Framework of Affordances for Virtual Reality and Augmented Reality

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Journal of Management Information Systems / 2019, Vol. 36, No. 3, pp. 683–729.

ISSN 0742–1222 (print) / ISSN 1557–928X (online)
DOI: https://doi.org/10.1080/07421222.2019.1628877

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Abstract: Virtual reality (VR) and augmented reality (AR) technologies continue to grow and present possibilities to change the ways we learn, accomplish tasks, and interact with the world. However, widespread adoption has continually languished below purported potential. We suggest that a more complete understanding of the underlying motives driving users to take advantage of VR and AR would aid researchers by consolidating fragmented knowledge across domains and by identifying paths for additional inquiry. Additionally, practitioners could identify areas of unmet motives for using VR and AR. To examine the motives for virtualization, we draw upon Gibson's seminal work on affordances to create a framework of generalized affordances for virtually assisted activities relative to the affordances of physical reality. This framework facilitates comparison of virtualized activities to non-virtualized activities, comparison of similar activities across VR and AR, and delineates areas of inquiry for future research. The validity of the framework was explored through two quantitative studies and one qualitative study of a wide variety of professionals. We found that participants perceive a significant difference between physical reality and both VR and AR for all proposed affordances, and that for many affordances, users perceive a difference in the ability of AR and VR to enact them. The qualitative study confirmed the general structure of the framework, while also revealing additional sub-affordances to explore. Theoretically, this suggests that examining the affordances that differentiate these technologies from physical reality may be a valid approach to understanding why users adopt these technologies. Practitioners may find success by focusing development on the specific affordances that VR or AR is best equipped to enact.

Key words and phrases: augmented reality, virtual reality, technology affordances, virtually assisted activities, theoretical framework, adoption motivations, technology adoption.

Introduction

Methods for interacting with computers continually evolve to grant users more intuitive methods of accessing and manipulating information. From switches, dials, punch cards, mice, keyboards, and now touch screens, voice commands and mid-air gestures, additional interaction choices allow for improved human-computer interaction [9]. As interactions become increasingly natural, the line between physical and digital can be blurred. Both virtual reality (VR) and augmented reality (AR) present promising opportunities for novel interactive applications. Virtual reality technologies "provide the effect of immersion in an interactive three-dimensional computer-generated environment in which the virtual objects have spatial presence" [11, p. 13]. Augmented reality technologies display virtual components within the context of a user's surroundings.

However, despite decades of research [36, 64] and commercial attempts [52], widespread adoption of devices using these technologies has floundered, in what some refer to as the "VR Winter" [1, 36, p. 27]. Certainly, the lack of success could be largely attributed to significant hardware challenges that make instantiating specific possibilities of VR and AR difficult in simple and affordable forms. However, we argue that many practitioners and researchers lack a more complete understanding of the underlying motives that would drive users to adopt VR and AR technologies. Extant research has much to say regarding engineering possibilities and specific applications of VR and AR. However, no research adequately guides toward understanding the motives driving VR and AR adoption.

Understanding VR and AR activities is of growing importance as they become more integrated into society and business. Despite the "VR Winter," growth in both VR and AR is occurring, though AR is growing at a quicker rate. One prediction asserts the value the VR and AR market will be \$108 billion USD by 2021, with AR taking an estimated \$81 billion of the share [18]. Beyond just its growth, VR and AR are poised to change the way we learn and interact in business and in academia [62, 65, 71]. To understand the potential advantages of these technologies, myriad studies have examined specific applications and uses in various contexts, including education, healthcare, manufacturing, and others [9, 36]. While benefits are reaped from the study of specific implementations, a deeper theoretical understanding requires recognition of patterns across areas of application. Such understanding can reveal the relative advantages of each reality (VR, AR, or physical reality) for different types of activities.

The goal of this paper is to provide a basis for theoretical understanding of the motives behind user adoption of VR and AR. Our assertion is simple: users adopt virtual and augmented reality because they afford activities that are impossible or advantageous when compared to the activities afforded by physical reality. To examine this assertion, we draw upon Gibson's [28] seminal work on affordances to develop a framework of abstracted affordances of VR and AR in comparison to physical reality. Affordances were chosen because they are a generalizable lens through which user goals and technical features are combined [44, 49]. In order to verify whether the proposed affordances explain the motivations for virtualizing with VR or AR, we conducted a multi-method set of studies to better understand the affordances of VR and AR that would motivate their use as opposed to physical reality. These three studies represent an effort to establish a theoretical basis for understanding the motives for adopting VR and AR. Together, the framework and studies delineate the affordances that lead users to virtualize and aids future research by identifying affordances enabled by virtualization that have not been adequately studied. Studies 1 and 2 are quantitative efforts to validate the theory-driven framework of affordances. Study 3 is a qualitative effort to explore potential additional affordances derived from interviews with practitioners in which they experience VR and AR and then propose ways they might use these technologies in practice. The quantitative studies were needed to provide some empirical validation of what was only theoretically derived from our understanding of Gibson's [28] work on affordances. The qualitative study was then needed to explore, in practice, what affordances could not be derived or anticipated solely from theory.

This paper is structured as follows: First, we review past literature on VR and AR. Then, we discuss and compare the different features of VR, AR, and physical reality that lead to different possible affordances. Next, we present and explain our framework of affordances for virtually assisted activities. After, we present our three studies, including: (1) experiential survey to explore the validity of the framework, (2) instructive survey to cross-validate the experiential survey, and (3) interviews from a wide variety of professionals to both explore and confirm the theorized affordance framework. Finally, we discuss insights from these three studies and make recommendations for further research.

Literature Review

Virtual reality and augmented reality have been defined in various ways, so it is worth reviewing past literature to establish clear definitions for VR and AR and examine frameworks to uncover areas unaddressed. Additionally, because we compare virtual activities to their non-virtualized counterparts in the physical world, a brief review and precise definition of reality is warranted.

Reality

Reality is commonly defined as "the quality or state of being real" [53], while real is defined as "occurring or existing in actuality" and "having objective independent existence" [51]. For centuries, philosophers have deliberated over what constitutes reality and the extent to which reality can be known. George Berkeley asked, "what do we perceive besides our own ideas or sensations?" [8, p. 196], while David Hume stated "the mind has never anything present to it but the perceptions, and cannot possibly reach any experience of their connexion with objects" [35, p. 115]. These observations call into question the assumption that our perception of a physical world implies its actual existence. However, a metaphysical discussion is far beyond the scope of this paper; therefore, we define physical reality as the environment we naturally perceive without any additional information provided by communication technologies.

Virtual Reality

Many early definitions describe VR as a technological system with specific features, such as 3D goggles and wired clothing [61]. But rather than focus on technological specifics that change with time, others discuss the underlying attributes of virtual reality. Defining VR without reference to specific hardware makes the definition more robust to technology changes and facilitates the establishment of theories and frameworks that remain applicable for future research. For example, one such framework examines virtual reality through the lens of telepresence, or "the experience of presence in an environment by means of a communication medium" [61, p. 76]. Thus, virtual reality is "a real or simulated environment in which a perceiver experiences telepresence" [61, p. 76-77]. This is a useful definition, though an admittedly broad one. For the purposes of this paper, we focus on VR technologies with a high level of visual vividness and interactivity, such as head-mounted displays. Additionally, we argue that a key feature of virtual reality is immersion, or as Gabriel Ofeish suggested, "As long as you can see the screen, you're not in virtual reality. When the screen disappears, and you see an imaginary scene … then you are in virtual reality" [50, p. 7].

Augmented Reality

Augmented Reality has been defined as "any case in which an otherwise real environment is 'augmented' by means of virtual (computer graphic) objects" [46, p. 4]. The definition we adopt is any system that 1) combines real and virtual content, 2) is interactive in real time, and 3) is registered in three dimensions [5]. Notably, this definition excludes content such as movies that add virtual effects (they are not interactive) or systems that merely display 2D virtual effects on top of live video (the virtual effects are not registered in 3D). Because augmented reality does not require complete immersion, a wider number of specific technologies could be used to implement AR.

Summary of Past Literature and the Need to Understand User Motives

In summary, virtual reality immerses a user in a virtual environment, excluding them from their current physical environment. Augmented reality renders 3D virtual components in the context of a user's physical environment. Extant literature provides useful definitions, taxonomies, and frameworks for classifying various technologies used for VR and AR. These include classifying mediums by vividness and interactivity and differentiating degrees of virtual and physical representation of mixed reality hardware [46, 61]. Other related literature includes a taxonomy for visual representation in general, or "real space imaging" [47], a taxonomy of mediated synthetic experiences of head-mounted displays [55], and a framework of the factors that influence immersion and presence in virtual environments [60]. Others look at VR in a specific domain, such as a framework for VR systems used for motor rehabilitation in health contexts [24].

Plenty of frameworks and taxonomies clarify, delineate, and describe the technologies themselves, but not the actual affordances of the technologies. Thus, past research has been necessary and helpful, but does not provide a theoretical explanation of the driving motivations to use VR and AR based on their generalizable affordances.

Myriad studies examine the effects of VR and AR in specific domains like education, architecture, marketing, entertainment, manufacturing, military, health care, and others [9, 40]. Examining what would motivate users at this micro level is relatively easy. For example, therapists would adopt VR when they know it can improve treatment of stress disorders [31]. But we are lacking in a theoretical understanding as to why, generally, people would choose to virtualize. At the macro level, no framework exists that describes VR or AR in relation to users. To initiate this body of research, we create a framework that considers user motivations in conjunction with the features of the technologies. We do this in the next section by examining affordances and the features of VR and AR.

Affordances and Features of VR, AR, and Physical Reality

For any type of experience, what determines preference for VR, AR, or physical reality (PR)? In order to better understand what would drive users to perform an activity with VR or AR, we examine the affordances of each technology. The concept of affordances originated in the field of ecological psychology to describe the features that environments provide animals [28]. Later research more specifically describes affordances as “relations between the abilities of organisms and features of the environment” [13, p. 189], more clearly indicating the idea that the features of an environment may afford certain actions to some animals, but not others. For example, the features of a tree include its trunk, bark and branches. These features afford climbing to those with an ability to climb (like monkeys) but they do not afford climbing to animals without that ability (like turtles). As this example shows, affordances are not properties of environments that exist independent of actors. An object only affords something when an actor capable of using the features interacts with such an object [57]. This idea has been extended to the field of information systems as a method to explain IT effects, particularly why the implementation of particular IT artifacts can produce various outcomes with different actors [44]. Markus and Silver extend the idea of affordances of an environment to technical objects and define what they call functional affordances as “a type of relationship between a technical object and a specified user (or user group) that identifies what the user may be able to do with the object, given the user’s capabilities and goals. More formally, functional affordances are defined as the possibilities for goal-oriented action afforded to specified user groups by technical objects” [44, p. 622].

Examining VR and AR through the lens of what they afford is useful for at least three reasons. First, affordances help examine user goals. By creating a link between technology features and user capabilities and goals, affordances create a lens to examine why users would actually use the technologies. Affordances are great for examining the goals of users implementing technology, so identifying relevant affordances helps to understand the motives driving use. Consequently, understanding motives helps accomplish our stated goal of understanding how to implement and apply VR and AR technologies in more useful ways.

Second, affordances are relatively generalizable and constant across specific implementations [44]. VR and AR technologies have evolved, becoming more powerful over time and will surely continue to do so. But because affordances focus on features that align with user goals, they can apply more broadly to a wide variety of implementations. For example, several specific implementations of AR currently exist, such as through holding up a smartphone or wearing a head-mounted display. But despite differences in how AR features are implemented, both afford altering an environment with virtual representations. Sufficiently generalized affordances facilitate comparisons and discussions that are not tied to one specific set of properties. As such, a framework based on generalized affordances is applicable to future iterations and implementations of virtualizing technology.

Third, affordances facilitate examining VR and AR in comparison to physical reality. Affordances are particularly apt at describing VR and AR technologies because the concept has been extensively applied to IT artifacts and, in its original conception, to environments. VR and AR technologies are IT artifacts that virtually create or alter environments. Given the history of affordances, examining the affordances of VR and AR is an appropriate and useful application of the concept. If VR creates environments and AR alters environments, it seems appropriate to ask why a new environment would need to be created or an existing environment altered. We already exist in a physical environment that affords a multiplicity of interactions. By examining what virtual and augmented environments afford in comparison to physical reality environments, we can better understand the goal-driven motives that would lead users to choose VR or AR.

Because affordances are the relation between features and abilities, we begin by examining the features of VR, AR, and physical reality. Both VR and AR technologies have features that improve activity execution when compared to execution in physical reality. Activities that can be completed using VR and AR could be grouped into two main categories: those that would be literally impossible to accomplish in the physical world because of physical laws (such as visiting a city as it appeared hundreds of years ago), and those that are possible to perform in physical reality, but the addition of virtuality provides some benefit in terms of convenience, safety, or method of information delivery. In both categories, VR and AR are suited to certain types of activities due to a fit of inherent features and the abilities of users, enacted in certain activities. Classifying affordances enabled by virtualization, therefore, requires an understanding of the basic features of VR, AR, and physical reality, and what advantages and disadvantages those features afford.

Features of Virtual Reality

The defining attribute of virtual reality is immersion in entire environments or even entire virtual worlds. VR technologies have improved in their ability to immerse participants, which lead to an increased sense of being present in another environment [60]. Necessarily, a key aspect of immersion in virtual reality is exclusion from immediate physical reality. This exclusion affords both benefits and costs. Because the environments created by VR are virtual by definition, another key feature of VR is the ability to create experiences that do not follow the physical laws to which we are bound in physical reality. Several sub-attributes based on this observation are important to highlight. For example, virtual representations can jump through space and time, presenting recreations of physical environments that existed centuries in the past or those that have not yet come into existence. Because traditional laws of nature need not be followed, experiences like flying, breathing under water, controlling objects through telekinesis, or any others can be created (we playfully refer to these types of activities as "magic school bus" activities). Entire environments can be created with beings and objects that have no physical world counterparts, allowing for activities such as flying on a dragon.

VR's features also create disadvantages, the most prominent being the lack of haptic richness that the physical world provides, or "vividness" [61, p. 80]. If a certain experience requires high haptic richness and VR technologies struggle to recreate that, the sense of presence will suffer [60]. The degree to which this matters depends on the specific activity. However, technological developments may significantly decrease the gap between virtual and physical in coming years, making this less of a concern. Beyond this, exclusion from the context of immediate physical surroundings can be disadvantageous. While some social and economic gains are made in virtual worlds [30], many valuable social interactions and relationships exist primarily in the physical world. Thus, immersion in a virtual world potentially limits the impact one has on his or her immediate surroundings. Perhaps VR's best uses are those where knowledge or experience gained outside physical reality's context can later be used to bring benefit to the physical world, whether through some learned skill or through an improved emotional or mental state.

Features of Augmented Reality

Augmented reality strikes a balance between the advantages of context in physical reality and highly adaptable virtual presentations. AR's defining feature is the ability to have "virtual and real objects [coexist] in the same space" [5, p. 356]. Whereas VR strives to establish a sense of presence in a virtual environment, AR maintains a sense of presence in a user's immediate physical surroundings. As such, the virtual components of AR are intended to enhance the physical world or provide components that could not otherwise exist without virtualization. Similar to VR, a key feature of AR's virtual components is that they need not follow physical laws. While the physical portions of the environment will obviously conform to physical law, any virtual object can defy these laws and present objects that defy space/time linearity, have no physical counterpart, or break other physical laws (such as gravity). These two features, combining physical and virtual scenes, as well as the ability to break physical law, allow for activities like interacting with a historical figure within the context of a traditional classroom. Other uses, like presenting training information with additional visual cues and data, do not necessarily defy physical laws, but can enhance the learning process.

However, presenting real and virtual objects simultaneously does present some disadvantages. Similar to VR, reproduction fidelity of virtual images may not be high enough to make virtual objects sufficiently convincing and useful in certain contexts. Another technological challenge is anchoring, or accurately positioning virtual content in a physical space. Interactions are less effective when virtual and physical objects “collide” and occupy the same space [37]. Current technology restrictions make it difficult to dynamically map large, open areas. Some methods for combining virtual and real objects, like virtual mirrors and optical see-through head mounted displays can also potentially darken and limit the view of the physical world. All of these factors can lead to a less enjoyable and effective experience, though technological improvements are rapidly making these nonissues [9]. In other contexts, the introduction of too much information and stimuli can lead to information overload [38]. Augmenting physical reality with additional information and images could perhaps distract and decrease performance at a certain point, though more research is needed to know at which point this is reached. AR’s best uses will likely be situations in which context or interaction with the real world is paramount to a task’s success, but the success is increased or made more likely, enjoyable, or efficient through additional visual information presented alongside the physical world.

Features of Physical Reality

In other situations, interacting in physical reality will likely remain the most useful and preferred method for many activities. One of physical reality’s best features is its complete sensory richness. Humans’ senses have evolved in the context of interacting with physical, not virtual worlds. Steuer [61] suggested that sensory vividness is determined by both the number of different sensory inputs delivered (breadth), as well as the quality of each sensory channel (depth). For example, the sensation of lying on a beach is not only dependent on visual stimuli, but also the feeling of the sun’s warmth, the spray of water, the rhythmic sound of crashing waves, the smell of salt, and other subtle stimuli. The culmination of each stimulus provides an experience that a single stimulus in isolation cannot replicate. Physical reality can simultaneously present an array of stimuli, with no lag, and seamless immersion with human senses in their natural, highest quality state. While certainly advantageous in most cases, if the constant presence of sensory feeds that are not pertinent to the execution of an activity, they could be potentially distracting and disadvantageous.

Another key attribute of physical reality is its tight binding with physical laws, including the linearity of time, restrictions on movement, gravity, size, and forth.

Such laws provide a structure to our environment that allows for reliable interactions. As a simple example, the effortless act of walking would be greatly complicated if gravity were to fluctuate from day to day. However, these same laws pose restrictions on what can be accomplished. These basic features of VR, AR, and physical reality are summarized in Table 1. Table 1 is not intended to be comprehensive or exclusive, but does include salient examples to illustrate some key differences in these types of reality.

Summary

Certain forms of reality afford certain activities better than others. For example, virtualization may not afford activities that greatly depend on the breadth and depth of sensory stimuli. Related problems have been observed with many communication mediums. Comparisons of face-to-face and telecommunication interactions have widely shown asynchronous outcomes in many areas, such as identity perception and work results [6, 29]. As such, it is reasonable to assume some differences will occur when using VR and AR technologies as well. When those differences are disadvantageous, physical reality may prove to be the preferred method of interaction. When physical laws and limitations prevent or impede physical interactions, virtual and augmented reality may be preferred instead.

A Framework of Affordances for Virtually-Assisted Activities

Examining only the features of a technology is insufficient. Any study of technology must also include an examination of the users, their abilities, and their motives or goals in implementing a technology [41, 49]. Affordances are "the possibilities for goal oriented action afforded to specified user groups by technical objects" [44, p. 622]. So, understanding how a technology is actually implemented and used depends on understanding the goals of a user or user groups. Of course, individual goals and motives can vary widely, far too widely for a parsimonious framework to capture. Additionally, specific implementations of VR and AR can vary just as widely, from environments simulating deep sea diving to displaying instructions on manufacturing equipment. Past research has examined how specific affordances of VR and AR enable goal-directed behavior in certain domains and situations [15, 21, 27, 54, 59]. However, examinations at a micro level do not provide a generalized understanding of what motivates users to adopt VR or AR across domains. Such an understanding requires identifying affordances that apply to all implementations of VR and AR. While activities can vastly differ in their purposes and executions, examining them from some base affordances allows for generalizable implications that can be further analyzed. Thus, frameworks allow for a "sameness of reference" [32, p. 34] by which technologies can be studied in varying contexts.

At the most generalized level, the unifying factor of all activities utilizing VR or AR is the use of virtualization in some form. We adapt a previous definition of

Table 1. Summary of Features of VR, AR, and Physical Reality

Type	Features	Advantages	Disadvantages
Virtual Reality	Full immersion	A sense of presence can be delivered in highly adaptable environments.	Loss of direct interaction with immediate surroundings.
	Not bound by physical laws	Depict what is normally impossible or impractical.	Potentially decreased naturalness of interaction.
Augmented Reality	Mix of virtual and physical objects	Physical world can be enhanced while maintaining a sense of presence with immediate surroundings.	Imperfect synching of virtual and physical can decrease effectiveness. Potential information overload.
	Virtual components not bound by physical laws	Virtual components can depict what is normally impossible or impractical.	Potentially decreased familiarity of interaction.
Physical Reality	Sensory richness and seamless immersion	All depictions naturally create a high level of immersion and multiple stimuli provide information on many levels.	Potential of unneeded, distracting stimuli.
	Bound by physical laws	Laws provide a reliable structure for existence and behaviors.	Laws limit possible activities to those that fall within the bounds of physical law.

activities and refer to these as "virtually assisted activities" (VAAs), or any function by a specific actor (or actors), at a particular location, utilizing some visually presented virtual object (or objects), enacting a particular affordance, and producing an outcome [26]. What is specifically intriguing about VAAs is *why* some component of an activity is chosen to be virtualized. To create a useful framework for VAAs, we suggest examining the abstracted affordances that motivate users to virtualize a portion or the entirety of an activity. The use of affordances as the determining factor for the framework enables greater generalizability than using activity types as the determining factor – while there are many types of activities that may or may not be relevant across contexts, affordances can be sufficiently generalized to remain applicable across all contexts. But despite the generalization, they still describe overarching motivations, making them a useful lens.

The very fact that virtual reality and augmented reality have found relative widespread use suggests that human interactions with the physical world lack affordances required to satisfy some motives. Affordances of VAAs can therefore be framed in terms of motivations for including virtuality in the activity. A prime benefit of classifying by motivation-for-virtualization is that it allows for the easy comparison of certain types of affordances to their physical world counterparts. Also, understanding the motivations for virtualizing could allow better discernment between different types of VAAs, such as those that are truly superior in activity outcomes, and VAAs whose ubiquity is solely driven by convenience.

Thus, VR and AR have affordances that differentiate them from physical reality. But which generalized affordances are the most useful to examine? As the theoretical foundation of the affordances presented in our model, we reference Gibson's seminal introduction of affordances. While discussing affordances that exist in the natural environment, Gibson recognized the fact that humans often seek to modify their environment. "Why has man changed the shapes and substances of his environment? To change what it affords him. He has *made more available what benefits him* and *less pressing what injures him* … Over the millennia, he *has made it easier for himself* to get food, easier to keep warm, easier to see at night, easier to get about, and easier to train his offspring" [28, p. 130 italics added]. The key idea is that humans do in fact change their environments, whether by emphasizing the positive or minimizing the negative, to reap some benefit. From this discussion we can develop specific, yet generalized affordances viewed through the lens of VR and AR, providing a novel way to create an altered environment. We suggest four general affordances based on Gibson's key idea of altering our environment by introducing affordances that overcome negatives or enhance positives: First, virtualization enables the idea of making "less pressing what injures him," [28, p. 130] which we call an affordance of *diminishing negative aspects of the physical world*. For our second and third affordances, we reference the ideas to "[make] more available what benefits him" and "make it easier for himself" [28, p. 130]. Namely, virtualization can alter or add to aspects that already exist in the world and improve upon them, which we refer to as *enhancing positive aspects of the physical world*.

However, virtualization can also recreate existing elements of the physical world. Benefits in these situations are derived from the convenience or ease of use that virtualization brings. We call this *recreating existing aspects of the physical world*. Gibson also explained, “No matter how powerful men become they are not going to alter the face of earth, air, and water—the lithosphere, the atmosphere, and the hydrosphere, together with the interfaces that separate them. For terrestrial animals like us, the earth and sky are a basic structure on which all lesser structures depend. We cannot change it” [28, p. 130]. Despite mankind’s intentions, there are elements of the physical world that cannot be altered. However, VR and AR create benefits otherwise not possible by breaking those limitations. We call these creating aspects that do not exist in the physical world.

Table 2 outlines the four affordances and we describe each in more detail in the following sections. Table 2 is not intended to be comprehensive or exclusive; it is a *proposed* framework that we subsequently seek to validate through exploratory and confirmatory data collection. Each of the four affordances can be further separated into sub-affordances, of which we give some examples. Additionally, the effectiveness of each affordance can be modified by two factors, the importance of sensory vividness, and the importance of physical context. Activities that require high levels of sensory depth or breadth will likely suffer if virtualized, as VR and AR may not afford presenting a sufficiently vivid experience [61]. The importance of physical context modifies how an activity is virtualized. If physical context is required, AR or physical reality would be preferable, while activities that have no need for physical context (or those that are improved when physical context is completely removed) are more advantageous in VR.

Affordance: Diminish Negative Aspects of the Physical World

Many good activities have decidedly negative aspects to them, which potentially lead to negative outcomes. One clear sub-affordance of virtualization is reducing the physical risk inherent to some activities. Military training illustrates this point, as mistakes made while learning can have serious and long-lasting effects. In pilot training, for example, virtualization provides “safety because training pilots can make mistakes and learn to avoid them safely on the ground” [19, p. 79]. In such cases, the purpose of virtualizing is to present the activity without physical risk, so that the benefit inherent to the rest of the activity would still be reaped. The same benefit is applicable to medical training [70] and a host of other contexts.

A related sub-affordance is virtualization used to decrease the effects of mental or emotional risk. A large area of research of VR examines positive effects for sufferers of post-traumatic stress disorder. Patients are reintroduced to potentially mentally harmful environments in which the presentation of harmful stimuli is artificially decreased through virtualization. One such example is recovering from post 9-11 trauma. Participants virtually relived situations similar to 9-11 but artificially decrease the emotionally disturbing aspects until they felt able to face

Table 2. Framework of Affordances for Virtually Assisted Activities

Primary affordance motivating virtual representation	Examples of sub-affordances	Sub-affordance descriptions	Modifiers	
Diminish negative aspects of physical world Virtual representations of activities that normally have large negative effects, but those effects are artificially diminished.	Reduce Physical Risk	Virtual depictions circumvent the physical risk normally inherent to an activity.	Importance of Sensory Vividness The importance of the breadth and depth of detailed sensory representation for successful activity execution.	Importance of Physical Context The degree to which an activity depends on the participant's immediate physical surroundings.
	Reduce Emotional/Mental Risk	Virtual depictions circumvent the emotional or mental risk normally inherent to an activity.		
Enhance positive aspects of the physical world Virtual representations are used to present information in a method that improves upon methods available in physical reality.	Facilitate Additional Information	Efficacy of an activity's completion is aided by virtually represented information.		
	Filter Information	Efficacy of an activity's completion is aided by virtually highlighting and diminishing certain information.		

Recreate existing aspects of the physical world Virtual representations are used to replicate some object or experience in the real world, not because it is better represented virtually, but because it is more practical to do so.	Reduce Resource Cost	Virtual representation decreases the amount of time, effort, or financial resources required for an activity.
	Enable Physically Incapable Participants	Virtual representation affords activities to additional users that normally cannot participate in an activity due to physical limitations.
Create aspects that do not exist in the physical world Virtual representations are used because reasonable physical counterparts simply do not exist.	Depict the Nonexistent	Activities involve fantasy or hypothetical representations that have no existing physical counterpart.
	Overcome Space-time Linearity	Activities involve interaction with objects or environments that existed in the past or have not yet come into existence.

them. Such treatment led to a decrease in negative effects of PTSD [17]. Another study found that virtual treatment for patients with a fear of flying proved just as effective as standard exposure treatments, but virtual treatment had additional benefits of convenience, safety, and low cost [56].

Affordance: Enhance Positive Aspects of the Physical World

Virtualization affords enhancing aspects of the physical world that improve outcomes compared to activities without virtual components. One sub-affordance is improving an activity through additional information. Virtual visual cues can guide users [10]. For example, a surgeon's vision might be augmented with an overlay of the patient's most recent MRI [42]. AR-enhanced books have been shown to decrease the gap between high and low achievers in narrative internalization [20]. AR can afford improved engagement and interest, as one study found students were more motivated to learn when material was presented using AR technology [58]. VR medical training has the potential to increase participants' feeling of presence compared to other methods [34].

Another sub-affordance could be using virtualization to filter out surrounding stimuli to focus exclusively on the task at hand. AR could redesign a physical workspace with virtual walls and dividers that are not physically present, but still block line of sight to potentially distracting scenes. In situations with an overload of information, pertinent details could be highlighted while other details be blurred or removed. In some contexts, virtual reality could also serve this purpose, as it isolates users from their surroundings, enabling them to focus more completely on the virtual environment and objects presented to them [39]

Affordance: Recreate Existing Aspects of the Physical World

Many regularly performed activities are positive experiences, but virtualization affords recreating them more practically. One sub-affordance is reducing resource cost for activities that normally require significant amounts of time, exertion, or financial resources. For example, automobiles can be shown to potential customers through AR [72]. Examining a car through virtualization is likely inferior to a physical encounter that provides more haptic feedback, but a virtualized car is easily duplicated at low cost and presented to customers without spending time and effort in travel. Similarly, Amazon's AR View app allows certain products to be viewed through a smartphone in the context of a consumer's home, enabling them to see how a product would look on a desk or a wall before buying it [4]. Students could collaborate in virtual classrooms when it is too difficult to meet physically [23]. The benefits reaped from such virtually-assisted activities are convenience and efficiency.

Another sub-affordance refers to the participant's physical capabilities. Participation in many activities requires capabilities that are afforded to many but not all, such as being able to walk or run. Virtualization affords experiences to user groups whose abilities and physical limitations would normally prevent participation in certain activities. As an example, one study examined the use of VR treatment for hospital patients recovering from strokes. The patients' state of health did not allow them to participate in simple activities, such as walking through a town and purchasing groceries. VR allowed for faster rehabilitation through virtualized participation in routine activities [43]. In this case, virtualization did not create an improved experience of purchasing products at the supermarket. On the contrary, the study's virtualized version of the activity is rather crude compared to a non-virtualized experience. But virtualization provided a version that allowed benefits to be reaped by a disadvantaged population who would otherwise have no access to the activity. This concept could even be extended to activities requiring a level of physical expertise not commonly held. A novice snowboarder could virtually experience a demanding mountain slope whose difficulty would otherwise put it out of their skill range. Virtual snowboarding likely pales in comparison to real snowboarding, but it does open up the possibility to participants who would normally be excluded due to lack of skill or experience.

Affordance: Create Aspects That Do Not Exist in the Physical World

Because virtualizations need not follow the laws bound to our physical world, such laws can be broken to provide experiences that simply have no close non-virtualized counterpart. One such sub-affordance would be creating objects or environments that do not exist in the physical world. Physical environments do not afford riding dragons simply because dragons do not exist. But such an activity is possible through virtualization. One prominent example is the AR smartphone app Pokémon Go, which places digital monsters in the context of user's world and incentivizes users to seek and capture the monsters. The captivating combination of social phenomena, virtual representations, and users' physical surroundings led the app to an estimated 650 million downloads, suggesting that the general public is open to fantasy virtualizations [14]. Other more educational uses would also be possible, such as the ability to shrink to a subatomic size and explore the structure of different molecules in VR, or use AR to increase the size of particles and view them in the context of a classroom [66]. Many other such activities exist that are physically impossible to accomplish but would be interesting and educational to virtualize, such as exploring the center of a supernova or walking along the bottom of the ocean.

Another sub-affordance is overcoming the limits of space-time linearity. Generally speaking, we can only observe the world as it currently exists in time, but virtualization affords viewing places or objects as they previously existed or how they will exist in the future [12]. One paper explored using an AR game to visualize Cologne, Germany as it appeared in the past, as well as how it might look in the future [33]. In the construction industry, buildings could be seen at true scale as they will appear before construction ever begins, allowing for more accurate models to be communicated. Additionally, overcoming space/time linearity can also apply to people. Important historical leaders and figures could be virtually recreated and interacted with. Classroom instruction could possibly become more engaging when hearing history from a virtualized "firsthand" account rather than a book or regular instructor.

Modifiers: Importance of Sensory Vividness and Physical Context

While each of the aforementioned affordances and sub-affordances describe why someone would be more inclined to participate in a virtually assisted activity instead of a non-virtualized activity, we suggest other factors influence the choice, even when a strong motivation to virtualize is present. The first of these modifiers refers to the importance of sensory vividness, or the importance of the breadth and depth of detailed sensory representation. For example, consoling a friend that recently experienced a tragedy may be better served with a real, warm hug than a virtual embrace. Some research has shown that touch can relay a comparable range of emotional information as facially and vocally transmitted emotional cues [22]. Of course, many activities do not depend on realistic, simultaneous sensory stimulation. However, as long as VR and AR have difficulty transmitting high-fidelity sensory information, non-virtualized activities will be preferred when sensory vividness plays a central role in the activity.

Manufacturing products, repairing equipment, examining existing buildings, administering care to people, and many other activities all depend on interaction with real, physical objects. When an activity requires that an action effect some change in the physical world, VR may not afford a preferred interaction. AR affords actors to remain in contact with their surroundings, so it would likely be the preferred method for virtualization in such instances. This can be seen in several manufacturing companies already implementing AR in their processes, such as Boeing reporting a 25 percent productivity increase of wiring harness assembly [2]. However, it is possible to interact with the physical world using VR in some cases, such as controlling a remote machinery maintenance system [7]. We next report on three studies that use and validate this framework.

Methodology

We employ a multi-method, multi-study approach, which is more inductive than abductive, to provide support for our proposed framework and its underlying affordances offered by virtual reality and augmented reality in comparison to physical reality. Quantitative data was derived from two separate data collections where participants were exposed to VR and AR technologies and their features, followed by a survey to capture the relative strength of the affordances presented in the framework. During a third study, supporting qualitative data for the affordances listed in the framework was gathered from semi-structured interviews with experienced professionals across numerous disciplines and roles. We first present the quantitative then the qualitative portion.

Quantitative Evaluation of Framework

To validate that the affordances proposed in the framework do in fact reflect advantages over physical reality, each of the quantitative studies asked participants to rate the ability of VR, AR, and PR to enact each affordance. To ensure understanding of the technologies, we introduced VR and AR to the participants before asking them to evaluate the relative appropriateness of VR or AR for each sub-affordance. The studies varied in their approach to introduce the capabilities of VR and AR and also in the subjects that were recruited. However, both studies asked participants to rate VR and AR for each sub-affordance.

Study 1

Study 1 was conducted as an experiential survey at a large, private university in the western United States. Ultimately, 263 participants were recruited and completed the study. To ensure participants understood the typical capabilities and features of VR and AR, they received a standard description of the technologies and their respective features, participated in a hands-on experience with both VR and AR, and evaluated scenarios that highlighted some potential situations for implementing VR or AR. After the instruction and exposure, participants were asked to rate how well VR and AR enable each affordance. Respondents also rated these affordances for physical reality, which serves as a baseline for comparison.

Upon arriving at the lab, participants were given an overview of the purpose of the study and research procedure, including a brief description of VR and AR. After giving their consent, participants were given a 5-minute hands-on experience with VR and a 5-minute hands-on experience with AR. The order of VR/AR experience was randomized to minimize any potential ordering effects. Each of the experiences included two different scenarios so that participants had an appreciation for the various features of each technology. However, this hands-on experience was simply illustrative of the feature set, not an exhaustive review of all potential features. After the hands-on experience, participants completed a survey that further exposed participants to potential uses of the technologies by introducing scenarios where these technologies could be beneficial. The survey then asked participants to rate VR, AR, and physical reality in terms of their ability to enable each sub-affordance (see Table 3 for example survey question). We also gathered demographic information.

VR Experience. The VR experience was given through a Samsung Gear virtual reality headset. Participants were led to a room where they put on the Samsung Gear headset and viewed two different 360-degree videos. 360-degree videos allow

Table 3. Survey Question about the Affordances Enabled by Each Eeality

To what extent does *[Physical Reality, Augmented Reality, or Virtual Reality]* allow you to do the following (where 0 is not at all and 10 is perfectly)?Reduce physical risk • Reduce emotional/mental risk • Obtain useful additional information not available by default • Highlight, filter, or block certain information • Reduce costs associated with time, effort, or financial resources • Participate in an activity that would otherwise be impossible for me • Gain access to objects or activities that cannot exist when using another approach (fictional constraints) • Gain access to objects, activities, or environments that existed in the past or have not yet come into existence (time constraints) • Experience the breadth and depth of detailed sensory inputs (e.g., smell, touch, etc.) • Leverage important details in my immediate physical surroundings (within the scenario)

participants to interact with the video by looking up, down, and around in continuous 360 degrees to gather information from any direction. Participants sat in a swiveling office chair to allow for this freedom of movement. The first video was a benign 3D conference room that allowed participants to orient themselves with the technology. As seen in Figure 1, the conference room was fairly sterile, with a table in the middle, white walls, a window, and a door. Participants were allowed to look around the office for approximately 2 minutes.

Afterwards, participants interacted with a 360-degree immersive action movie. In the movie, participants are chased by an alien through the subway system in a metropolitan city. The action movie was selected as it was exciting and interactive in that it required the participants to look around to take in information from all

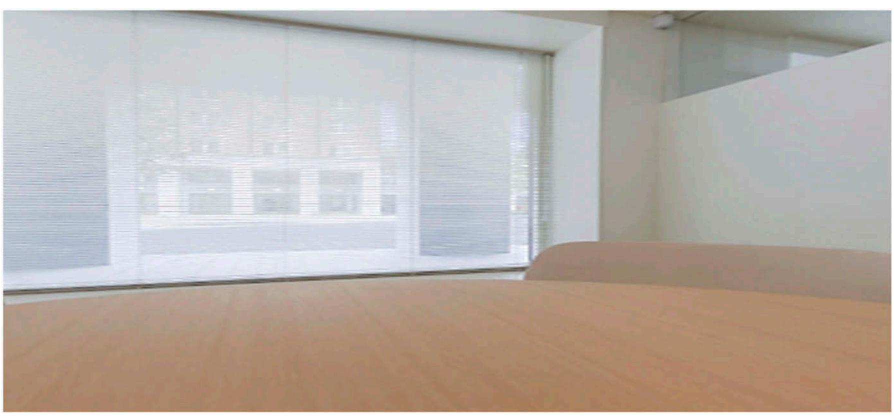

Figure 1. Conference room video

directions. Participants watched this alien invasion video for approximately 2 minutes. A few scenes from the movie are included in Figure 2.

AR Experience. For the AR experience, participants were led to a room where they used the Microsoft HoloLens. The HoloLens is a holographic computer that uses specialized components like multiple sensors, advanced optics, and a custom holographic processing unit to produce holograms that are situated in the user's environment [45]. The HoloLens is worn like a pair of glasses and all processing is done directly on its self-contained computer. The HoloLens was selected because it is the most powerful augmented reality device currently available [3] and allowed participants to experience a highly interactive form of augmented reality [67].

Participants first saw a few different holograms that had been placed in the room and were encouraged to look at them from different angles. Participants were also taught the *air tap* and *bloom* gestures that they would use to interact with their environment. A bird hologram was placed on the table and would chirp and move when *air tapped*. A planet was floating near the ceiling in the corner of the room, and a RoboRaid game icon was placed on a wall directly in front of the participant. Figure 3 shows the layout of the holograms in the room.

Figure 2. Scenes from the virtual reality alien invasion movie

After becoming acclimated with the technology, participants air tapped the RoboRaid game icon and played the interactive game. In RoboRaid, robots come through the physically present walls and participants must destroy the robots by shooting lasers. Some robots crawl around the walls while others fly around the room. Shooting lasers destroys the robots, but also destroys the wall, revealing the structure behind the wall, as if an actual hole were being created. Figure 4 illustrates

Figure 3. Holograms in room when participants first put on HoloLens

a sample scene from the AR experience. Participants played the RoboRaid game for 3 minutes.

It is important to note that the scenarios selected for both the VR and AR introduction were meant to simply be illustrative, not exhaustive or equivalent. Many participants reported having some familiarity with VR and AR; however, our experiential lab time was intended to ensure that all participants had at least some hands-on exposure to some of the most prominent features of each technology. Another strength of this approach is that participants, since they experienced both technologies in a short period of time, were able to draw distinct contrasts of the features of each technology compared to if they had only experienced one of the technologies or learned about them in a more general/broad way (as in Study 2). In an effort to broaden their perspective of potential applications of these technologies and to ensure they weren't biased or constrained to the context of the interactions with VR and AR, we also presented 10 different scenarios based on the framework for them to consider.

Survey. After gaining experience with VR and AR, participants completed a survey that gathered their perceptions of these technologies. In this survey, participants were asked to evaluate the affordances of virtual reality, augmented reality, and physical reality that were identified in the framework. Table 3 contains the actual question. These questions were derived from the sub-affordances outline in our framework (see section titled An Affordance Framework for Virtually-Assisted Activities for related literature and justification). The physical reality condition serves as a baseline against which the responses for the other conditions can be compared.

Participants. A pilot study was conducted to test the methods and procedures which resulted in no substantive changes. Over a one-week period, we collected

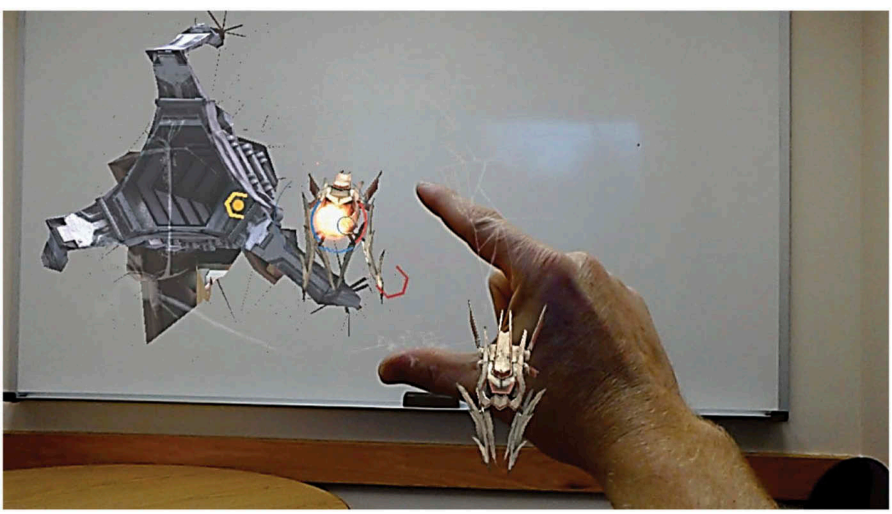

Figure 4. Samples scene from RoboRaid game

data from 263 participants. The participants were recruited across various majors at a large private university. Among the participants, 28.9 percent were female and 71.1 percent were male. The average age was 21.75 (SD = 1.7). We also asked participants about their familiarity with these technologies which is displayed in Table 4.

Study 1 Results

To explore how the overarching motivations differed among AR, VR and physical reality (PR), we analyzed participants' responses to the questions found in Table 3. Specifically, we ran Analysis of Variance (ANOVA) tests for each of the eight affordances and two modifiers comparing AR, VR, and PR, followed by post-hoc comparisons using Bonferroni corrections. All affordances/modifiers showed significant differences between modes. Appendix A provides ANOVA results for each of the affordances and contains a narrative related to post-hoc comparison findings. Descriptive statistics and post-hoc comparisons with Bonferroni corrections are summarized in Table 5.

These results show that the affordances significantly differ across the various mediums. In fact, in all cases, VR and AR were rated significantly different than the baseline PR condition. Further, for all but two affordances (Reduce Emotional/ Mental Risk, Facilitate Additional Information), VR and AR provide significantly different levels for each affordance. These results suggest that the framework may be generally useful in distinguishing between these two mediums.

The results show that virtual reality provides the highest ratings across most of these affordances. Virtual Reality is rated highest for five out of the six affordances where VR and AR are significantly different from each other including reducing physical risk, reducing resource costs, enabling physically incapable participants, depicting the non-existent and overcoming space time linearity. Augmented reality was rated significantly higher for facilitating additional information.

As expected, the baseline ratings for the modifiers for physical reality are significantly higher than VR and AR. In both cases, these modifiers are rated lowest for VR. In other

Table 4. Familiarity with VR and AR

Familiarity	AR (percent)	VR (percent)
Not familiar at all	47.53	22.05
Slightly familiar	29.28	27.76
Somewhat familiar	15.21	27.76
Moderately familiar	6.46	19.77
Extremely familiar	1.52	2.66

Notes: VR, virtual reality; AR, augmented reality.

Table 5. Study 1: Descriptive Statistics and Post-hoc Comparisons with Bonferroni Corrections for Each Motivation and Modifier

	Mean			Std Dev			Significantly different?		
Affordance/Modifier	AR	VR	PR	AR	VR	PR	AR-VR	AR-PR	VR-PR
Reduce Physical Risk	7.90	8.81^{H}	2.07^{L}	2.15	1.78	1.94	$p < .001$	$p < .001$	$p < .001$
Reduce Emotional/Mental Risk	6.79^{VA}	7.23^{VA}	2.94^{L}	2.04	2.00	2.30	$p = .062$	$p < .001$	$p < .001$
Facilitate Additional Info	7.65^{VA}	7.36^{VA}	4.15^{L}	1.70	2.03	2.92	$p = .420$	$p < .001$	$p < .001$
Filter Info	8.15^{H}	7.12	2.75^{L}	1.76	2.25	2.18	$p < .001$	$p < .001$	$p < .001$
Reduce Resource Costs	7.56	7.96^{H}	3.03^{L}	1.64	1.72	2.18	$p < .050$	$p < .001$	$p < .001$
Enable Physically Incapable Participant	7.65	8.93^{H}	2.07^{L}	1.89	1.38	2.55	$p < .001$	$p < .001$	$p < .001$
Depict the Nonexistent	7.72	8.43^{H}	2.44^{L}	1.72	1.83	2.96	$p < .001$	$p < .001$	$p < .001$
Overcome Space-time Linearity	7.69	8.82^{H}	1.33^{L}	1.82	1.47	1.98	$p < .001$	$p < .001$	$p < .001$
Importance of Sensory Vividness	4.16	3.07^{L}	9.46^{H}	2.78	2.65	1.28	$p < .001$	$p < .001$	$p < .001$
Importance of Physical Context	6.53	4.01^{L}	7.60^{H}	2.65	2.99	2.45	$p < .001$	$p < .001$	$p < .001$

Notes: ^{H} Highest mode for affordance/modifier; ^{L} Lowest mode for affordance/modifier; ^{VA} VR/AR are not statistically different from each other.

words, in situations where sensory vividness or physical context is important, AR is rated more highly than VR but does not reach the level of physical reality.

Study 2

Study 2 was designed to extend and complement the results of Study 1 by exposing participants to a wider spectrum of VR and AR uses and to broaden the sample of participants. In Study 1, participants received a description of VR and AR and then had a 5-minute hands-on experience with both technologies. Because of the time limitations, the hands-on experience in Study 1 only provided an illustrative overview of some of the most prominent features of VR and AR. The purpose of Study 2 was to expose participants to a broader feature set of VR and AR, and then have them answer the Study 1 questions listed in Table 3. Similar to Study 1, each question was asked for AR, VR, and PR. Again, the physical reality condition serves as a baseline against which the responses for the other conditions can be compared.

Upon agreeing to participant in the study, participants viewed a website defining both VR and AR and then participants were shown three promotional videos highlighting the broad range of features for AR and then three similar promotional videos for VR. Half of the participants were randomly selected to view the AR videos first, before watching the VR videos. The videos were product promotion videos adopted from 3 prominent AR companies and their associated products—Microsoft HoloLens, Magic Leap, and Meta—and three prominent VR companies/products—Samsung VR, Oculus, and HTC Vibe. The videos were chosen because they demonstrated a wide variety of applications of these technologies in a short amount of time and highlighted the potential of these technologies. Each video was approximate 2 minutes long. Participants watched all 6 videos to maximize exposure to the technology use cases. After watching the videos, participants completed the survey about AR, VR and PR.

Participants. Study 1 was conducted with a student population. To extend our findings to a more diverse population, we conducted Study 2 using participants from Amazon's Mechanical Turk. Participants were paid two USD for participating. We collected data from 204 participants. Among the participants, 30.39 percent were female and 69.61 percent were male. The average age was 32.7 (SD = 10.1). We also asked participants about their familiarity with these technologies. Table 6 provides their familiarity with VR and AR.

Results of Study 2

Similar to Study 1, we ran Analysis of Variance (ANOVA) tests for each of the eight affordances and two modifiers comparing AR, VR, and PR, followed by post-hoc comparisons using Bonferroni corrections. All affordances/modifiers showed significant differences between modes. Again, Appendix A provides ANOVA results for each of the affordances for this study and contains an explanation of

Table 6. Familiarity with VR and AR

Familiarity	AR (percent)	VR (percent)
Not familiar at all	15.69	20.10
Slightly familiar	29.41	34.80
Somewhat familiar	8.33	3.43
Moderately familiar	24.02	13.73
Extremely familiar	22.55	27.94

Notes: VR, virtual reality; AR, augmented reality.

the post-hoc comparison findings. Descriptive statistics and post-hoc comparisons with Bonferroni corrections are summarized in Table 7.

Study 1 and Study 2 differed in terms of the sample population (students versus participants on Amazon's Mechanical Turk) and in exposure to VR/AR (interacting with AR/VR in a single scenario versus watching product promotion videos of VR/AR in various scenarios). Hence, differences in mean rating are expected and present because people have different points of reference. However, despite these expected mean differences, the relative rankings of affordances for AR, VR, and PR are remarkably consistent with Study 1 with just a handful of exceptions. Like Study 1, these results show that the affordances significantly differ across the various mediums. Again, the ratings of the affordances for VR and AR are all significantly different than the baseline PR condition.

Ratings for four of the affordances are significantly different for VR compared to AR. All four of these affordances (i.e., reduce physical risk, enabling physically incapable participants, depicting the nonexistent, and overcome space-time linearity) are significantly higher for VR compared to AR. In Study 1, reducing resource costs was significantly higher for VR than AR and filtering information was significantly higher for AR than VR. In this study, these affordances are not significantly different for VR and AR.

As expected, the baseline rating for the importance of sensory vividness modifier is higher for PR than for VR and AR; however, in this study VR and AR ratings for this modifier are not significantly different from each other. Surprisingly, the importance of physical context modifier is greatest for AR and not significantly different between VR and PR.

Overall, the results which are largely consistent with Study 1 in terms of relative rankings, suggesting that the framework provides a mechanism to differentiate between AR, VR, and PR based on their affordances.

Table 7. Study 2: Descriptive Statistics and Post-hoc Comparisons with Bonferroni Corrections for Each Affordance and Modifier

	Mean			Std Dev			Significant difference		
Affordance/Modifier	AR	VR	PR	AR	VR	PR	AR-VR	AR-PR	VR-PR
Reduce Physical Risk	6.95	7.69^{H}	5.65^{L}	2.48	2.37	3.33	$p < .050$	$p < .001$	$p < .001$
Reduce Emotional/Mental Risk	6.16^{VA}	6.75^{VA}	5.39^{L}	2.72	2.63	3.20	$p = .110$	$p < .050$	$p < .001$
Facilitate Additional Info	7.71^{VA}	7.36^{VA}	6.11^{L}	2.02	2.22	2.83	$p = .410$	$p < .001$	$p < .001$
Filter Info	7.43^{VA}	7.00^{VA}	4.68^{L}	2.24	2.65	3.28	$p = .330$	$p < .001$	$p < .001$
Reduce Resource Costs	7.28^{VA}	7.16^{VA}	5.42^{L}	2.21	2.36	2.98	$p = 1.00$	$p < .001$	$p < .001$
Enable Physically Incapable Participant	7.10	8.25^{H}	4.31^{L}	2.30	2.03	3.54	$p < .001$	$p < .001$	$p < .001$
Depict the Nonexistent	6.99	8.07^{H}	4.46^{L}	2.18	1.99	3.49	$p < .001$	$p < .001$	$p < .001$
Overcome Space-time Linearity	6.88	8.05^{H}	4.24^{L}	2.44	1.96	3.60	$p < .001$	$p < .001$	$p < .001$
Importance of Sensory Vividness	5.52^{L}	5.66	7.46^{H}	2.94	3.07	2.73	$p = 1.00$	$p < .001$	$p < .001$
Importance of Physical Context	7.25^{H}	6.48^{VP}	6.52^{VP}	1.99	2.68	2.82	$p < .050$	$p < .050$	$p = 1.00$

Notes: ^{H} Highest medium for affordance/modifier; ^{L} Lowest medium for affordance/modifier; ^{VA} VR/AR aren't statistically different from each other; ^{VP} VR/PR aren't statistically different from each other.

Qualitative Exploratory and Confirmatory Evidence

While our theory-derived framework may be "good in theory," we wanted to know if there were missing affordances which could be derived from practice. Therefore, in addition to conducting quantitative experiential surveys to validate the theory-derived framework, we conducted a qualitative study to both confirm the existing framework and to explore possible missing affordances not currently found in the framework. Our goal with this qualitative study was to learn from professionals across a diversity of expertise and fields regarding the affordances of VR and AR in their workplace. Inasmuch as their ideas for using VR/AR indicated affordances matching the ones from the framework, they lend support to our theory. However, because we used an open-ended interview approach, this created the opportunity to explore potentially new affordances we had not previously considered. This qualitative data collection happened concurrently with the quantitative data collection. Thus, the results from either study could not be used to inform or redesign the other study.

Sample Description

The research team reached out to professionals within their respective social and professional networks to identify participants from varying backgrounds. This approach may be considered a form of convenience sampling. Any form of random sampling would have been impractical for such a study in which we sought breadth of field coverage from real professionals from various industries and organizations. Our efforts resulted in interviews with 18 professionals, with an average of 16 years of professional experience in their respective field. The average age of the participants was 43. Half of the participants work in frontline positions and the other half are in management positions. The full list of interviewed professionals includes one each of the following: Animator, Professor, Fireman, Pilot, chief operating officer (COO), Lawyer, Freelance Software Developer, Nurse Practitioner, Athletic Coach, Head Chef, Chemist, Paleontologist, Novelist, Cognitive Neuroscientist, Car Mechanic, Media Producer, Marketing Manager, and Surgeon. The goal of this sample was to obtain perspectives from "real" people (i.e., not students or mTurks) with real and substantial experience from a wide array of fields. A few fields are missing (such as religion, politics, and military); however, the breadth of the fields covered should be sufficient to identify patterns in affordances across diverse fields.

Protocol

For the full interview protocol, see Appendix B. The open-ended interviews began with casual banter to help the participant become comfortable and adjust to the interview setting. Prior to the interview, the researcher prepared the interview room for VR and AR experiences. To prepare for VR, a swiveling office chair was placed in the center of the room and the floor was cleared around it to allow for full 360 movement. To prepare for AR, the room was 3D mapped (with the built-in HoloLens environment 3D mesher), and holograms were placed throughout the room, including static objects (e.g., shark and elephant), interactive objects (e.g., animated puppy and astronaut), and functional windows (e.g., browser and app store).

After a brief explanation of the purpose of the study and some instruction regarding the use of the 2 devices (Samsung Gear VR and MS HoloLens), the participant engaged in a VR experience. First, they adjusted the focus, looked around a virtual room, and became accustomed to being in VR. Then they were instructed to navigate to the videos section, select the appropriate video (the same video used in the experiential survey), and then experience the two-minute VR 360 movie. This navigation allowed them to interact with virtual objects through a head-mounted controller.

After finishing the VR experience, the participant tried on the HoloLens for an AR experience. No discussion of features or ideas was permitted between the two interactive sessions. The researcher walked the participant through the physically-present room, pointing out holographic objects and encouraging the participant to interact with the interactive objects. The researcher then guided the participant through the placement of a new hologram and adjusting its size and position. The participant then engaged in a short AR game: RoboRaid (the same as used in the experiential survey).

After the AR experience, the participant sat for the recorded interview. The interview began by asking about the participant's area of expertise, years of experience, position, and a brief explanation of their responsibilities. The participant then described a couple different "typical" days at work. This part of the interview was primarily for the benefit of the participant to recall their tasks and duties so that when the researcher asked for ideas, they would have these tasks already in mind.

The next and most critical part of the interview started with the researcher reminding the participant regarding the differences in the feature sets of the 2 technologies. These feature sets were explained in non-biased, strictly fact-based language. Then the participant was requested to reflect out loud about the possible applications of VR specific to their occupation and field. Once ideas for VR had tapered (after prodding and questioning), the participant was then requested to reflect in the same way about AR. Anytime the participant came up with an idea for how to use these technologies, the researcher asked for more details on how it might be implemented and why they would need to use VR or AR to accomplish this idea, rather than using traditional technologies. This mode of inquiry elicited affordances behind the ideas. Importantly, the participants were not privy to the framework or set of motives we had theorized *a priori*. In this way, they would not be anchored or swayed in any way to provide ideas that intentionally confirmed our framework.

Analysis

For the sake of consistency, all interviews were conducted by the same researcher who is experienced in interview research methods. Interviews were audio-recorded, transcribed, and then coded by 4 separate researchers. During the open coding stage, we followed a combination of guided and unguided coding. The guided coding was used to find affordances that already matched the framework. The unguided coding was to find any other affordances not already included in the framework. As recommended by Strauss and Corbin [63], this stage was followed by an axial coding stage, during which we consolidated newly discovered affordances (during the unguided open coding) either into existing affordances (from the framework) or combined newly discovered affordances where sufficient overlap existed. For example, two of the newly discovered affordances were *training* and *teaching*. During the axial coding stage, we combined these into just *training*. This axial coding stage was followed by a final selective coding stage in which the four researchers sought consensus on the labeling of a final set of codes (affordance labels) that best captured the affordances in the data without too much overlap and without neglecting any affordances identified in prior stages. These final selective codes are shown in Appendix C.

To ensure the validity of our subsequent coding of the data, the four separate researchers each initially coded the same three interviews using this list of final selective codes. Where discrepancies manifested, the four researchers conferred to reconcile differences. A second round of 3 different interviews was then coded by the 4 researchers to assess interrater reliability. Again, differences were reconciled. To reach sufficient interrater reliability, a third round of 3 different interviews was required. On this third round, interrater reliability reached 0.96. With the 4 researchers at sufficiently high interrater reliability, all 18 interviews (including the nine already coded) were randomly assigned to 2 researchers each. Interrater reliability was again 0.96 on this final round.[1]

During the iterative coding process, the researchers flagged and extracted relevant quotes and then each coded all of their quotes for the specific affordances from the list of selective codes. Each quote was permitted to represent multiple affordances (although not all did). A total of 58 quotes were extracted and coded, with an average of 3.2 usable quotes per participant, and 2.75 affordances per quote, resulting in a total of 160 affordances identified (not unique). More details regarding these codes and a full listing of extracted quotes can be found in Appendix C.

Findings from the Qualitative Study

Overall, we found strong support for the existing set of affordances outlined in the framework. All affordances from that framework were identified independently by the professionals interviewed (i.e., the professionals had no knowledge of the framework). Some affordances were more frequently identified, while others were rarely mentioned.

As shown in Table 8, the most common affordance was to *facilitate additional information*, being indicated 37 separate times, followed by *depict the nonexistent* 21 times. The least common affordance (from the original framework) identified was *reduce emotional-mental risk*, being indicated only two times, followed by *reduce physical risk*, being indicated only five times. Twenty-nine quotes included affordances not contained within the framework, which represented 10 new unique affordances (indicated by ^{N} in Table 8). The most frequently identified new affordance was *training* (5 times), followed by *coordination* (4 times); while perhaps the most unexpected new affordance was to *amplify reality*. This unexpected affordance was emphasized by the fireman/paramedic who explained that augmented reality would enable far more realistic training exercises than are currently in place. Table 8 lists all original and new affordances, with their respective frequencies and illustrative quotes from the interviews. The relatively higher frequency of original motives compared to new motives provides some level of confirmation of the theoretical soundness of the framework. However, the number of new affordances also suggests the framework may not have identified all relevant sub-affordances. Additionally, the low representation of some affordances (such as "reduce emotional/mental risk") might indicate either a limitation in the sampling (i.e., broader sampling may increase their relative frequency), or the low salience of those particular affordances (i.e., broader sampling would not change relative frequency; it is just a less critical affordance motivating the use of augmented or virtual reality). Thus, whether it is a saliency issue or a sampling issue can be resolved through additional data collection.

Discussion

The affordance framework for virtually assisted activities implies a simple assertion: users adopt virtual and augmented reality because these realities enable affordances that are advantageous when compared to physical reality. By utilizing affordances that use physical reality as a baseline for comparison, rather than specific applications depending on a certain activity, we provide a lens for examining activities across a wide range of applications and determining whether VR and AR truly provide an advantage. While our framework attempts to generalize the affordances to be device agnostic, the advantages and differences of VR and AR we observed in the studies were made in reference to current devices; as the technology improves or shifts focus, VR and AR may evolve in how they enact their affordances or gain new affordances altogether.

Findings and Insights from Studies 1 and 2

The two quantitative studies each support the idea that users find differences between what physical reality affords and what virtual and augmented reality afford. Across all affordances, the rated applicability of each was significantly

Table 8. Original + New^{N} Affordances with Illustrative Quotes and Frequencies

#	Affordance	(Source) Illustrative Quote
37	Facilitate Additional Information	COO: “It would be interesting to be able to pick up your own bottle that you have now and be able to overlay different labels or a different artwork and say ‘yeah I get how that works’, I like that. That would be cool. … [It] could be interesting to be able to quickly say ‘what you think about this, what do you think about that’ might also decrease costs because right now every time you do that you having to make physical samples and mockups and pilot runs and things like that.”
21	Depict the Nonexistent	Paleontologist: “One of the things that we can’t really do now is recreate the people. We can show what they used and the things they made and worked with, but what if we could have a holographic historical character in an exhibit, you know, making an arrow-head, or skinning something, so you can bring the individual from the past, to the public.”
19	Overcome Space-time Linearity	Nurse: “You can imagine, like, for example, if a nurse is currently with a patient in one room but there’s trouble in another room down the hall. Maybe with this she hears a warning notification in her ear and a window shows up on her glasses and flashes or something. The warning could even be a live video feed of the other patient’s room with his vitals showing up too. What if she could tap the warning in her glasses and that maximized the warning image to become a fully immersive, like 360-degree live stream into the other patient’s room, and even she could have a microphone connection to the patient’s room. I mean, she could look around the room like she’s actually in there, she could see if the patient is in his bed. She could look around and maybe she finds the patient lying on the floor. She could try to communicate with him from a speaker in his room. And you know, she’s doing this all from some other patient’s room, or from anywhere, even while she’s walking down the hall toward his room.”
17	Filter Information	Car Mechanic: “If you could see where the bolt was in the engine bay and it gave you depth so that you could look through the engine bay and just see an augmented view of that bolt and it still gave you depth perception and you knew where it was, you wouldn’t have to feel you could just see the bolt.”

(continues)

Table 8. Continued

#	Affordance	(Source) Illustrative Quote
15	Enable Physically Incapable Participants	Athletic Coach: "Showing in real space what the gymnastics skills should look like. A professional gymnast could do the skill and front of them so that they could analyze body position and what the technique of that skill is. See a full routine in 3D and walk around it, stop it, slow it down."
15	Reduce Resource Cost	Fireman: "For training exercises, it's not like we can just, you know, go light a building on fire and ask real people to go lie down in it somewhere. Even when we can get a real building, it's still limited because it is totally staged and not real. But with augmented, we could use nearly any building and we could change it every time, whereas right now, I've been through some of these training buildings 100 times and I know where everything is and it's not like I'm going into a real building and have to be on my toes."
5	Reduce Physical Risk	Fireman: "We do use real people, but only for the benign conditions. We just can't do the more severe condition, like cardiac arrest, or if you need to intubate them, or shock them, you can't do that with a real human. But in VR you could do all that without the real human."
5	Training	Professor: " … that's a real challenge in chemistry, connecting up what the applications and properties of compounds are you know, to something you can actually see, you know because we babble in the classroom all the time … I try to relate it to things, and there are certain classes where it's naturally relatable. But, you know, those poor kids in general chemistry are just going through all these general topics and the struggle is to show them, you know, the applications of different scales. I think of different objects that way and something like that could be really needed."
4	Coordination[N]	Paleontologist: "When we first get to a site, we have to all walk in a line, and it is really important that we are almost perfectly in sync. So if we had some kind of line projected in front of us that we could all see, like in football, the 1st down line, that would help a lot. We also have to all follow our transect line, and we have to stay on that. So, if we could project that kind of information in our space, as well as maybe if there has been a site that's already been recorded, we could see those boundaries on the ground, or artifacts labeled."

3	Amplify Reality[N]	Fireman: "All the training we do, it's just like in 2D on a computer screen, or it's in a real building, but we have to pretend the hazards and constraints. So the augmented would be the coolest thing because you could make it look like there is fire and smoke everywhere, and a ceiling could be caving in, or the stairs on fire, and you could block out a door or put holes in walls, and a patient could be anywhere and really look like a patient with a pale face, or not breathing, you know, like it really would be."
3	Collaboration[N]	Neuroscientist: "It would be cool to have VR meetings or augmented reality meetings … maybe in the case where you have multiple people remoting in. That might make it a little bit easier to attend to everybody in the room-in virtual room rather than everybody on my laptop screen … that would be good just from like an attentional perspective where you can attend to different locations and you can spread your attention out and take advantage of your of your surroundings a little bit more not be constrained to just the size of a laptop screen."
3	Enhanced Computing[N]	Animator: "I would foresee it as extending my workplace. So I'm working on a desk with my two monitors and then to the left me to the right of me where I have some space I have my 3D model literally pasted into my environment."
3	Physical Interaction with Digital Objects[N]	Novelist: "I'm kind of old fashioned I mean I'm using a computer, and you know, but if I could like lay on the bed and sort of interface with my work that way that would be kind of cool … like a mind map interface where I can actually take components and move them around."
2	Communication[N]	Freelance Developer: "You can work with someone else remotely and they see what you see."
2	Reduce Emotional/Mental Risk	Fireman: "We need real fire scenarios, but most the time we just have to simulate it by describing it. But what missing is that we have to tell you what it's like and so there's no realism, no fear, no risk. So when you get into a real situation, your heart and your brain, they work differently than in these benign training games. But with the augmented one, we could make it so much more real, like they're really there, and even though it isn't real, it would at least feel more real so that when they get to, you know, the real thing, it's not like they haven't done this before."
2	Mobile Computing[N]	Lawyer: "I would do away with having my monitors so I could just have everything in front of me in windows. You're not tied to your physical environment it's great you can be sitting on an airplane and do all your work."

(continues)

Table 8. Continued

#	Affordance	(Source) Illustrative Quote
2	Video-logging[N]	Paleontologist: “If it’s just glasses you’re wearing, you could be recording everything you’re doing.”
1	Increase Empathy[N]	Lawyer: “[Using VR,] you could show to a jury what this person’s life is like after an injury. They would show the injuries suffered, what someone does to just get out of bed in the morning and how people take care of them during the day, which has an impact on juries and gives you empathy or sympathy. You can also show what kinds of damages the person suffered and what kind of insurance coverage children need to be able to live the rest of his life in a way that gives him dignity and the ability to maneuver through life.”
1	Understand Proximal Positioning[N]	Lawyer: “An attorney will tell jurors during some closing argument to look over to the right where you’ll see the car coming.”

Notes: COO, chief operating officer.

higher for VR and AR when compared to the baseline of physical reality. This confirms the basic general assertion of the framework.

Additionally, we suggest that the ability of VR and AR to enact the generalized affordances is affected by two modifiers: the importance of sensory vividness and the importance of physical context. Study 1 showed a significantly lower rating for VR and AR compared to PR for the importance of sensory vividness. The same is true for the importance of physical context. Additionally, AR has significantly higher ratings than VR for both modifiers, suggesting it is better at enacting the affordances in situations requiring sensory vividness and immediate physical context. This may partly explain why AR is currently growing at a faster rate than VR [25, 52]. However, while Study 2 similarly shows a difference between VR/AR and PR for sensory vividness, it does not show a significant difference between VR and AR for the importance of sensory vividness or a difference between VR and PR for the importance of physical context. This discrepancy may be due to participants in Study 2 not being provided hands-on experience with the technologies. Future research can continue to explore the points at which the desire to enact an affordance is diminished by the presence of either of the identified modifiers.

The framework itself provides an interesting way to examine whether VR or AR is perceived as being better able to afford certain actions by comparing the technologies across each category of affordances. These differences across affordances are summarized in Table 9.

Table 9. Summary of Study 1 and Study 2 Findings Comparing VR and AR

		Higher Rating	
Primary Affordance	Sub-affordance	Study 1	Study 2
Diminish negative aspects of physical world	Reduce physical risk	VR	VR
	Reduce emotional/mental risk	No difference	No difference
Enhance positive aspects of physical world	Facilitate additional information	No difference	No difference
	Filter Information	AR	No difference
Recreate existing aspects of physical world	Reduce resource cost	VR	No difference
	Enable physically incapable participants	VR	VR
Create aspects that don't exist in physical world	Depict the Nonexistent	VR	VR
	Overcome space-time linearity	VR	VR
Modifiers			
Importance of sensory vividness		AR	No difference
Importance of physical context		AR	AR

Notes: VR, virtual reality; AR, augmented reality.

In Study 1, participants ranked VR and AR significantly different for most affordances and significant differences also remained in Study 2 for three sub-affordances. This suggests that not only the choice to virtualize, but also the type of virtualization – AR vs. VR – may impact how effectively an affordance is fulfilled. For example, VR may be perceived as more effective for removing physical risk because it isolates users from the physical world. AR may prove better at filtering information because that may often require contextual information from users' surroundings. VR may be better at recreating existing aspects of PR because it affords control over the entirety of an environment rather than recreating only specific portions. For the same reasons, creating entirely new aspects is likely perceived as being more easily afforded by VR.

These perceived differences are important because they provide evidence that users do in fact perceive a difference in what the technologies afford. Those differences in perception may make it easier or more difficult to successfully introduce VR or AR to industry or the general public for specific applications.

Findings and Insights from Study 3

The qualitative analysis also provides important implications. It confirmed the framework's basic premise, as all professionals suggested myriad ways that VR and AR could enhance their current work through means not traditionally available. The framework was confirmed in that all the sub-affordances we identified *a priori* were expressed in various forms by the professionals as they generated ideas for how to use VR and AR. However, the additional sub-affordances identified suggest that our original list of example sub-affordances overlooked some interesting and important additional sub-affordances. By having a wide range of professionals ideate on applications that they personally would find useful, other nuanced affordances became clear to us that we didn't initially address. The new sub-affordances identified included: coordination, amplifying reality, training, collaboration, enhanced computing, physical interaction with digital objects, communication, mobile computing, video logging, increasing empathy, and understanding proximal positioning.

Yet, when abstracting the specificities of each of these new sub-affordances within the context that the affordances were identified, we were able to place them comfortably within the context of our framework under the grander over-arching affordances – thus demonstrating the high-level robustness of the framework. Specifically, all of the new sub-affordances fit within either the affordance *to enhance positive aspects of the physical world* or the affordance *to recreate aspects of the physical world*. Thus, while we readily concede that many specific affordances of virtualization exist, our framework is sufficiently robust and generalizable to accommodate several unpredicted affordances and potentially many more affordances still unidentified by this research. The new sub-affordances grouped under the general affordances for virtualizing are shown in Figure 5. We opted to

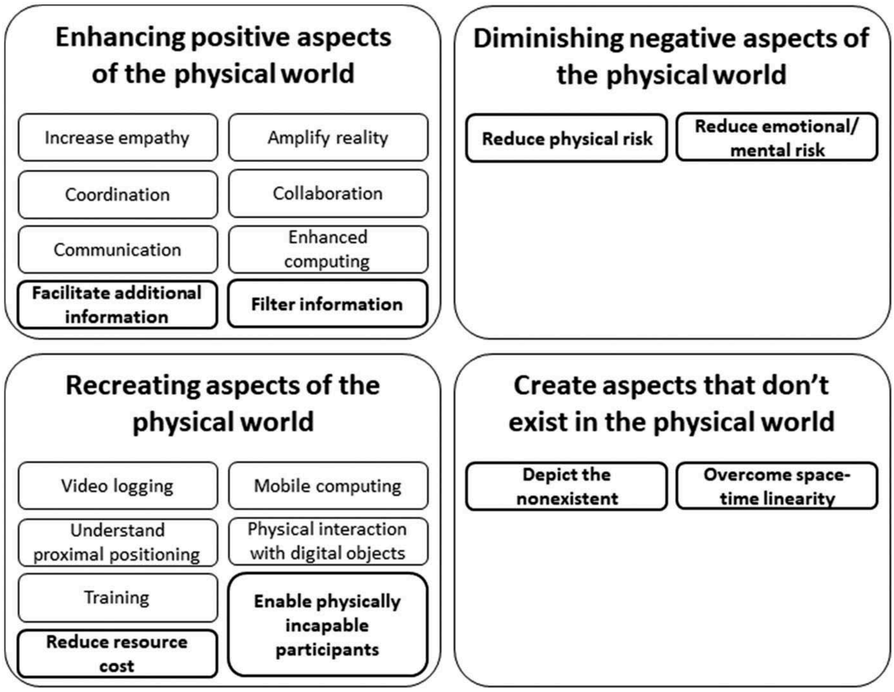

Figure 5. Positioning new affordances into the affordance framework

include even the sub-affordances with only one or two occurrences. This reflects our belief that we have not identified all potential affordances and that additional research may reveal additional affordances, or a higher frequency of the few outliers in our study. In Figure 5, the original 2 sub-affordances for each main affordance are shown in bold to distinguish them from the new sub-affordances.

If we were to visualize the frequency of sub-affordances identified within their respective parent affordances (i.e., frequency of interviewee mentions), a pattern emerges that helps identify the main affordances of virtualizing. Namely, VR and AR are most often associated with enhancing positive aspects of the physical world. Next, and roughly equal to each other in frequency, are the recreation aspects of the physical world and creating aspects that do not exist in the physical world. A distant last is the affordance to diminish negative aspects of the physical world (see Figure 6). Perhaps this last affordance would have been more prominent if we had interviewed professionals from the military and police (although we did interview others for whom reducing risk could have been considered important: fireman, surgeon, nurse, pilot, coach).

Our findings support the implication that professional users want to use VR and AR to enhance positive aspects of the workplace. A prevailing view of VR and AR is that it merely provides an overly expensive form of entertainment [25]. Until general consumers are substantively shown the value in VR and AR's ability to

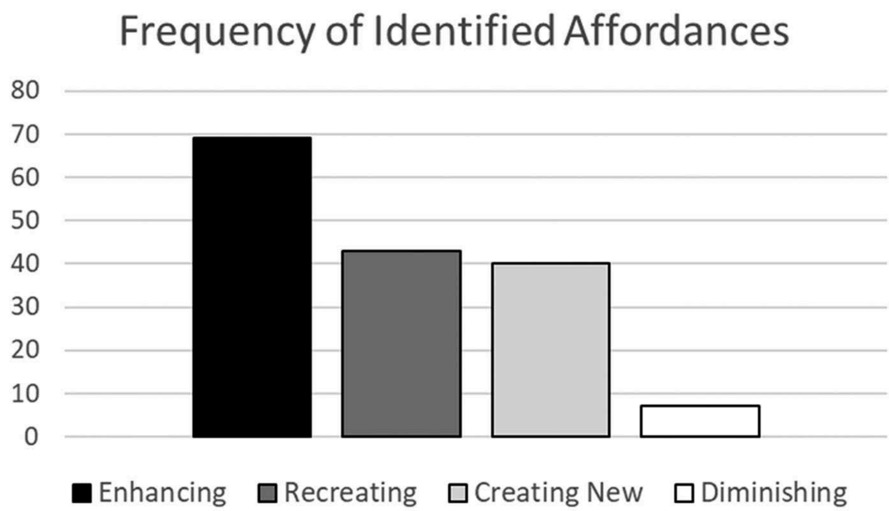

Figure 6. Primary affordances identified for using virtual reality/augmented reality (VR/AR) in practice

create wildly new opportunities, perhaps developers should focus on enhancing the tasks and processes currently performed and understood by a majority of the workforce.

Future Research

Additional research can explore the specific affordances delineated in the framework and the differences of VR and AR in enacting them. We mention some specific paths for doing this.

As adoption of VR and AR proliferates, industries may experiment with converting current activities and process into virtually assisted activities [2]. Significant differences may occur between VAAs that enhance current processes and VAAs that create entirely new methods of work creation. Researchers should uncover whether or in what situations VR and AR just afford efficiency gains through enhanced work or disrupt entire workflows and industries.

Additionally, as VR and AR create possibilities to recreate existing aspects of reality, an interesting question arises: at what point are users willing to sacrifice sensory vividness in exchange for reduced resource costs? Future research can explore the boundaries of potential determinants for the decision to virtualize in these situations, such as the format of information displayed, and the types of sensory experiences being sought. Determining when a VAA is “real enough” is also important for affordances of diminishing negative aspects of physical and mental harm [68, p. 533]. Researchers should seek to specifically explain which aspects of a virtual experience must be sufficiently real, which aspects do not, and why those differences exist. Industry would benefit by knowing which attributes deserve highest focus when developing software and hardware for specific needs. Such findings will need to be adapted to individuals' varied levels of competence in applying virtual tools [69].

Researchers should also examine how perceived differences between VR and AR change with time. We utilized user perceptions to show that people do believe VR and AR possess affordances that diverge from physical reality. But the perception of VR or AR more aptly affording certain activities may change as the general public and industry become more familiar with the technologies and their features. Likewise, technological advances will create new possibilities for VAAs, and additional sub-affordances will surely become apparent as methods of virtualizing activities continue to evolve. While we found evidence that our framework is reasonably robust, we expect further refinement to it as VR and AR technologies evolve and researchers continue to evaluate how and why individuals use these technologies.

As with all research, the studies conducted to validate the framework are not without limitation. While each of these studies has strengths (e.g., Study 1's hands on experience that allows finer differentiation between affordance, Study 2's breadth and vision of these technologies, Study 3's exposure to experienced workers across a number of industries), each could be further extended and complemented with additional research. For example, there could be advantages to having the tasks in Study 1 be equivalent or for the exposure time to each technology to be longer. While we validated the framework with a variety of users with different backgrounds and experience and in a variety of ways, researchers could further narrow in on specific industries, expertise, or exposure to provide additional validation and/or insights with regards to the framework. For instance, future research could replicate these studies with longer exposure times with each technology, by altering the tasks to be even more similar, to highlight a wider breadth of features, or to gather feedback from potential users in a wider variety of domains.

Conclusion

We wonder whether the historical floundering of virtual and augmented applications has partly been due to a failure to understand the natural affordances of these technologies. The affordance framework for virtually assisted activities helps provide clarity about how and why individuals might choose virtualization. The framework extends past research on both the technical features of VR and AR as well as using IT affordances to explain IT outcomes in order to examine the goal-directed actions that VR and AR enable. We suggest that further examination of specific affordances identified in the framework can create additional knowledge that can be used to inform and guide the successful adoption of VR and AR in practice.

Contributions to Research

The proposed framework and findings from the three studies contribute to research by providing a foundation for others to build upon. Until now, research regarding the affordances of VR and AR has been fragmented, focused largely in specific domains [54, 59]. Our work provides a theoretically driven and empirically validated consolidation of generalized affordances that apply across various fields. We map out this knowledge in a way that allows others to build and extend. Elements of the framework have been discussed independently in extant research, but a cohesive framework like the one we propose creates a more complete view of the knowledge landscape for others to extend and build upon.

Specifically, the framework helps researchers identify paths of additional inquiry. The framework creates delineations in the purposes of applying VR and AR, which can greatly aid in revealing areas where a minimal amount of research has been performed, as well as create groupings of research where results can be more systematically compared. For example, research that examines VR and AR applications that *recreate existing aspects of the physical world* will likely have significantly different results than research examining applications that *enhance positive aspects of the physical world*. Without accounting for these differences in affordances, research findings on VR and AR will be murky. The potential for these technologies to bring about life-improving changes requires an understanding of why outcomes differ across users and applications [16]. This framework can help identify why apparent contradictions exist in areas of application and reveal areas that researchers have not adequately explored. By conceptualizing VR and AR's applications by their affordances, we are extending past research of affordances in a way that "help[s] us hypothesize about, and investigate, their potential effects" [44, p. 611]. This research is not the final answer on VR and AR affordances, but offers a strong foundation for others to extend.

Implications for Practice

Our framework and results also provide insight for the application of these technologies in practice. In the qualitative study, every single participant interviewed provided specific examples of the practical application to their industry. None wrote off VR and AR as gimmicks or just gaming platforms; none suggested that there were no useful applications for their particular field. This suggests that industry is eager to adopt VR and AR if they can address motives that are currently unable to be met through current technologies and processes.

The framework can also help inform hardware and software developers to know how to position VR and AR to best address a goal or motive. Companies could potentially find success by finding niche areas that address a specific affordance or user group. The barrier to entry in VR and AR might be intimidating because there is a large landscape of hardware and software affordances. However, using the framework to identify a *single* area where VR or AR afford something beyond what the physical world provides (rather than developing a hardware or software solution to address the whole affordance landscape all at once) may prove more feasible for a larger portion of the commercial industry.

Additionally, we argue that VAAs should be cautiously judged by the value they provide when compared to activities in physical reality. VR and AR have shown great promise for solutions that no other tools can provide. However, if VR and AR find widespread use for activities that have little additional benefit when compared to physical reality (such as VAAs whose primary purpose is recreating what already exists to save on resource costs) there may be negative consequences. Other technologies, like smartphones and social media, can contribute to negative effects like depression and decreased communication skills when used without restraint [48]. Industry and developers should focus on those activities that are clearly enhanced by VR and AR, and those that increase safety. If most VR and AR activities simply offer a less vibrant alternative to physical reality with no clearly discernable advantage granted by virtualization, VR and AR will likely continue to flounder.

Summary of Implications

Our framework and studies suggest that users perceive that VR and AR afford activities that are impossible or advantageous when compared to activities afforded by physical reality. Researchers can examine VR and AR through the lens of comparison to physical reality to understand differences in adoption and use. Practitioners should consider how VR and AR experiences will be compared to physical reality, and focus on enacting those affordances that are most advantageous to VR or AR.

Note

1. We note that 2 new affordances were suggested during the second round of coding, and one new affordance was suggested during the third round of coding. We consolidated the 2 new affordances into one, and we kept the third new affordance. These 3 new affordances were accounted for in our final selective codes.

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