouses AR factors using DSR methodology. Third, we evaluate the design product (AR artifact) and the design process (DSR methodology) using a DSR evaluation framework. AR continues to make inroads as a computing innovation, and many expect it to become a staple in everyday life similar to other communication media such as television, email, and video conferencing. As AR adoption proliferates, industry practitioners will look to unlock AR's full potential as a communication medium, and our study will guide AR designers and industry practitioners in designing AR artifacts.

We follow Gregor and Hevner's (2013) schema for presenting DSR in this paper. Thus, in this first section, we discuss the problem, its significance, objectives/goals, and the methodology we adopted. In Section 2, we review the existing literature and communication theories that support AR factors. In Section 3, we discuss the DSR methodology that we followed in this research. In Section 4, we discuss the design principles we used to incorporate AR factors in our artifact. In Section 5, we discuss the evaluation method, evaluation criteria, and framework we used to evaluate the AR artifact. In Section 6, we discuss our research findings and implications, make suggestions for research directions in the future, and conclude the paper.

2 Literature Review

2.1 Augmented Reality

Azuma (1997) described an AR system as a system that augments the real world with virtual computer-generated objects and enables real-time interactions with the system. AR means adding something to reality and creating a projection as if the reality has changed when it has not. Milgram and Colquhoun (1999) modeled the real and virtual worlds as two opposite poles along the reality-virtuality continuum. Reality and virtuality differ in that a real environment includes living organisms as objects, whereas a virtual environment includes only non-living (virtual) objects. AR mixes reality and virtuality such that virtual objects seem to co-exist with real objects.

The literature has defined AR in several ways (see Table 1). Researchers often quote Azuma's (1997) definition as it defines AR technology characteristics succinctly. Milgram and Kishino (1994) define AR more broadly and do not identify AR technology characteristics. The definitions from Reitmayr and Drummond (2006) and Van Krevelen and Poelman (2010) view AR technology through the lens of computing devices. These AR definitions focus more on virtual objects and AR technology's interactive nature rather than outcomes from using AR technology. We find extant definitions as restricting AR to technology capabilities. We view AR from a communication perspective and its potential as a communication medium. Therefore, we define AR as communication technology that super-imposes a visual canvas that contains virtual objects on the real world in real time, enables users to interact with the virtual objects, and provides an immersive user experience that results in successful communication outcomes for users when using the AR media.

Table 1. AR Definitions in the Literature

Study	AR definition
Milgram & Kishino (1994, p. 4)	*Augmented reality refers to any case in which an otherwise real environment is "augmented" using virtual (computer graphic) objects.*
Azuma (1997, p. 2)	*Augmented reality is an extension of the virtual world that combines both virtual and real and has the following three characteristics: 1) combines real and virtual 2) interactive in real-time 3) Registered in 3-D*
Reitmayr & Drummond (2006, p. 1)	*Augmented reality is a promising user interface technique for mobile, wearable computing, and location-based systems.*
Van Krevelen & Poelman (2010, p. 1)	*Augmented reality supplements the real world with virtual (computer-generated) objects that appear to coexist in the same space as the real world.*
Carmigniani et al. (2010, p. 2)	*Augmented reality is a real-time direct or indirect view of a physical, real-world environment that is enhanced/augmented by adding virtual computer-generated information.*

2.2 AR Factors

We reviewed papers that discussed AR factors directly or indirectly to identify and distinguish AR factors that pertain to our study. To do so, we analyzed studies from among 13 journals in the combined basket of Senior Scholars' basket of journals (SSBJ) (Association for Information Systems, 2021) and Special Interest Groups (SIG) journals on human-computer interaction (HCI) to ensure we obtained high-quality research from credible sources. The SSBJ covers information systems journals and includes *European Journal of Information Systems* (*EJIS*), *Information Systems Journal* (*ISJ*), *Information Systems Research* (ISR), *Journal of the Association for Information Systems* (*JAIS*), *Journal of Information Technology* (*JIT*), *Journal of Management Information Systems* (*JMIS*), *Journal of Strategic Information Systems* (*JSIS*), and *Management Information Systems Quarterly (MIS Quarterly)*. The information systems (IS) academic community widely recognizes these journals as having methodological rigor, international leadership, and diverse content (SSBJ, 2021). The College of Senior Scholars has also recognized some journals from the AIS Special Interest Group (SIGs): *AIS Transactions on Human-Computer Interaction* (*AIS THCI*), *ACM Transactions on Computer-Human Interaction* (*ACM TOCHI*), *International Journal of Human-Computer Studies* (*IJHCS*), *Human-Computer Interaction* (*HCI*), and *Computers in Human Behavior* (*CHB*). We identified papers from these journals through a systematic search in the EBSCO database.

We performed the search with the following keywords: “augmented reality”, “AR factors”, “AR mediation”, and “AR communication”. Upon collecting the papers, we removed the ones that made only a cursory reference to “augmented reality”. Next, we excluded papers related to AR engineering-related themes and papers that used AR in a broader context such as mixed reality or virtual reality. Finally, we reviewed the remaining papers in detail to synthesize the AR factors that they discussed. Overall, from the literature review, we identified several factors; namely, interaction, visual interface, immersion, interactivity, virtuality, connectivity, location specificity, mobility, visualization, visual cues, collaboration, telepresence, local presence, visual projections, visual appeal, enjoyment, and excitement. Some AR factors such as connectivity, location specificity, and mobility relate to device characteristics. In this study, we include only AR factors that support AR-mediated communication. We logically group the factors into three distinct categories due to their similarity and relevance in communication: 1) interaction, 2) visual canvas/cues, and 3) immersion (see Table 2). We summarize the AR factors in Appendix B.

Table 2. AR Factors

AR factors	Similar AR factors from the literature
Interaction	Interaction, interactivity, collaboration
Visual canvas/cues	Visual interface, visualization, visual cues, visual projections, visual appeal
Immersion	Immersion, virtuality, telepresence, local presence, enjoyment, excitement

Users interact with AR media just like other communication media such as television, websites, and mobile devices. AR technology can offer an interactive medium and allow users to experience virtual content in a real-world environment. Steuer (1992) defined interactivity “as the extent to which users can participate in modifying the form and content of a mediated environment in real time”. AR helped patients interact with insects and overcome specific phobias in clinical therapy sessions (Botella et al., 2011). Martín-Gutiérrez et al. (2015) found that interaction with three-dimensional (3D) electric machine models in AR helped students’ autonomous studying and improved their laboratory collaboration with other engineering students. Yilmaz (2016) studied AR-embedded educational toys and found that teachers and children liked interacting with 3D models and Flash animation and suggested that one should design interaction and collaboration according to children’s cognitive level. Fonseca et al. (2016) identified AR as offering new interactive and collaborative methods to visualize architectural and urban models as an informal way of learning. Dube and Ince (2019) showed that AR interactions help generate effective and efficient choreography compared to VR, mobile, or personal computer (PC)-based media. Interaction allows users to manipulate virtual 3D content in real time.

The AR experience is synonymous with rich visuals. Projecting visually rich information such as pictures, 3D models, and audio-visual content in real time provides sensory stimulation to users. Researchers have described visual canvas/cues as an AR factor variously as visual layer, visualization, visual cues, and visual appeal. In a study on spatial augmented reality (Coovert et al., 2014), robots projected arrows and simplified maps as visual cues as a signal to effectively communicate intended movement. Chung et al. (2015) found that the visual appeal of an AR application for tourist destinations affected its perceived usefulness and ease of use. Similarly, Akçayır et al. (2016) suggested that visual appeal—made possible through videos, animations, and images—helped students visualize molecules in a laboratory setting and enhance their science learning capabilities. Vanneste et al. (2020) found that machine operators who received instructions via AR performed better than operators who received instructions via traditional media. Operators using AR instructions produced fewer errors when compared to operators using traditional instruction media and experienced less stress. Che Dalim et al. (2020) found that a system that visualized colors, shapes, and spatial orientation helped non-native young children learn English easily and quickly and that they found the experience enjoyable. These studies emphasize visual canvas/cues as a critical AR factor to generate a rich AR experience.

Georgiou and Kyza (2017) defined immersion as a multi-level continuum that grades users’ cognitive and emotional responses to experiences and as comprising three stages: engagement, engrossment, and total immersion. Sylaiou et al. (2010) found that users experienced a “sense of presence” when experiencing cultural objects in a museum in AR. They positively correlated the sense of presence with enjoyment. Verhagen et al. (2014) demonstrated that the extent to which users perceived “local presence” (in other words, their engagement in the present) highly predicted product touch and product likability in AR-based product presentations. In psychotherapy, patients’ continued engagement with virtual small animals in AR helped them reduce their animal phobias (Wrzesien et al. 2015). Suh and Prophet (2018) described AR as an immersive technology and identified immersion as a cognitive response by users in response to AR technology stimuli. This cognitive response can manifest in different ways such as enjoyment, excitement, or local presence. Verhulst et al. (2021) observed that users enjoyed and found AR and VR effective immersive storytelling tools in a cultural institution. Georgiou and Kyza (2021) found that students experienced increased immersion and high conceptual learning when exposed to AR activity under the right conditions. The literature shows that a well-designed AR experience can influence the way in which users perceive experiencing virtual objects projected in a real-life environment and yield an immersive feeling. Thus, we found immersion an important AR factor.

We distinguish and label three AR characteristics from Azuma (1997):

1) Interaction: users' ability to interact with and control the AR experience in real time and the system's ability to respond to users' actions.

2) Visual canvas/cues: the aesthetically pleasing 3D objects (i.e., images, video and text) and helpful cues that appear as a visual layer superimposed on the real world.

3) Immersion: combining the real and virtual worlds to give users an illusionary feeling of reality and retain their interest, which can result in their losing awareness of time.

Javornik (2016) identified the media characteristics of interactive technologies similar to AR as interactivity, modality, virtuality, hypertextuality, connectivity, location specificity, and mobility. Without interactivity, modality, and virtuality, users may not optimally enable and use other media characteristics such as hypertextuality, connectivity, location specificity, and mobility in their communication. McLean and Wilson (2019) found three AR factors (namely interactivity, vividness, and novelty) to positively impact user experience and consequently brand engagement. All three AR factors we identified (i.e., interaction, visual canvas/cues, and immersion) have similarities with other studies in the literature (see Table 3). These factors form the core blocks when building immersive AR experiences and enable AR technology to become a communication medium. We apply these factors in our design. These three AR factors form the AR artifact's "meta-requirements" as we discuss next.

Table 3. AR Factors Definition

AR factors	Our definition	Similar definitions from the literature
Interaction	Users' ability to interact with and control the AR experience in real time and the system's ability to respond to users' actions.	Interactivity (Javornik, 2016) AR interactivity (McLean & Wilson, 2019)
Visual canvas/cues	The aesthetically pleasing 3D objects (i.e., images, video and, text) and helpful cues that appear as a visual layer superimposed on the real world	Modality (Javornik, 2016) AR vividness (McLean & Wilson, 2019)
Immersion	Combining the real and virtual worlds to give users an illusionary feeling of reality and retain their interest, which can result in their losing awareness of time	Virtuality (Javornik 2016) AR novelty (McLean & Wilson, 2019)

2.2.1 Interaction

Researchers have conceptualized interaction in various ways. Sohn (2011) identified three interactivity dimensions: 1) sensory (multimedia or functional features of the medium), 2) behavioral (degree of user control and modification of the interaction), and 3) semantic (verbal and non-verbal elements that help in personalized interaction). Johnson et al. (2006) empirically confirmed responsiveness, non-verbal information, and response speed as essential facets of perceived interactivity. Their model pertains to AR-mediated communication for various reasons:

1) As inherently responsible systems, AR artifacts engage users based on the controls embedded in their display

2) The AR experience pertains more to non-verbal information than verbal information. Computer-generated 3D images and videos create an illusion of the artificial objects merging with the real world. Though AR provides textual information, it more greatly involves graphical representation.

3) AR artifacts rapidly change how they represent information based on users' control and maintain information continuity as they deliver seamless communication.

McMillan and Hwang (2002) identified three interactivity dimensions: real-time communication, immediacy, and engagement.

Interaction's three subfactors pertain to all communication mediums such as television, websites, mobile devices, augmented reality, and virtual reality. However, we can highlight several differences from a user perspective among communication mediums (see Table 4). One can consider television to have low interaction since it features unidirectional communication. Users view transmitted visual and audio information and cannot interact with the medium (no real-time communication). Television responds to limited user action such as browsing channels, volume control, and picture contrast changes (low immediacy), and the visuals/audio may not keep the user engaged (low engagement). As for websites, users can interact with the medium by navigating to different webpages (low real-time communication), obtaining a medium response to user queries (medium immediacy), and two-dimensional (2D) visuals with audio and personalized content keep the user engaged (high engagement). In the case of augmented reality, the user can interact with 3D models (high real-time communication), the medium responds to user action (high immediacy), and 3D models with audio keep the user engaged (high engagement). Interaction in virtual reality more closely resembles augmented reality than traditional mediums such as television, websites, and mobile devices.

Table 4. Interaction Factor—Media Comparison

Interaction subfactors / medium	Real-time communication	Immediacy	Engagement
Television	Asynchronous; minimal to no interaction	No response due to minimal/no user action	Low to medium if the media serves user needs
Websites	Synchronous; medium interaction	Immediate response based on user action but 2D content	High if the content is personalized for user needs
Mobile devices	Synchronous; medium interaction	Immediate response based on user action but 2D content	High if the content is personalized for user needs
Virtual worlds	Synchronous; high interaction	Immediate response based on user action and 3D content in virtuality	High if the 3D representation in virtuality looks realistic
AR applications	Synchronous; high interaction	Immediate response based on user action and 3D content in AR	Very high as AR applications superimpose 3D models on reality

2.2.2 Visual Canvas/Cues

The media naturalness theory (MNT) states that face-to-face communication is the most natural form of communication. Further, with other things being equal:

> *A decrease in the degree of naturalness of a communication medium leads to the following effects in connection with a communication interaction: (1) an increase in cognitive effort, (2) an increase in communication ambiguity, and (3) a decrease in physiological arousal.* (Kock, 2002)

In a digital communication, for example, in a boring entertainment show on television, audience members will have to exercise increased cognition to understand the show and may misinterpret the message, which may lead to more ambiguity in understanding it and decreased physiological arousal (Kock, 2002). Unlike television, AR creates a visual layer, provides an illusion of being in reality, and encourages the user to interact with 3D objects. The AR communication medium sustains the degree of naturalness if the 3D objects create a high degree of realism and sustain user interest in the AR experience without approaching the uncanny valley (Mori 1970). For example, a medical student wearing AR glasses can study the human anatomy by interacting with the body parts projected as 3D objects and, thereby, feel as though they interact with a real human being. When viewed from an MNT perspective, AR-mediated communication enhances media naturalness by creating a visual effect close to the real world, increasing physiological arousal, reducing cognitive effort, and communicating ambiguity. In this way, it pushes digital communication closer to face-to-face (F2F) communication. The visual canvas/cues factor is a tangible aspect of the visual overlay with two properties: aesthetics and content. Aesthetics represents the "how" of the AR presentation, and the content represents the "what" of the AR presentation.

2.2.3 Immersion

Jennett et al. (2008) defined immersion as “a lack of awareness of time, loss of awareness of the real world, sense of complete involvement, and sense of being in the task environment” (p. 17). Singer and Witmer (1999) defined immersion as “a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences” (p. 227). Both these definitions suggest that immersion is an individual experience. AR addresses users’ psychological need to experience pleasure, excitement, or knowledge growth while engaging with this new communication medium with its inherent virtually generated and embedded objects. As they use the AR media, users experience different engagement levels, as Brockmyer et al. (2009) claim, starting from immersion and leading to higher engagement levels. Like gaming, AR can offer involvement at varying degrees such as engagement, engrossment, and complete immersion. Engagement occurs when users try to understand the AR interface by interacting with it. Engrossment occurs when users further engage with AR displays, which triggers their emotions. Total immersion occurs when users temporarily detach from reality and focus entirely on the AR experience. The real and virtual world mix creates an illusion of reality for users during this engagement process. In this immersive state, users experience joy or satisfaction and lose track of time. One can use the length of time users spend viewing an AR display to measure the immersion factor.

2.2.4 Communication

At their core, media aid communication. If AR artifacts constitute a new communication medium, then we must evaluate their utility against communication research theories. Shannon and Weaver’s (1949) well-known communication model postulates communication as having the following elements: 1) sender produces the message, 2) encoder encodes it, 3) channel transmits it, 4) decoder decodes it, and 5) receiver receives it. The hyperpersonal model of communication (HPMC) posits that users leverage computer-mediated communication (CMC) for media affordances (Walther, 1996). Users benefit from media affordances such as interaction, asynchronous communication, absence of physical proximity, and effective use of cognition for intergroup and interpersonal communication. Walther (1996) hypothesized HPMC two decades ago when digital communication relied more on text. However, technology has evolved since then and amplified the benefits from media affordances. Walther and Whitty (2020) posit that the HPMC remains relevant after 25 years though the technology contours have expanded since 1996. As new-age media such as AR and VR have emerged in recent years, HPMC has come to pertain to many more efforts to study communication channels and communication effects. AR as a communication channel can enhance the communication effects much more than a text-based or voice-based communication channel. For example, a watch manufacturer can use AR technology in watch advertisements to visually project watches on a customer's hands as a virtual try-on. As per HPMC theory, customers interested in buying watches indulge in the AR experience and leverage the media affordances. Customers who experience the AR effects feel a sense of enhanced self-esteem and self-control while using the new technology, try different watches on their hands virtually, and focus their cognitive thoughts on understanding more about the product. One can significantly enhance communication’s richness with AR technology through visual cues, graphics, video, and audio, which can help users interpret messages, enable them to exchange messages, and propel interactions between users. Visual cues such as “thumbs up” or “like” buttons signal users to interact with a system. According to Griffin (2006), communication is a summation of content and relationship. Here, content refers to what actors express verbally, and the relationship encompasses non-verbal conveyance. Extending this principle, AR enriches the communication at the content and relationship levels. For example, one can transform an operator’s manual into a lively audio/video feed using AR and, thereby, enrich the communication’s content and relationship aspects.

3 Method

Natural science research focuses on understanding reality, whereas DSR focuses on creating things that solve human problems (March & Smith, 1995). Researchers have used DSR to address many different research problems such as designing IT artifacts (Adomavicius et al., 2008), designing and evaluating hospital-based business intelligence systems (Kao et al., 2016), and designing process hierarchies for omnichannel capabilities (Wulf, 2019). Hevner et al. (2004) recommended that information system (IS) research projects use DSR when building and evaluating IT artifacts such as constructs, models, methods, and instantiations. We follow the Hevner et al.’s DSR guidelines, which comprise seven stages: design as an artifact, problem relevance, design evaluation, research contributions, research rigor, design as a search process, and communication of research for IS research. The guideline helps researchers conduct rigorous and high-quality research and identify contributions.

Hevner et al. (2004) recommend that researchers create an innovative and purposeful artifact to address a specified problem. For example, Strohmann et al. (2019) created a virtual reality prototype virtual in-vehicle assistant using design science research. Similarly in our research, we created an AR artifact with a specific focus on the three factors – interaction, visual canvas/cue, and immersion – when designing it. In doing so, we demonstrate AR's potential as a new form of communication medium. DSR is iterative in that one follows mutually reinforcing design and evaluation cycles to arrive at the final AR artifact. We use an evaluation framework that we derived from extant literature to evaluate the AR artifact we designed during the evaluation cycle.

The design cycle involves designing each identified AR factor—interaction, visual canvas/cues, and immersion—considered in the artifact design. We ground our design in theory and provide the details and rationale behind incorporating the factors in the design. We evaluated the designed AR artifact at two levels: design product and design process. The design product denotes the designed AR artifact, and the design process refers to the DSR methodology followed in designing it. The evaluation also considers two dimensions: time (when the evaluation happens) and setting (where the evaluation happens). In this research, we had continuous feedback between the design and evaluation cycles. Due to the rigorous nature of system development, we followed a prototype approach with a few design and evaluation iterations before we fully realized the AR artifact.

4 Artifact Description

In this section, we explain the AR artifact and how we designed and developed it. As the artifact has to address a specific business need, we render a car as an AR experience. First, we describe how we developed the features based on the factors that we discuss above. Next, we describe the platform we used to develop the artifact. Finally, we present screenshots to show the developed AR artifact.

4.1 Description

The AR artifact provided a digital AR experience of a Lamborghini car via a mobile app. Users can invoke the different AR features (see Table 5) embedded in the mobile app.

Table 5. AR Features

AR feature	Description
3D model	A car model represented in 3D
Video in 3D view	Car model video embossed on the three-dimensional object
Audio	Audio effects that enhance the AR experience of the car model
Textual overlay	3D text that provides information about the car model
Color overlay	Different car colors overlaid on the 3D car model
Fonts / icons / color	Fonts, icons, and color that enhance the AR experience of the car model

4.2 Design

In this section, we discuss details about the artifact and the rationale for the design choices we implemented. The design addresses interaction through real-time communication, immediacy, and engagement; visual canvas/cues through aesthetics and content; and immersion through time involvement (McMillan & Hwang, 2002; Kock, 2002; Jennett et al., 2008) (see Figure 1). Additionally, we modeled certain design aspects using the semi-formal notation for IT artifact design from MacLean et al. (1989) (see Tables A3 and A4 in Appendix A). The entire design enables functions that we show in Table 6.

4.2.1 Interaction Factor

We designed interaction in such a way as to achieve real-time communication, immediacy, and engagement.

Real-time communication refers to two-way interactive communication between a user and AR artifact. A user's actions and an artifact's response to those actions model the interaction level. We designed our AR artifact such that users could interact with it in real time using the rotate function to review its output. . We analyzed a few design choices to implement the rotate function. For example, when the user clicks on the left rotate button (user action), the car's 3D model rotates by a certain degree to the left (artifact response). We iterated on these design choices and picked the action buttons to rotate the model by a certain degree to promote a high interaction level between the user the AR artifact. Likewise, the design incorporates other user functions.

Table 6. User Functions

Name	Description
Car view function	3D car model in standard view (showing exterior) or exploded view (showing internal elements such as the engine, chassis, transmission, wheel/rim)
Video function	Video in 3D view showing a multimedia car demonstration
Zoom function	User can scale the 3D car model up or down in size
Rotate function	User can rotate the 3D car model left or right by a few degrees
Color picker function	User can select the color overlaid on the 3D car model
Textual Information function	Textual overlay that mentions specification details about the car model, engine, wheel, interior, exterior, suspension, etc.
Audio function	Car-specific audio effects playing in the background

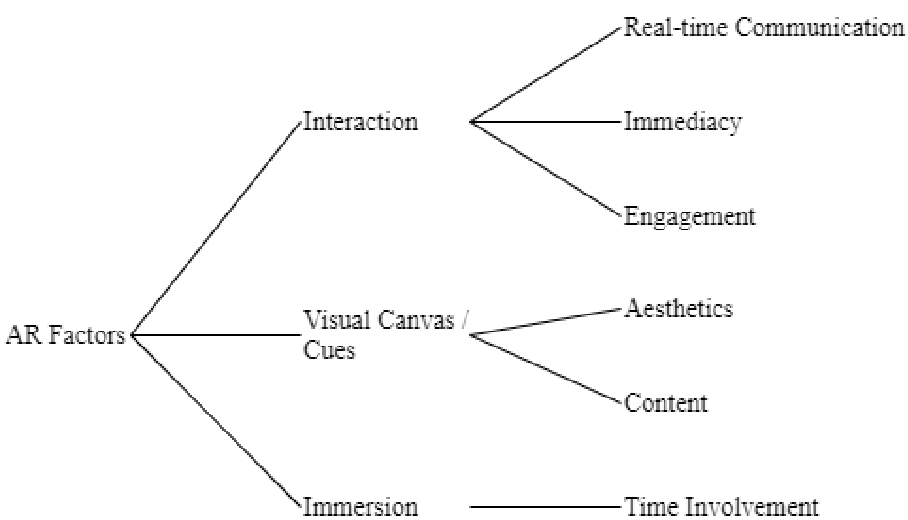

Figure 1: AR Factors and Subfactors

Immediacy denotes an AR artifact's immediate response to a user's actions. AR features should load without any noticeable delays for seamless user interaction. Moreover, the speed at which artifacts respond a user's action should serve to retain their interest in using it. For example, a user can interact with the 3D model using the zoom function and instantly enlarge or reduce the 3D car model's size. We iterated on a few design choices to implement the zoom function. For example, when a user clicked on the zoom-in button, the car's size instantly increased by a certain length on the x, y, and z axes. We designed our artifact so that users could trigger the change in the size using action buttons or finger swipes. Again, our design iterations eliminated design choices such as linear increase in model size and finger swipe action since they introduced appreciable delay in redrawing the 3D model. We modeled the zoom function using action buttons and step-wise increase and decrease in the 3D model's size.

Engagement refers to the details that keep users engaged with an AR artifact. We designed the AR representation to present users with information about the car, such as standard view, exploded view, car parts specification, colors available for the model, and model details. For instance, the user could interact with the engine component in the exploded view and receive information on the engine specification using the textual information function. The user could also use the audio function to hear the car engine's sound, a sound effect that enhanced the AR experience. Our initial design encompassed only the standard view, colors available for the model, and basic model details. In order to keep users engaged with the AR artifact, we revised the design to include more features such as the exploded view, video in 3D view, and audio to enhance the AR experience.

4.2.2 Visual Canvas/Cues Factor

We considered aesthetics and content to design the visual canvas/cues factor. Aesthetics refers to the screen design and graphics in the visual canvas/cues that visually appeal to the user. We designed the visual canvas of the screen by logically grouping the functions. The visual design comprises graphics such as 3D models, colors, and fonts to enrich the overall look. As the AR experience depends heavily on model quality (in this case, the 3D car model's quality) we continuously refined its size, shape, and depth to generate a realistic model. Likewise, the color function helps the user experience the car in different color shades that the car manufacturer offers.

Content refers to the meaningful information that the AR artifact displays to users in both the textual and non-textual manner in the visual canvas/cues. In our artifact, the textual information contained details about the car specification, engine details, or a simple pop-up text appearing as a textual overlay. Non-textual information comprised a 3D model to help the user understand the car's structure, appearance, and dimensional aspects. Also, a multimedia video feed of the car in a 3D view demonstrated the car's visuals and auditory aspects to users.

4.2.3 Immersion Factor

We achieved immersion through time involvement, which refers to the total time that users spend in engaging with the artifact. The more time users spend using the artifact, the more they engage with the AR experience. We designed our AR artifact to provide users with many functions such as zoom, rotate, the ability to change the car's color, textual information, video, and audio to explore the car's visual/non-visual aspects. In doing so, we focused on keeping users engaged with the artifact for a longer time.

4.3 Development

Many AR platforms provide tools and technology to create AR artifacts (see Table A2 in Appendix A). We evaluated many AR platforms such as Vuforia, Catchoom, Zappar, and Layar. However, we found they had limitations from a development perspective, such as tool-learning time, flexibility to edit models, options to add and edit controls, and deployment environment. We eventually decided to use Zappar due to its ease of use and plug-and-play environment. We developed the AR app using ZapWorks Studio (see Figure A1 in Appendix). Using the studio, designers and developers can create a fully customized AR experience across different industry segments (e.g., retail, education, manufacturing, gaming, and health).

4.4 Demonstration

In this section, we present some selected screenshots to demonstrate the AR experience we developed. As per the "design as a search process" DSR guideline, we conducted several design and evaluation cycles before we settled on the AR app's final design. We encountered problems in design layout, design elements, and content richness. Early designs had AR features such as 3D models, a color overlay, and 3D video distributed on different screens. However, we found that users felt the AR experience too scattered, which hindered their immersion. Hence, we revised the design and situated all AR features together on a single screen to give users a more focused experience. We also enabled users to change the 3D model's size and rotate it using finger swipes, but it hindered the interaction with the model due to uneven swipes. Thus, we replaced the finger swipes with button controls that users found easy to use and that improved user interaction. The visual canvas/cues containing the 3D model (only standard view) were not vivid and user engagement was lacking. The redesign included additional 3D models (both standard and exploded view) and textual overlays to engage the user. Overall, in our design and evaluation cycles, we focused on fully incorporating the AR factors that would provide a compelling AR experience to users (see Table 7).

The AR app's final version (see Figure 2) allowed users to switch between different ways to view the car (e.g., standard view, exploded view, video 3D view, textual overlay view, and color picker view). Figure 2 also shows the QR code to be scanned using any QR code scanner to launch the AR experience in a web browser.

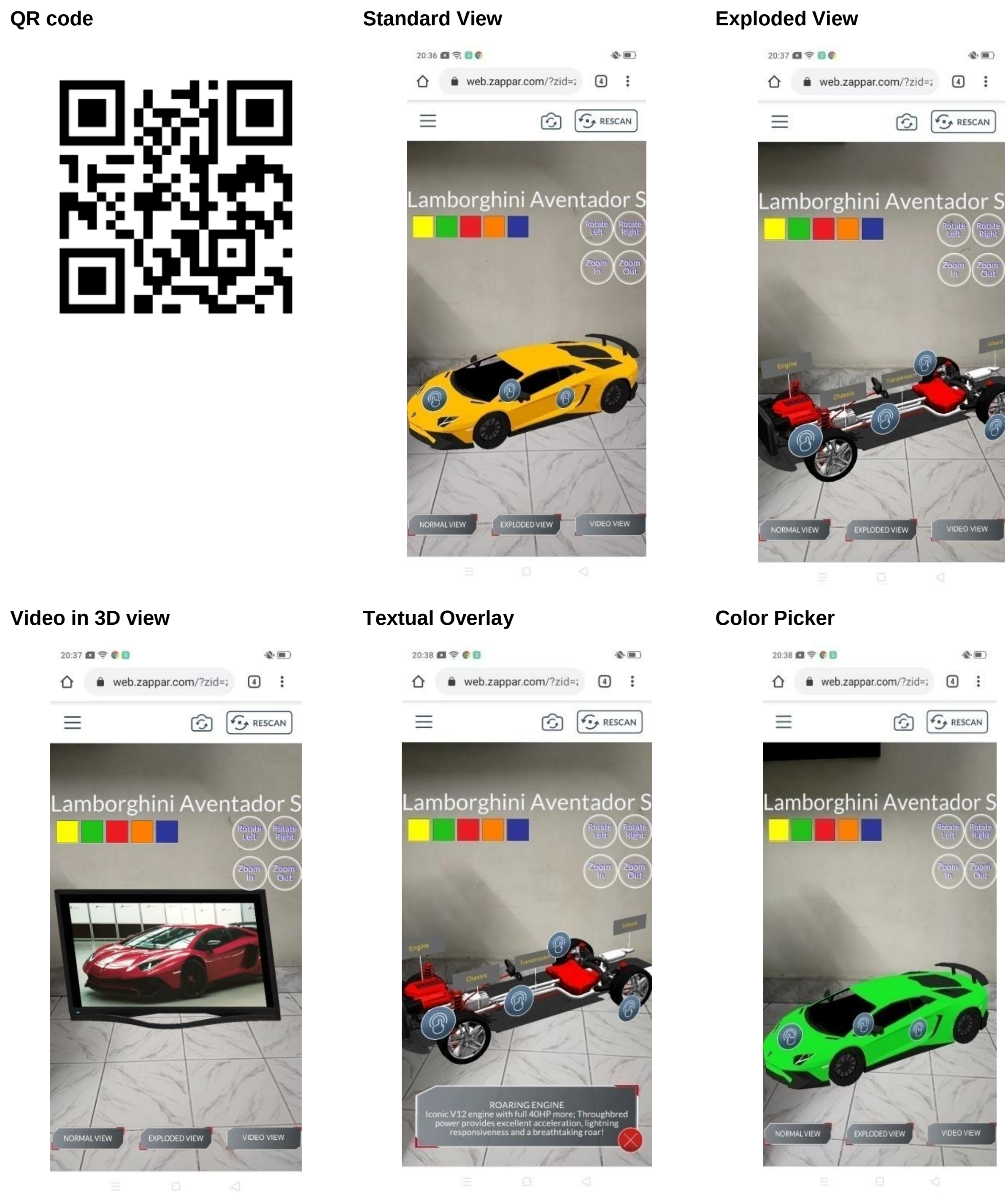

Figure 2. Different Views of the Designed AR Artifact

5 Evaluation

The DSR evaluation strategy framework by Pries-Heje et al. (2008) is followed. We conducted the evaluation from two perspectives: 1) the design product (i.e., the AR app) and 2) the design process (i.e., DSR methodology). The evaluation strategy focused on two dimensions: timing (ex ante or ex post) and setting (artificial or naturalistic). We evaluated the design product and process during and after we created the system (as ex ante and ex post evaluations) in a naturalistic setting (with a real artifact in a real environment). We used evaluation methods that Hevner et al. (2004) identified.

Table 7. Design and Develop Iterations

AR feature	AR factors	Design / develop choices	Final choice
3D model	Visual canvas/cues (content)	A standard 3D model view	A standard view and an exploded 3D model view
	Visual canvas/cues (aesthetics)	3D model texture (e.g., patches with grains)	3D model texture with a smooth finish for more realism
	Visual canvas/cues (aesthetics)	Textual content not clearly visible against the 3D model due to color similarity	Textual content displayed in a contrasting color for better visibility
	Interaction (real-time communication)	3D model rotation by a pre-determined degree or continuous motion	3D model rotation by pre-determined degree based on user action
	Interaction (immediacy)	3D model zoom by pre-determined size or linear motion	3D Model zoom by pre-determined size based on user action
	Interaction (engagement)	Limited information about the car presented to the user	More textual information related to the car's engine, wheels, transmission, and exterior presented to the user
	Immersion (time involvement)	Limited functions such as color change and textual information	More functions such as zoom, rotate, color change, video and audio to engage the user.
	Immersion (time involvement)	Video in 3D view and audio not included	Video in 3D view and audio to enhance the AR experience

5.1 Design Product Evaluation

Hevner et al. (2004) identified several evaluation methods such as observational, analytical, experimental, testing, and descriptive to evaluate an IT artifact. We applied two descriptive evaluation methods to evaluate our app: informed argument and scenarios to evaluate the designed product.

5.1.1 Descriptive Evaluation (Informed Argument)

Prat et al. (2015) identified an evaluation framework to help researchers evaluate IS artifacts in DSR. They identified what constitutes the evaluation object(s), the associated evaluation criteria, and how these object evaluations occur using various methods. They organized evaluation criteria under different system dimensions, such as goal, environment, structure, activity, and evolution. Additionally, they proposed a framework of generic evaluation methods. We applied system evaluation criteria such as efficacy, validity, utility, understandability, ease of use, performance, accuracy, and generic evaluation methods (see Table 8) to evaluate the AR app we developed.

Efficacy: Prat et al. (2015) defined efficacy as "the degree to which the artifact achieves its goal considered narrowly, without addressing situational concerns" (p. 37). The synergy between and harmonious working of these AR factors generates the AR experience and enables users to interact with the car virtually and gather meaningful and valuable information, which demonstrates its efficacy. We designed an AR app from the ground up, embedded AR factors into it, and evaluated it for communication utility. The visual canvas/cues factor constituted the virtual car layer, the Lamborghini, superimposed on the real world that shows the car in 3D both in the standard and exploded view. The interaction factor constituted the various touch points such as zoom, rotate, and color change buttons superimposed on the virtual layer to help users interact with the car. The immersion factor exhibited more nuance and constituted the numerous user functions that kept users engaged with the AR app.

Validity: validity refers to whether an artifact works correctly (Prat et al., 2015). AR uses computer-generated objects in a space that blends with the space that real-world objects use (Van Krevelen & Poelman, 2010). The AR app generated a 3D representation of a Lamborghini using the visual canvas/cues factor and created an illusion of it merging with the real world. The rotate and zoom functions validated the car's 3D representation. The color picker function allowed users to change its color as desired and experience the 3D view in various colors.

Table 8. Generic Evaluation Methods

No.	System dimension / assessed criterion	Form of evaluation	Secondary participant	Level of evaluation	Relativeness of evaluation
1	Goal / efficacy	Analysis and logical reasoning	Researcher	Instantiation / Real Example	Absolute
2	Goal / validity	Analysis and logical reasoning	Researcher	Instantiation / Real Example	Relative to comparable artifacts
3	Environment / consistency with people / utility	Analysis and logical reasoning	Researcher	Instantiation / Real Example	Relative to comparable artifacts
4	Environment / consistency with people / understandability	Analysis and logical reasoning	Researcher	Instantiation / Real Example	Relative to comparable artifacts
5	Environment / consistency with people / ease of use	Qualitative	Researcher	Instantiation / Real Example	Relative to comparable artifacts
6	Activity / performance	Qualitative	Researcher	Instantiation / Real Example	Absolute
7	Activity / accuracy	Qualitative	Researcher	Instantiation / Real Example	Absolute

Utility: Prat et al. (2015) defined utility as "the value of achieving the artifact's goal" (p. 37). For our AR representation, we used a Lamborghini, a luxury car brand associated with a high price, high quality, and deep symbolism in consumers' minds. Cheah et al. (2005) found that consumers with higher experiential values toward luxury brands have higher purchase intentions. The utility of the app is to allow users to experience the car. The fact that users could experience the car's aesthetics, color, shape, size, and other characteristics through the app makes it valuable to end users.

Understandability: according to Prat et al. (2015), understandability refers to the degree to which one comprehends an artifact "both at a global level and at the detailed level of the elements and relationships inside the artifact" (p. 29). These criteria deal with an artifact's structural aspects. At a high level, the AR app represented an object (car) in 3D that triggered the AR experience's illusionary effect. At the detailed level, the 3D representation had AR features such as 3D models, video in 3D view, and textual and color overlays, and each representation co-existed to augment the visual canvas and enable users to interact with the app. The AR features disseminated different information based on the characteristics of the same car.

Ease of use: ease of use refers to how easily users can use an artifact (Prat et al., 2015). Users could interact with the AR app using touch actions and perform actions quickly using action buttons. The AR appeared on a single screen to ensure users maintained their focus on the AR experience in interacting and controlling the AR projection. We also ensured users found the navigation controls intuitive and straightforward to use.

Performance: Prat et al. (2015) defined performance as "the degree to which the artifact accomplishes its function with given constraints of time and space" (p. 39). To determine the app's performance, we analyzed its response speed and throughput. We analyzed the response speed using the visual canvas, which was updated in under a second for every user-triggered interaction without a noticeable delay. We analyzed the apps throughput based on how quickly the app downloaded data—around 30 megabytes (MB) in five seconds (6 MB per second)—when it initially loaded the visual canvas. The AR app's memory usage fluctuated around 200 MB (comparable to similar graphic-rich mobile apps such as YouTube).

Accuracy: accuracy refers to the extent to which an artifact's outputs agree with its expected outputs (Prat et al., 2015). The AR world and the real world constitute two distinct phenomena. Hence, one cannot compare an object modeled in the AR app against the same object's real-world representation. The accuracy criteria should weigh only the object's AR experience and assess its illusory effect against a similar digital object. In this study, as the AR app generated an experience of a Lamborghini, we compared the 3D model generated in the app against the 3D model on the Lamborghini (Europe) website. Both models resembled each other in size, shape, and color, which satisfied the accuracy criteria. Moreover, the audio and video feed of the Lamborghini used in the AR app is the same as those available on the model's YouTube website.

5.1.2 Descriptive Evaluation (Scenarios)

To evaluate the AR experience we developed, we asked participants to evaluate it when using the AR app. We used mixed modes to obtain their feedback: email exchanges and online phone discussions. Our participants comprised professionals who belonged to different industries such as education, technology, communication, and manufacturing. We reached out to the participants, solicited their support for this study, and informed that their participation was voluntary. We briefed them about the nature of the research and our objective in conducting it. We assured them that we would strictly maintain their confidentiality and anonymize all data. We provided them with details on accessing the AR app and triggering the AR experience using a QR code. We then gave them open-ended questions (see Table 9) on the AR factors and AR as a communication media. We required that participants capture their responses as a post-AR experience activity. Ten participants participated in this evaluation (see Table 10). We then analyzed their responses, which we report in this section.

Table 9. Interview Questions

#	Questions
1	How would you describe your interaction with the product (AR experience)?
2	What information (3D images, videos, pop-up window, etc.) about the product (AR experience) is useful to you?
3	How did you feel about the AR experience in visualizing the product?
4	How different is the visualizing of the product (AR experience) compared to a website or news article?
5	How does this AR experience trigger or motivate your interest level?
6	How much time did you spend (in minutes) in using this AR app?
7	How the information helps in evaluating the product (AR experience)?

When we sought feedback over the phone, we recorded and then transcribed the interviews. We used QDAMiner to analyze the email and transcribed recordings. In the analysis, we adopted the streamlined codes-to-theory model for qualitative analyses (Saldaña, 2021). We coded the interview transcripts to identify patterns, apply filters, and consolidate findings. The emerged codes constituted either specific keywords or phrases that highlighted the user feedback and the AR experience, which we then logically grouped into categories from which we then identified themes or concepts (see Table 11). In the qualitative analysis, we evaluated each user's AR experience when using the AR app. In addition, the users also shared their expectations about how AR technology will evolve in the future.

AR as a communication media: Users could interact with the car by changing its color, size, rotation, and external and internal views. They could get the necessary product information from the 3D model, videos, and textual overlays. They looked for the same information from AR as is possible from traditional media such as newspapers, websites, or television. The users were excited with the graphics, videos, text, and audio used in the communication. They felt that the interactive features of the app improved the communication and information exchange. The following feedback confirms users' excitement about AR communication capabilities:

AR artifacts are better than a website.

The necessary information using the zoom and rotate on the 3D model, video, and information pop-up is helpful.

It was terrific, though, may not be very professional. Both zoom in, zoom out, and both right view, left view were great.

Not many websites/news articles allow rotated and exploded views.

I was able to visualize the product by seeing various views and the video.

I find 3D images and color visualization most useful.

I liked the app, and it helps in visualizing the product.

The experience was excellent and interactive. I could change the color and read to see the artifact from various angles and inside. The movement and sound also gave a different experience.

I can see the product in detail, change the color, listen to the engine sound, zoom in and view specifications. The view allows me to see the professional advertisement—all in one place. Therefore, it is useful.

Table 10. Participant Details

Participant	Age	Gender	Qualification	Industry	Prior experience with using AR technology
1	46	Male	Post-graduate	Technology	Aware but not used
2	43	Male	Post-graduate	Education	Aware but not used
3	40	Male	Post-graduate	Manufacturing	Aware but not used
4	35	Male	Post-graduate	Communication	Have used
5	50	Male	Post-graduate	Technology	Aware but not used
6	49	Male	Post-graduate	Communication	Aware but not used
7	35	Male	Post-graduate	Technology	Never used
8	24	Male	Graduate	Technology	Have used
9	26	Male	Graduate	Technology	Never user
10	28	Male	Graduate	Technology	Never used

Table 11. Codes, Categories, and Themes

<table>
<tr><th>#</th><th>Codes</th><th>Categories</th><th>Themes or concepts</th></tr>
<tr><td>1</td><td>Existing features</td><td rowspan="2">AR features</td><td rowspan="2">AR as a communication media</td></tr>
<tr><td>2</td><td>Features needed</td></tr>
<tr><td>3</td><td>Artifact quality</td><td rowspan="3">User perception</td><td rowspan="3">AR for product evaluation</td></tr>
<tr><td>4</td><td>Evaluation</td></tr>
<tr><td>5</td><td>Trust</td></tr>
<tr><td>6</td><td>Motivation</td><td rowspan="2">User interest</td><td rowspan="2">AR for user engagement</td></tr>
<tr><td>7</td><td>Time involvement</td></tr>
</table>

Users enjoyed the AR experience and desired more interactive functions from the AR app, such as the ability to change the rims, brakes, calipers, and top hood. The ability to interact with the car generated their interest in using the AR app. For example, users said:

More product features could have been there, but I understand it was only a test product experience. However, I could imagine a full product view, and it will be a fantastic buyer (user) experience.

However, I will look for a detailed description of the product, claims made, disclaimers, pitfalls.

However, more feature controls are needed so that the car can be customized based on user input. However, I understand that this is a prototype developed without any professional support.

AR will add value if we could include technical specifications and dimensions also. Some notes will help guide the users looking for technical specifications.

AR experience triggers a feeling to see more of the product and more interaction with the artifact, if possible, to provide a more real-life experience.

If I can see the interiors—it would be even better as an immersive and interactive experience. That would prompt me to take some action. Maybe if I have a link to buy or contact a salesperson for more inquiry, it will be a good indicator of my action.

AR for product evaluation: Overall, users felt right about the AR experience. It gave them a different experience in visualizing the car, and they felt satisfied. Users mentioned product visualization in AR as far superior compared to a website or news article. They enjoyed the ability to see the 3D car model from different views (standard and exploded views), which static 2D representations in media such as a website or news article do not allow. Users found the AR experience useful for evaluating a product. For example, users said:

> *From the AR experience, the product information may be a deciding factor because I might have liked and sold on the product or solution. You might have already biased my mind to your product, and I may go ahead with the product, assuming that there is no mismanagement in the ordering and delivery process.*

> *I may not buy directly from this experience; I may want to reassure what I am getting before placing an order on the website.*

> *The appearance of the products helps in making decisions.*

> *As all the information is available in one place, product evaluation is much more comfortable.*

Users felt that a good AR experience requires good production visualizations. Any compromise in the quality may yield poor results. Another user pointed out that the quality and appropriate 3D model designed plays a vital role in the AR experience. For example, users said:

> *Yes, the AR product visualization helps. However, it depends on the model selected, which has to be specific to the task the user is trying to visualize.*

> *Yes, AR helps in visualizing the product or solution.*

> *Product visualization via AR is immersive and interactive.*

> *Product experience was average to good as I could not maximize the screen in "video view" and though "video view" was small, it was eye-catching.*

> *Yes, it helps in visualizing the product or solution. It depends upon the quality of the AR artifact. If the quality of the artifact itself is terrible, it may be counter-productive. However, it may not replace the physical display.*

> *Product visualization via AR is immersive and interactive compared to a static website or news article in 2D.*

However, users also pointed out that the product visualization may not entirely replace the real-life experience and that they would prefer to experience the product first-hand before purchase decisions.

> *Can I trust these views? What if somebody shows fancy ones like this, but what I get in hand may be pathetic? So, without experiencing it, I may still not buy.*

> *If there are no reviews of the product, I may not buy it even though the artifact looks excellent and compelling.*

> *I may believe some neutral experts more than the artifact itself.*

> *I may still trust the human rather than an AR artifact.*

> *It provides a different perspective that is not possible from a non-AR medium.*

AR for user engagement: The AR experience triggered participants' interest, and they wanted to experience more. All users expressed that the AR experience motivated them to take the next step in the buying process—to visit a car dealership or enquire with a sales representative based on their interest. Users spent 10 minutes on average using the AR app—a duration that far exceeds average industry estimates (approximately two to three minutes). All the users were somewhat familiar with AR before they used this app. The degree of involvement as gauged by the time spent shows a deep engagement or, in other words, high immersion. The AR functions kept the users engaged and made them explore further and better understand the car, and it also provided an opportunity for them to become more familiar with AR. For example, users said:

> *It is exciting.*

> *However, this motivated me to go to the showroom to get first-hand physical experience.*

This AR experience helped me in getting a feel for the product.

As a motivator of human action—I think it surely helps.

I think I spent 20 to 30 minutes.

I spent around 10–15 minutes on the app.

5.2 Design Process Evaluation

We used seven DSR guidelines that Hevner et al. (2004) proposed to concisely understand, implement, and evaluate AR research in the IS domain.

5.2.1 Guideline 1: Design as an Artifact

Azuma (2016) postulated that AR offers a compelling communication medium and that it provides real benefits to end users. We produced a viable IT artifact (an AR app) that incorporated AR factors during the design and showcased AR's potential as a communication medium.

5.2.2 Guideline 2: Problem Relevance

Gartner (2018a) identified AR as a top strategic technology trend. Hence, it warrants an investigation into AR artifact design. However, industry-designed AR apps have exploited AR partially and have not fully realized the technology's value. Furthermore, few studies have studied AR factors and their effect on AR as a communication medium, which makes our study very relevant.

5.2.3 Guideline 3: Design Evaluation

According to Hevner et al. (2004), a design artifact must robustly demonstrate its value, quality, and efficiency. We used two descriptive evaluation methods (informal argument and scenarios) to evaluate the design product (AR app). Specifically, we leveraged the evaluation criteria and generic evaluation methods that Prat et al. (2015) proposed to evaluate the design product (AR app) and the DSR methodology that Hevner et al. (2004) proposed to evaluate the design process.

5.2.4 Guideline 4: Research Contributions

Adam et al. (2021) elaborated on research contributions in three DSR modes (exterior, gestalt and interior) in HCI studies. We used the DSR interior mode and focused on AR artifact design in HCI and gives out design prescriptions. Our study contributes to the theoretical knowledge on designing AR artifacts with measurable improvements that support the technology evolution (design artifact) and adds to the prescriptive knowledge base about IT artifact design that augments the existing scientific knowledge base (design theory).

5.2.5 Guideline: Research Rigor

IT artifact design and evaluation rely on extant theories and standards. We used extant theories and standard guidelines regarding the user interface, information processing, and structured query language to develop and evaluate our artifact.

5.2.6 Guideline 6: Design as a Search Process

We designed the AR artifact in an iterative manner. In the initial design stage, we focused on developing a prototype solution to address the problem. Then, we repeatedly revised the design and tested the solution before deploying the final solution.

5.2.7 Guideline 7: Communication of Research

This study makes two contributions to AR research. First, the AR artifact design provides valuable information to the IS community on AR artifact instantiation and subsequent evaluation. The AR artifact proves the AR media's enhanced communication capability and potential application across different industry domains through a prototype system. Second, by applying the evaluation method to the AR artifact, we contribute to the research knowledge base. Industry and academic practitioners may also find our research relevant since they can easily replicate how we developed and evaluated our AR artifact.

6 Discussion

In this study, we followed design science guidelines to design and evaluate an AR app. Our results offer insights into the role that AR factors play in AR-mediated communication. We found that AR factors such as interaction, visual canvas/cues, and immersion form the AR experience's foundation blocks. We described these AR factors using interactivity, MNT, immersion, and communication theories as a theoretical lens. We developed a systematic approach to design an AR application that espouses these AR factors.

We found that interaction has a strong impact in generating the AR experience. Using the AR app, users obtained real-time information about the car, elicited a response to actions such as changing its color and size, and had a higher engagement level. Research has shown that interaction is an antecedent of flow that drives users' affective, cognitive, and behavioral responses in the digital world (Hoffman & Novak, 2009). In this regard, the design elements that promote interaction will appeal to user responses, and users will leverage AR technology for utilitarian purposes and move beyond simply exploring AR. We implemented interaction through real-time communication, immediacy, and engagement, and we found that users responded in an encouraging manner towards AR as a communication media:

1) We designed the real-time communication using user controls—button controls that activated different AR functions via user gestures such as taps and pinches. By doing so, users could interact in real time with the car model and obtain information. User feedback such as “The necessary information using the zoom and rotate on the 3D model, video, and information pop-up is helpful” and “Both zoom in, zoom out, and both right view, left view were great” shows the affective user response about AR communication capabilities

2) The immediacy enabled an AR experience that reduced cognitive load on users by providing contextual tasks—AR functions such as car view, zoom, rotate, and color picker designed for user actions. The AR experience was seamless and resulted in smooth user interaction with the AR app based on the user actions. User feedback such as “I could change the color and read to see the artifact from various angles and inside” and “I can see the product in detail, change the color, listen to the engine sound, zoom in and view specifications” show that the AR experience appealed to users’ cognitive response

3) The AR app engaged users through normal view and exploded view (see Figure 2). Another feature of the AR App that engaged users was through color configurations of the car model. Other features such as the 360-degree view and zoom functions also engaged users.

Users provided feedback such as “AR experience triggers a feeling to see more of the product and more interaction with the artifact, if possible, to provide a more real-life experience” and “As all the information is available in one place, product evaluation is much more comfortable”. A well-designed AR app can influence users’ behavioral response and keep them engaged in using the app to seek more product information. Yaoyuneyong et al. (2016) and Tsai et al. (2020) found that products advertised using AR print media to be more informative, novel, and effective when compared to traditional print media by end users. Our study further validates interaction as an important AR factor for using AR-mediated communication.

Users found the visual canvas/cues AR factor (i.e., the augmented visual layer that comprised the 3D models, graphics, and text superimposed on the real world) aesthetically pleasing and it provided content that retained their attention in the AR experience. Research has shown that visual cues in online stores delight customer more than information cues which, in turn, influences their intention to purchase (Koo et al., 2014). AR with superimposed visual canvas creates a visual effect rich in information. Representing a product in 3D in AR allows users to interact with it. However, one must ensure that the visual layer with its aesthetics and content appeals to users’ cognitive senses and does not serve as a distraction. We implemented visual canvas/cues via aesthetics and content. It aided communication between the app and the user as follows:

1) Realistic 3D models (both standard and exploded views) closely reflected the real car and achieved digital realism. The AR app used the same colors for the car as the car dealer’s website, and the augmented visuals resembled a real car. User feedback such as “Yes, AR helps in visualizing the product or solution” and “Product visualization via AR is immersive and interactive compared to a static website or news article in 2D” shows that users positively affirmed the way the AR app visualized the car.

2) Content such as visual and audio cues—embedded visual cues such as hovering hand symbols, color palettes, labels that elicited user actions, and audio cues engaged users. User feedback such as "From the AR experience, the product information may be a deciding factor because I might have liked and sold on the product or solution" and "The view allows me to see the professional advertisement—all in one place. Therefore, it is useful" shows that users found the visualized content helpful. In a similar fashion, in their AR-enabled presentation, Zarraonandia et al. (2014) found that visual cues from listeners helped a speaker to adapt better and improve the communication between them. Our study further validates the role that visual canvas/cues play in AR-mediated communication.

The immersion AR factor encourages users to become more involved with the AR experience. In the AR app, users experienced a continuous AR experience that appealed to their sensory stimuli. In studying 3D product visualization, Biocca et al. (2001) showed that increased sensory immersion led to higher engagement levels in consumers, which increased their brand attitude, product knowledge, and purchase intention. AR 3D-embedded product visualization can enhance users' immersive experience by appealing to their visual, auditory, and orientation senses. We designed immersion to represent the car model in diverse ways (i.e., we allowed users to view the same car model in different ways via standard view, exploded view, zoom, rotate, and color picker functions), which prolonged user involvement. The car model's diverse representation helped users lose track of time and enabled deeper AR engagement. Indeed, users provided feedback such as "Product visualization via AR is immersive and interactive" and "I think I spent 20 to 30 minutes". Scholz and Smith (2016) identified that, among other aspects, a successful AR immersive experience requires AR visuals that integrate with the social-physical world. In our research, the AR layer provided an immersive experience close to what users would experience in a real car.

We made some prescriptions for designing interaction, visual canvas/cues, and immersion. While participants validated our app, we assessed the extent to which a select set of apps applied these factors in their design. We did so by considering three apps from Google's AR core library. From the analysis, we inferred that these AR apps applied the AR factors to varying degrees on a low, medium, and high scale:

1) Drawalong AR, a calligraphy AR app (https://experiments.withgoogle.com/drawalong-ar), used design elements such as user controls, contextual tasks, ergonomics, aesthetics, visual cues, and realistic 3D models but did not have audio cues and diverse components (interaction—high, visual canvas—medium, immersion—low)

2) Notable Women (https://experiments.withgoogle.com/notablewomen), an app that depicts 100 historic American women in U.S. currency, used design elements such as contextual tasks, ergonomics, aesthetics, and visual cues but did not have user controls, audio cues, realistic 3D models, and diverse components (interaction—medium, visual canvas—medium, immersion—low).

3) Invisible Highway (https://experiments.withgoogle.com/invisible-highway), which showcases a robot car cruise along an imaginary highway, used design elements such as user controls, contextual tasks, ergonomics, aesthetics, and visual cues but did not have audio cues, realistic 3D models, or diverse components (interaction—high, visual canvas—medium, immersion—low).

Therefore, AR app designers need to incorporate these AR factors and their design elements systematically at the design stage to produce a more compelling and valuable AR experience.

We also evaluated the AR app we designed from multiple perspectives to demonstrate its utility. As per the third guideline that Hevner et al. (2004) posited (design evaluation), we applied much rigor during the evaluation cycle. We adopted the evaluation strategy framework that Pries-Heje et al. (2008) proposed and evaluated both the design product (AR app) and the design process (DSR methodology). We used descriptive evaluation methods (i.e., informal arguments and scenarios) (Hevner et al., 2004). We evaluated the design product using the IS artifact evaluation framework that Prat et al. (2015) provided and applied a criteria hierarchy to evaluate the developed AR app. We evaluated AR app system dimensions using evaluation criteria such as efficacy, validity, utility, understandability, ease of use, performance, and accuracy. Participant interviews also validated these system dimensions. We also applied the design process evaluation from Hevner et al. (2004). The design product and design process evaluations guide researchers and practitioners on the evaluation components to incorporate in their DSR projects.

Vom Brocke and Maedche (2019) proposed a DSR grid that comprises six core dimensions—problem description, input knowledge, research process, key concepts, solution description, and output knowledge—to plan and communicate DSR research. We provide such a grid for our study in Table 12 below. We chose DSR for our study because DSR helps one design and evaluate artifacts that help solve research problems and advance theory. The novel approach that we adopted in designing our AR app has created a new perspective on viewing and establishing AR as a new communication medium. We designed the AR app for a mobile device, a non-wearable device. However, our findings apply to wearable devices also, such as AR headsets and AR glasses. Whether any communication media succeeds depends on the value that it generates for the users that address their needs. AR as a communication medium helps to communicate seamlessly without any information distortion and offers higher information value to its users.

Table 12. DSR Grid

Problem One does not fully incorporate or exploit AR factors when designing an AR artifact	**Research process** We used DSR guidelines to concisely understand, implement, and evaluate our AR artifact	**Solution** We designed our AR artifact to incorporate AR factors / subfactors and evaluated it for utility, efficacy, and quality
Input knowledge We used AR factors that we derived from AR literature as input knowledge with support from extant theories in communication, information systems, and psychology	**Concepts** AR factors, AR characteristics, design principles, design evaluation	**Output knowledge** AR factors / subfactors design principles as prescriptive knowledge for designing our AR artifact. We designed, developed, and evaluated our AR artifact using descriptive evaluation methods (i.e., informed argument and scenarios)

6.1 Implications for Research and Practice

Our work makes several contributions to research and practice. First, we identified AR factors by analyzing the extant literature in a structured manner. We identified many AR factors from our analysis. However, we narrowed them down to the three factors that AR requires to function as a communication medium: interaction, visual canvas/cues, and immersion. Second, we leveraged DSR guidelines to design and evaluate AR artifacts. We studied an AR app's design by incorporating AR factors using design science and demonstrated a solution to the problem through a rigorous design and evaluation process. AR application design plays a critical role in enabling a novel experience using AR media. Applying Hevner et al. (2004) DSR guidelines, we iterated on our AR application's design from a communication perspective. We showed that AR design plays a critical role in enabling AR as a communication medium. Through this study, we demonstrate the design process that can help one design impactful AR experiences. To our knowledge, our study represents the first to apply DSR guidelines in designing and developing an AR application. Third, we analyzed the AR factors and their significance in AR-mediated communication using interactivity, MNT, immersion, and communication theories as a theoretical lens. We applied theories that researchers have used to study similar emerging immersive technologies such as virtual reality, augmented virtuality, and mixed reality. With assistance from these theories, we defined AR factors/subfactors and their design elements in the AR application design to enable AR media's communication affordance. Fourth, with this study, we set the stage for future empirical work. Our empirical study has high feasibility given that we already developed an AR artifact, which future research can deploy. Also, future studies can explore the relationship between the different AR factors to understand the AR phenomenon. Fifth, we contribute to theoretical knowledge on AR artifact design with measurable improvements that support technology evolution (design artifact) and add to the prescriptive knowledge base about IT artifact design that augments the existing scientific knowledge base (design theory). Our findings help augment AR as a new form of media that enables new types of experiences as Azuma (2016) has postulated and, thereby, contribute to the IS research field.

Wyatt and Piggott (2019) emphasized the need for strong collaboration between industry and academia while designing for emerging experiences such as AR, VR, wearables, and cloud voice assistants. We believe that our study will help AR designers and practitioners to design meaningful user experiences in AR. From an industry perspective, practitioners can design AR experiences for end users with a better functional insight into the underlying AR factors. We found that the AR factors interaction, visual canvas/cues, and immersion help one design AR experiences that enable AR-mediated communication. For example, in an AR app focused on educating students about planetary systems, the interaction factor design would help students manipulate AR objects modeled on different planets. Similarly, one can design the AR factor visual canvas/cues with an interface rich in content and has aesthetic appeal using graphic models and information about the planets that blends with the real environment. In our evaluation that used descriptive scenarios, we found that high-quality product visuals and more interactive user controls gave the user a good AR experience. Similarly, direct interactions and quality visuals should keep students engaged when learning about planets.

Further studies can include experimental design in studying the impact of various AR factors on communication outcomes. One may also use a quantitative research methodology and include a paper-based questionnaire to survey participants' experience using the AR artifact.

6.2 Limitations and Conclusions

As with any study, ours has some limitations. We considered only a subset of AR factors that Javornik (2016) and McLean and Wilson (2019) articulated to explain the AR phenomenon. Future studies should incorporate other factors, such as hypertextuality, connectivity, location specificity, and mobility, and theories such as hyperpersonal model of communication, media richness theory, and uses and gratification theory that may support AR as a communication medium. Furthermore, the impact that AR as a communication medium has on AR adoption needs further exploration.

To conclude, AR represents innovative technology that can aid in people's interaction and communication. We looked at AR technology potential as a new communication medium. We reviewed some AR applications and identified gaps in their design. We demonstrated the need to design and develop AR artifacts in a way that helps to establish AR technology as a new communication medium. We identified AR factors and analyzed some critical AR factors that support AR as a communication tool using extant literature. We elaborated on these critical factors and studied them using extant theories from the communication, information systems, and psychology disciplines. We designed and evaluated the AR artifact in a particular use context. We designed and developed an AR artifact grounded in design principles from the extant literature and applied design science research guidelines. We designed the AR factors with their respective subfactors and incorporated them into the AR artifact during the design cycle. We also developed a test mobile-enabled AR app, and the design/evaluation cycle happened iteratively to obtain the AR app's final design.

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Appendix A: AR Applications, AR Software Companies, Design, & Tool

Table A1. Industry AR Applications

#	AR application	Industry	Description
1	AR3D Science https://play.google.com/store/apps/details?id=in.pantherstudio.arscienceeducationlearning	Education	Interactive educational AR app presents an AR to help users learn biology, chemistry, and physics fundamentals. However, the AR restricts users to 3D models with no ways to control audio playback or seek more information about their parts.
2	Washington Post Classic App https://www.wikitude.com/showcase/washington-post-winter-olympic-ar-app/	Games	As part of communicating/educating readers about the Winter Olympic Games in Pyeongchang in 2018, Washington Post created this AR app as a fun trivia where users try to guess the different winter sports games and their speed comparison. However, the AR has limited interaction opportunities for users.
3	Lapp Group AR App https://www.wikitude.com/showcase/lapp-group-augmented-reality-app	Industrial	Lapp Group created 3D models of their products, which allowed its customers to evaluate products thoroughly before buying. However, the app has only a 3D model with little information details about its parts.
4	Toumanian Museum AR/VR https://play.google.com/store/apps/details?id=com.arloopa.dsegh	Tourism	The app acts as a museum guide for visitors. It helps scan photos/paintings and provide information through video and 3d images to create an engaging experience. However, the app has limited AR features and does not create a joyful experience

Table A2. AR Software Companies

#	AR software company	Description	Features
1	Layar https://www.layar.com	Interactive content, including video messages, Web and social links, photo slideshows, music clips, appearance animation, and widgets such as call, buy, vote, and so on	Basic, media and social buttons, video hosting and statistics
2	Catchoom https://catchoom.com	Image recognition and deliver augmented content via images, videos, or customized text. Provides content-management system and software development kits for mobile and web apps integration	APIs, SDKs for Android and iOS, Web service libraries, Unity plugins, and Web-based content management system
3	Vuforia https://www.vuforia.com	Creating digital content from 3D model targets, image targets, multi targets with flat surfaces and multi sides, cylinder targets, pre-loaded object targets, plaint texts and using specialty markers such as VuMarks	Vuforia Engine that supports AR on surfaces and objects, advanced APIs and Cloud database
4	Wikitude https://www.wikitude.com /	Creates augmented reality experiences through detection of location-based, marker or marker-less object targets	3D recognition and tracking, SMART support (ARCore / ARKit), image recognition and tracking, cloud recognition, location-based tracking, augmentation and visualizations, 3d encoder tools, enterprise API, mobile development plugins, smart glasses optimizations
5	AR Kit from Apple https://developer.apple.com/arkit/	Create AR experience based on 2D images such as posters, artwork, and signs or on 3D objects such as toys, furniture, or sculptures. ARKit 2 also adds the ability to detect known 3D objects such as sculptures, toys, or furniture	AR SDKs, quick look views of pre-stored object renders, persistent AR experience that can be saved and resumed later, share AR experience with other users, object detection and tracking
6	AR Core from Google https://developers.google.com/ar/	Build an augmented reality experience that blends with the real world	SDK, APIs, motion tracking, environmental understanding, light detection, user interaction,
7	Zappar https://www.zappar.com	Augmented reality platform and studio rolled into one	AR content creation tools, mixed reality kit, app and AR development studio

Table A3. Interaction Design

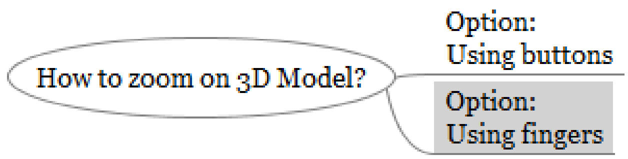
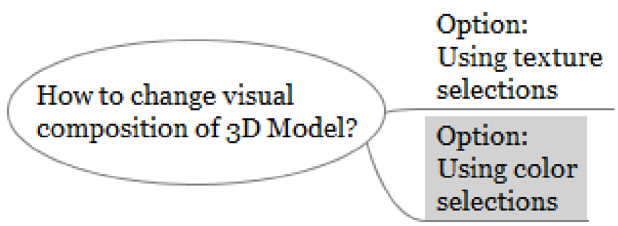
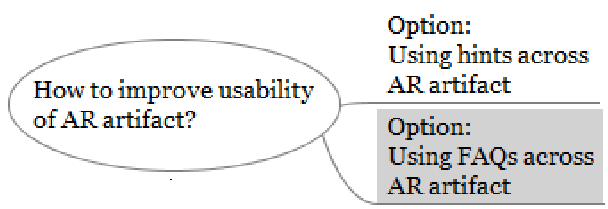
AR factor	interaction design
Interaction	
Visual canvas/cues	
Immersion	

Table A4. Detailed Design

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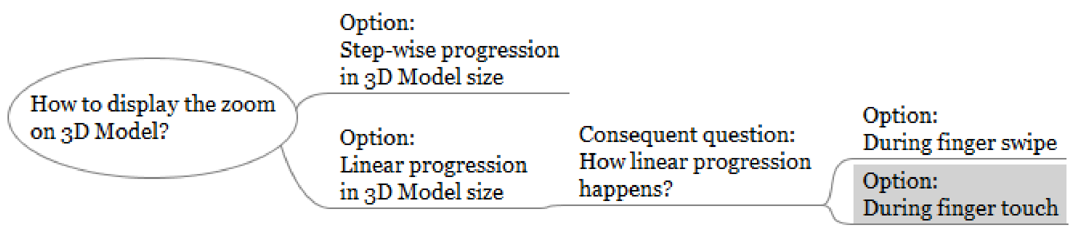
<tr><td>Interaction</td><td>
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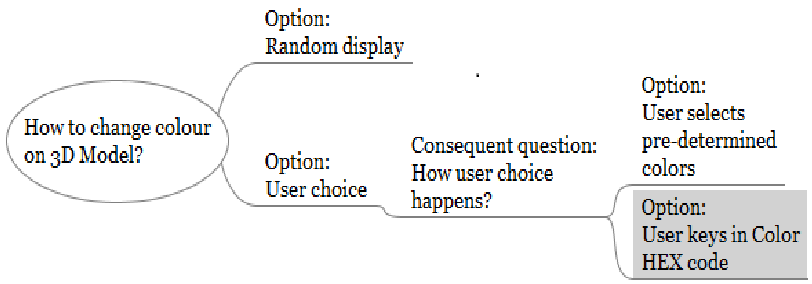
<tr><td>Visual canvas/cues</td><td>
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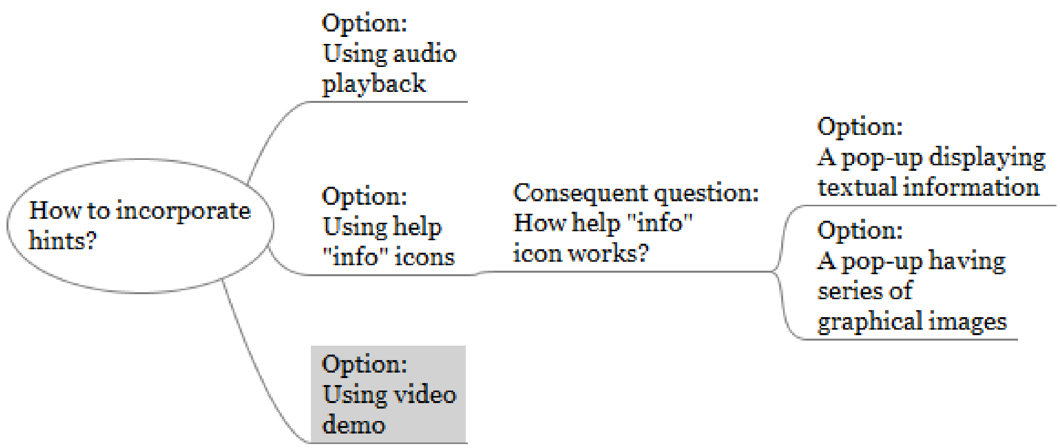
<tr><td>Immersion</td><td>
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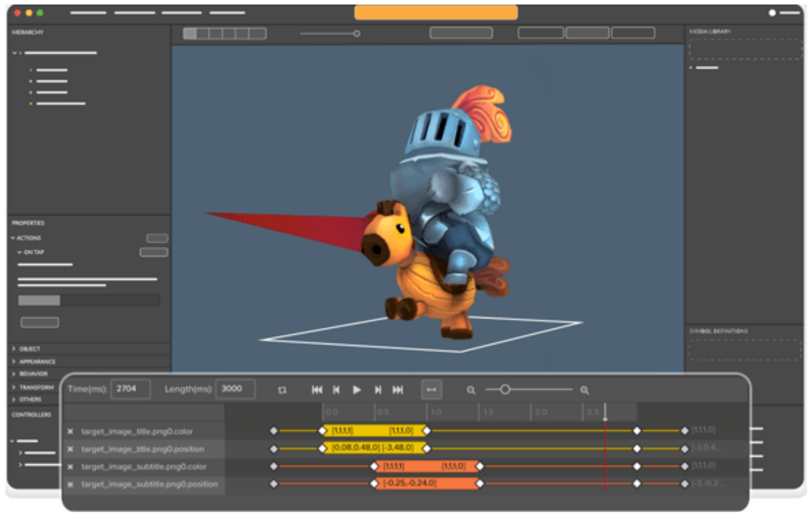

Figure A1. ZapWorks Studio

Appendix B: Summary of the Literature Review

Table B1. Summary of the Literature Review

Study / journal / area of study	Interaction	Visual interface	Immersion	Interactivity	Virtuality	Connectivity	Location specificity	Mobility	Visualization	Visual Cues	Collaboration	Telepresence	Local presence	Visual projections	Visual appeal	Enjoyment	Excitement
Botella et al. (2011) / CHB / clinical therapy	x													x			
Martín-Gutiérrez et al. (2015) / CHB / student learning	x					x			x		x						
Yilmaz (2016) / CHB / children games	x								x		x						
Fonseca et al. (2016) / CHB / architecture	x		x		x			x			x						
Joseph Dube and Ince (2019) / IJHCS / choreography	x	x							x	x							
Coovert et al. (2014) / CHB / robot navigation							x				x			x			
Chung et al. (2015) / CHB / tourist destination	x						x	x							x		
Akçayır et al. (2016) / CHB / student learning	x								x	x							
Vanneste et al. (2020) / IJHCS / machine assembly	x								x	x							
Che Dalim et al. (2020) / IJHCS / student learning				x					x								
Sylaiou et al. (2010) / IJHCS / Museum									x				x			x	
Verhagen et al. (2014) / CHB / online products	x								x				x				
Wrzesien et al. (2015) / CHB / psychotherapy	x													x			
Suh and Prophet / (2018) / CHB immersive technology			x	x			x	x	x	x		x	x	x		x	x
Verhulst et al. (2021) / CHB / cultural storytelling			x										x			x	
Georgiou and Kyza (2021) / IJHCS / student learning			x														

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