Quality Augmented Reality: Cognitive Task Design

J. Cabiria, Ph.D
Technology Psychologist, Teksylos, Philadelphia, PA, USA
Adjunct, Fielding Graduate University, Santa Barbara, CA, USA

Abstract – *The sensory stimulations experienced by modern people have become increasingly more powerful and persistent with the advent of newer technologies. Visual, aural, and tactile sensations that used to be relegated to destination sources (e.g. computers), to be called upon by demand, are now appearing in what was once open space. The human brain, the ultimate source of our cognitions of the environment, is called upon to understand the merger of real and virtual. The brain, however, is a physical entity whose capabilities are vast, but finite. Cognitive science informs us that people are subject to cognitive load issues that can affect their responses to sensory stimulation. Augmented reality designers, company owners, and project funders should be alert to cognitive demands as they design or fund their AR products. It can make the difference between a successful adoption by the end-user of the AR product, or product rejection.*

Keywords: Augmented reality, cognitive load, cognitive task design, media psychology

1 Introduction

Augmented Reality (AR) is poised to change our perceptions of the world in both subtle and very dramatic ways. The merger of actual reality with virtual reality has been steadily progressing for several decades, branching out into more diverse aspects of human experiences. Because the human experience of the world is usually visually perceived [1], the inclusion of virtual objects into the actual environment requires increased awareness by AR developers of how the human brain operates in order to make meaning of these merged realities. Fortunately, there is foundational work from within the social sciences that can aid technical designers, managers, and funders in the planning, development, implementation, and assessment of their AR initiatives. Of special interest will be three related topics that, essentially, serve to aid in the deconstruction of how humans make sense of all that they perceive, and how they respond to those perceptions: Cognitive science, cognitive load, and cognitive task design.

Cognitive science, cognitive load, and cognitive task design each play an important role in the AR lifecycle. They describe the capabilities and limitations of the mind when exposed to various stimuli and, from them, we can learn how to structure those stimuli in a way that maximizes the mind's potential to respond in a way that is intended [2, 3]. They offer powerful insights into how we behave, and provide endless opportunity for developers to design AR projects that are more likely to resonate with the end-user in a meaningful way. In this article, the role of cognition in AR design will be overviewed and will include design tips based on sound cognitive principles and theories. The overall purpose is aid all AR stakeholders in their decision-making so that the end product is more likely to be adopted by the end-user.

2 About cognitive science

Cognitive science studies the human mind and machine processes to describe how they operate, especially with regard to how information is perceived, processed and transformed [4]. It is a field of study that encompasses many social science and technological science disciplines, including psychology, neuroscience, sociology, artificial intelligence, and now … augmented reality. Foundationally, the cognitive sciences seek to describe precise functions whose stimulus-response patterns can be reliably observed [5]. Its essence is based on the idea that thought occurs through mental representations, much like computer data structures, and that the processing of thought occurs in a manner that is analogous to algorithmic computation [6][26]. In the AR design process, cognitive science principles are invoked along every step of the way, as questions are asked about the meaning and experiences that go into or arise out of the design concepts.

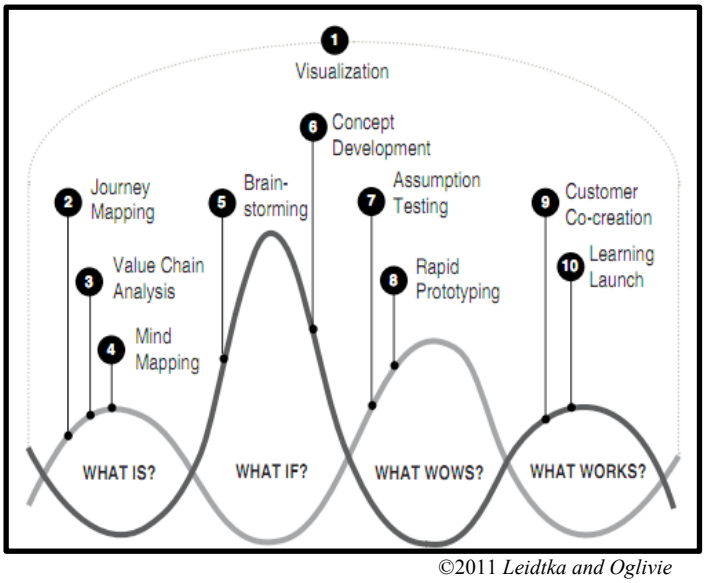

Figure 1 Cognitive Science in the AR Product Lifecycle [26]

In augmented reality initiatives, certain sensory stimulations are provided that draw upon existing experiences

in the mind of the end user. It is expected that the end-user will respond, with some level of acceptance, to the merged layers of real and artifice in such a way that they will function normally. That is, the mind will utilize its processing power to analyze the AR stimuli, relate it to experiences already stored in the mind, create sense and meaning of the stimuli, and engage with it in a manner that provides an expected outcome. For example, in an AR gaming program, in which live human players interact with AR human images, within an environment that is in real space with digital objects, the design of this game must be such that the brain does not reject the artifice at any point [7, 8]. Instead, it remains engaged and immersed at a level in which awareness of real and artifice disappears. If the design is flawed in some way, the mind will reject the environment and the premise: the goals of the AR game producers will not have been met. Certainly, this example is fundamental to any activity where people are asked to suspend disbelief; yet, the principles involved are complex and require deep understanding.

This brief overview of cognitive science serves as the basis for the more important aspects of this article: Cognitive Load and Cognitive Task Design. Cognitive load looks at how the mind chooses which information to process, and which information to ignore [9]. Cognitive Task Design looks at how AR products are designed to maximize human interaction [10].

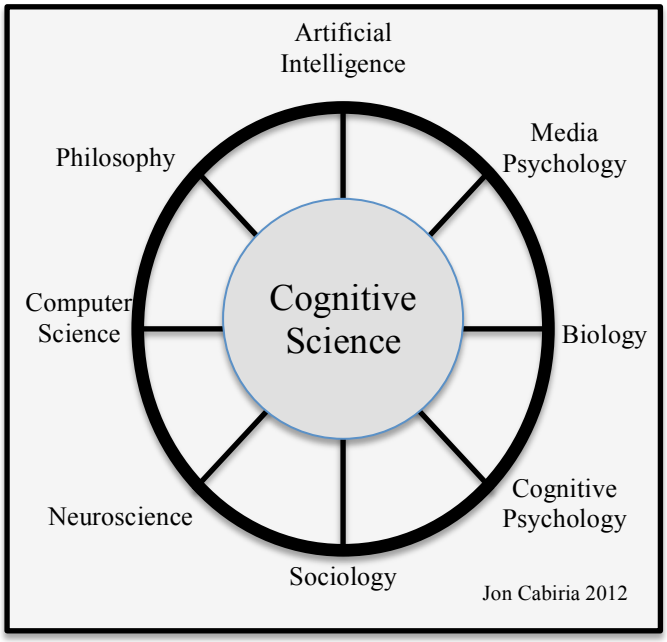

Figure 2 Cognitive Science informs and is informed by representative disciplines

3 Cognitive load theory

Cognitive load theory proposes that human beings are limited in their capacity to attend to and, therefore, store and recall sensory information [1]. As in a computer system, there are multiple procedures that are involved in information transmission and processing, and the capabilities of the body and brain to do this are limited [9]. There are considerations of available resources, as well as bottlenecks that occur when processing demands exceed capabilities. Therefore, cognitive load is an extremely important concept when designing AR applications due to the mental resource requirements of the end-user. In many other digital products, the cognitive load is generally relegated to the 'world' of the product itself (e.g. the digital gaming environment, the web page, the video stream, the social network forum or display). There is a new level of cognitive demand once the scenario includes blended environments, which requires the end-user to constantly cross-check multiple environmental sensory stimuli against real and digital relationships [11]. In essence, the brain is constantly translating what it perceives in a merged environment, based on stored similar memories, and at a higher level than it usually does individually, in either its own native (i.e. real world) environment or in a digital one [11].

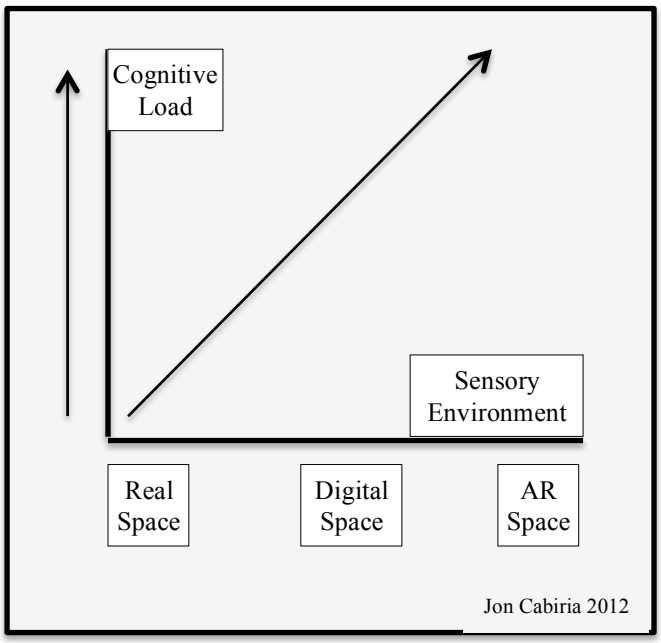

Figure 3 Cognitive load increases when sensory input includes digital aspects

An example of cognitive load process in merged environments is when an AR visual display incorporates both 3D and 2D objects. The natural context of human visual activity is 3D [12]. Cognitive load increases when the brain is presented with a 2D object because it must mentally reconstruct the object into a 3D representation in order to make better sense of it (12). When we add 2D objects into 3D spaces, the brain becomes further taxed trying to reconcile not only the 'intrusion' of virtuality, but also the conversion factors required [12]. This relates directly to the power of presence in AR functioning.

Sense of presence is a critical concept in measuring the effectiveness of an AR environment, part of which is

accomplished by reducing cognitive load. Presence is a mental state in which the end-user has either little or no awareness of the mediated environment [13]. Reaching a state of presence in an AR environment means the end-user's brain has accepted the environment as real, and it responds in a manner that would be expected if the environment were real. In recent studies, it was found that participants with higher levels of sense of presence experienced lower cognitive loads when interacting in an AR environment [14]. This is an important consideration when designing AR products, regardless of their purpose. High cognitive loads cause discomfort. At some levels, they even cause anxiety and distress [3].

For successful adoption of an AR product, designers would be advised to understand the cognitive load levels placed upon the end-user, especially during the end-user's initial introduction to the product. While some anxiety and tension can be pleasurable, the cognitive load, the load effects, and the AR product type should to be carefully aligned to avoid unpleasurable tension.

Cognitive loads have three distinct types: Intrinsic load, extraneous load, and germane load [9]. The first, *intrinsic cognitive load*, is a fixed stimulus response that addresses the end-user's actual exposure to the AR product, her or his existing understanding of how to use or respond to the AR product, and the effects it creates. The end-user's past life experiences and knowledge directly influence the ability to comprehend, or make meaning of, what is required to successfully interact with what is being presented [9]. The next type, *extraneous cognitive load*, is concerned with peripheral sensory stimuli that can interfere with the brain's ability to focus directly on what is needed for a successful AR experience [9]. An example would be a design that does not attract quick attention to create, more or less, an immediate sense of presence. The brain is still trying to process real world information, digital information, and disruptive information from the real world. Finally, the last type is the *germane cognitive load*. This is the most important type because it is focused solely on addressing the appropriate load level to enhance successful engagement with the AR environment [9]. Although the first type, intrinsic cognitive load, cannot be easily addressed by the AR designer because it deals with the embedded experiences and knowledge that the end-user brings to the initial AR experience, the other two load types can be manipulated by the AR designer.

Table 1 Cognitive Load Types

Type	Description	Example	Designer Power
Intrinsic Cognitive Load	Life-experiences and knowledge that the end-user brings to the AR product exposure.	End-user's existing understanding of menus, touch technology, GPS functioning, gaming controls, etc. can enhance initial experience. Lack of understanding can increase learning curve and create adoption resistance.	Low power to change what the end-user knows prior to engagement with the AR product.
Extraneous Cognitive Load	Information, generally in the form of distractions, that prevents direct focus on the AR experience; Stimuli that prevent the required level of sense of presence in the AR environment.	Guides (e.g. user manuals) on how to operate or use an AR program that are accessed within the AR environment; environmental visuals and sounds not pertinent to the AR experience; Glitches in the AR environment that create breaks in attention.	High power to design learning materials, user controls, visual layout, noise-cancelling devices, and quick-response processes that address product issues. All serve to help reduce cognitive load.
Germane Cognitive Load	Information and processes that attract end-user attention and direct it toward the AR environment; Stimuli that engage, and that create sense of presence.	Seamless AR stimuli that draw the end-user into the environment and then provide ongoing stimuli to maintain attention / engagement / immersion; intuitive, ease-of use processes; levels of engagement that match end-user's skills and ability to learn.	High power to engage end-users through skillful application of cognitive design principles. Companies have the power to hire/train those who know about cognitive design to aid in the planning, designing, implementing, and evolution of the AR product.

Jon Cabiria 2012

The key strategic consideration in thinking about designing the AR product for end-user application is the exploration how much cognitive load can be applied so that the end-user feels comfortable with the experience, yet challenged in a way that releases pleasure-inducing neurotransmitters in the brain. It is the nature of mammals, including human beings, to learn new things and to master new skills [15]. It is also the nature of mammals, including human beings, to have a certain level of environmental comfort when learning and using new skills [16]. The more pleasure that accompanies the use of a product, especially in the initial exposures before habituation occurs, the more likely the end-user will continue with the product through the learning curve and into adoption and integration into her or his life [17].

Here is an interesting example of cognitive load based on the Google promotion for their Projectglass AR glasses :

http://www.youtube.com/watch?v=_mRF0rBXIeg&feature=youtu.be

The video piece is a spoof of the Google promotion that incorporates advertising images into the visual field. It does a great job indicating what can go wrong with design from a cognitive perspective.

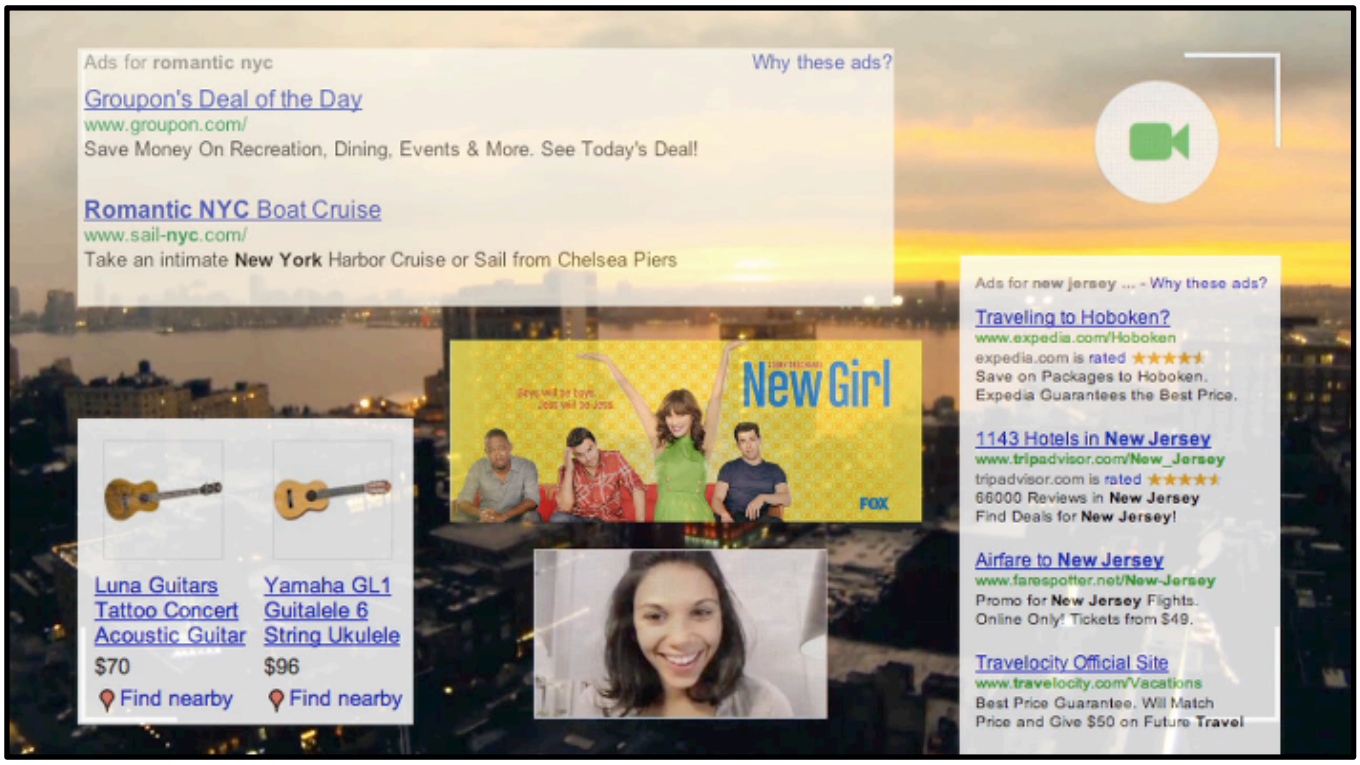

Figure 4 Crowded visual display creating high cognitive load Rebbeliouspixels.com

4 Cognitive Task Design

It is a matter of consequences. Basically, the question being asked is, "What are the goals that the AR design teams want to achieve as a result of the creation of the AR product, from a human sensory experience?" It all comes down to influencing human emotions in some way to create some level of positive connection with the product. Without a sufficient cognitive response by the end-user, the AR product will have a short market lifespan[18, 19]. Lacking the ability to experience ongoing cognitive stimuli at desired levels, the end-user gradually loses interest in the product and is more apt to seek engagement elsewhere. Therefore, the consequences of product use, cognitively speaking, need to be clearly understood in the beginning of the product lifecycle and need to be designed into every procedure of the design process.

It is recommended that the current mindset of 'task design' be elevated to include one that is more relevant - *cognitive task design*. It is important to note that cognitive task design is concerned not only with the sensory stimuli that are an output of the product (what the end-user experiences), but also the function and structure of the components in the context of world in which it exists. Any change in product technologies that end-users have become accustomed to can have important cognitive considerations on how the end-user thinks and behaves, right down to the essential brain wiring [20]. Intentional and unintentional changes to the world of the end-user via the technologies they use inevitably change their cognitive processes [21].

4.1 Through the eyes of the AR designer

The AR designer is a skilled professional who has a very definite and focused knowledge of her or his craft. This knowledge is typically years in the making and exists at a level beyond that of the consumer that will be using the AR products. It is not uncommon for the AR designer to lose track of the ability to see the basics.[10]. In fact, what the designer perceives as the basics may still be beyond the abilities of the end users. For example, in the above image (Figure 4) and its accompanying video of the spoofed Google Project Glass promotion (see the insert), the AR designer might very easily be able to cognitively parse out the real environment from the rapidly changing digital environment. The designer, having created how the product works, will have already adjusted to the cognitive load by virtue of selective attention [22] and familiarity.

Selective attention: tendency to give attention only to those things that address a need or interest.

The AR designer, in reviewing the product during the formative stages, will block out information in the sensory field that does not require her or his focus, in favor of items that do. As a result, the designer, over time, can lose the ability to experience the impact of the product in the way that a first time user would, or even a repeat user [22]. The designer 'experiences' discrete packets of information, while the end-user is inundated with all of it. The designer, operating on 'gut instinct', assumes that the cognitive load is light because she or he does not feel overwhelmed. For the designer, the load is light because she or he does not perceive everything in the same way as the end-user. The designer might see the AR landscape as distinct elements or as relationships among elements rather than holistically.

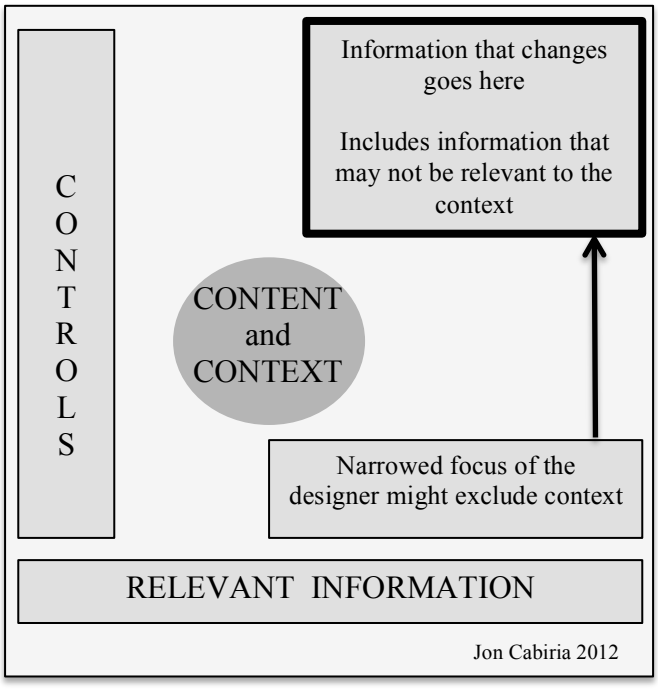

Figure 5 Design may not capture cognitive load issues

Ultimately, it becomes incumbent upon the AR designer, the project lead, and/or the technology psychologist to perform incremental assessments of cognitive load as part of the cognitive task design process. How information is presented, and when, is as much an art and science as any other part of the design process.

4.2 Through the eyes of the end-user

Typically, the end-user has no real experience with the design process and is usually unable to parse out design elements on which to focus or ignore. For the end-user, all of the information is relevant and, therefore, the cognitive load can be higher than that of the designer [11]. Each design element requires that the brain identify what the element is, the element's purpose, and its relationship to the other design elements. Additionally, it has to deal with areas of uncertainty or lack of procedural information that requires initiation of a learning process [9]. Finally, aside from the functional design elements, it must deal with the cognitive displays of color, images, and objects in ways that affect memory and emotion. In milliseconds, it searches its memory archives of information to make meaning of the display and accompanying sounds, along with the context in which it all appears. If the display environment includes a change or sequences of change, the cognitive load continues to remain high [11].

Augmentedplanet.com, 2010

Figure 6 AR Crowded Visual Field

Note in the above image how the brain needs to attend to a multitude of new, constantly changing information in both the real and digital environment. The brain has an extensive, yet still finite, ability to process information [3, 9]. The AR designer might see skillful layout and well-timed changes in content; yet, be only marginally aware of the real world background upon which the digital content is layered [selective attention]. A cognitive task design would be considered flawed if it did not take into account the more holistic experience of the end-user, and the needs of the brain to process sensory information effectively and efficiently.

For the AR designer to help decrease end-user cognitive load, the end-user must have more control over the display and the elements of the design need to be considered in unison with the expected real environment in which they will exist.

5 Implications

In the end, the goal is to create a useful product and to make a profit. Given the large amounts of time, money, and energy that go into the creation of AR products, it is important that the steps between the generation of an idea, all the way through to the end-user experience, be carefully attended to from multiple perspectives. One of those important perspectives is the focus on the desired cognitive sensations that arise from the end-user's engagement with the product, and how to incorporate that perspective into the design. Knowing how to identify, measure, and incorporate cognitive loads as part of a cognitive task design process is of considerable interest, or should be, to not only AR designers, but to company owners, venture capitalists, and other funders and stakeholders.

5.1 AR designers and cognitive design implications

It should be clear by now that the AR designer straddles the world between art and science. She or he not only needs to know the technical functioning of the AR product, but also have the knowledge or skill to incorporate how various cognitive effects, such as color, landscape change, velocity and frequency of change, object shapes, and sound (to name a few) influence end-user behavior. Beyond this, the designer also needs to understand the full context in which the product will be used, including the demographics of the end-user, the likely location of use, cultural considerations, and a host of other more complex intermingling of variables. Just as AR coding contains complexities and nuances of great precision, so, too, does the 'coding' of cognitive effects. The skill of the designer to blend technical art and science with the art and science of cognitive display, and resulting behavioral effects, is highly desirable because it increases the likelihood of successful adoption of the AR product [23].

5.2 AR company owners and cognitive design implications

Obviously, the owner of the AR company has a vested interest in the successful launch and adoption of the AR product. In a highly competitive environment, which will only grow more competitive as the industry matures, the creative and financial reputation of the owner is on the line. Criticism of flawed products is easily and quickly delivered to all sectors – technology, finance, media, and customers. It is imperative that the company owner be knowledgeable about more than the technical and financial aspects of the company and its products, but also to have base knowledge of the psychological implications of her or his products. Additionally, she or he would want to be networked with skilled cognitive experts for guidance in creating products most likely to be adopted by the intended customer and, more importantly, used and promoted by a growing, loyal customer base. Marketing experts can make the sale, but other professionals are needed to make sure that the product the customer purchases will address psychological expectations.

5.3 AR funders and cognitive design

Venture capitalists and other potential funders are understandably nervous when considering the funding of a company or project. They seek certain assurances. One of those assurances is quite simple – How do they know that the identified potential end-user will actually want the product? In essence, how does the owner and the designer know, beyond their own excitement and that of their friends, family, and co-workers, that the product will have any meaning for the targeted customer base? Some venture capitalists or angels will fund on 'intuition' and a great presentation, while others will go to extraordinary lengths to discover likely customer interest. Surveys, focus groups, trend analysis, and various kinds of statistical and qualitative research certainly offer insights. However, time and again, gaps between expectations and realities occur [25]. It could be that the right questions, the right prototypes, and/or the right contexts were not part of the discovery process: The 'mind' of the end-user was not fully explored beyond initial exposure to the product in a test environment. Even beta testing in the field doesn't always predict eventual adoption at the desired level to produce a profit. Funders would be wise to bring in technology psychologists or other experts in cognition to more fully explore important aspects of human perceptions and stimuli response as part of the design process. This would better accomplish the goal of answering the question, "How do I know this AR product will create the claimed effect?"

6 Conclusion

The days of simple, low-cognitive load experiences are fading quickly. Consumers are inundated with sensory stimuli from innumerable sources. Questions now to be asked are, "What determines which AR experiences are preferred over others, and which of these AR experiences have 'staying power'?" Human beings, while having strong intellectual abilities, are primarily creatures of emotions triggered by cognitive processes – they respond to everything on some emotional or reflexive level, and it is these very primary responses that compel them to seek out certain kinds of sensory stimulation over others [24]. Because of this, they are also subject to sensory, or cognitive, overload or deficit [23]. This is an unpleasant experience, which causes the person to reject certain stimuli in order to achieve more acceptable levels of cognitive input [7, 8]. AR designers, the company owners that employ them, and the funders that finance their projects, want to position themselves to create the best possible product that addresses the needs and desires of the intended end-user in a way that enhances reputations and profits. Toward this end, stronger attention to the art and science of cognitive task design is highly recommended.

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