Definition and Development of a Measurement Instrument for Compellingness in Human Computer Interaction

by

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ABSTRACT

Overly compelling displays may cause users to under or overestimate the validity of data that is presented, leading to faulty decision making, distractions and missed information. However, no measure currently exists to determine the level of compellingness of an interface. The goal of this research was to develop an empirically determined measurement instrument of the compellingness of an interface. Literature review and a semantics survey were used to develop a pool of items that relate or contribute to compellingness, and two expert reviews of the list resulted in 28 potential questions. These 28 questions were fielded in study with a map-based task. Exploratory Factor Analysis and Cronbach's Alpha were used on the results to eliminate questions, identify factor groupings, and quantify the amount each question loaded on the factor groupings. That analysis resulted in a final compellingness survey with 22 questions across six sub-factors and a final Cronbach's Alpha value of 0.92. Additionally, the survey is organized into three factors of compellingness: human, computer, and interaction, resulting in a two-level survey. An empirically-based measure of compellingness can be used in evaluations of human factors issues in domains such as aviation, weather, and game design. Understanding the underlying aspects of compellingness in an interface will enable researchers to understand the interaction between compellingness and other human factors issues such as trust, attention allocation, information quality, performance, error, and workload.

CHAPTER I

INTRODUCTION

1.1 Introduction of Compellingness

Compellingness describes how likely something is to capture attention, attract interest, and convince someone of different opinions, beliefs and actions (Collins English Dictionary, 2017). In the realm of Human-Computer Interaction, compellingness affects where attention is focused and may contribute to potential human factors risks (Conejo and Wickens, 1997). The aim of this thesis is to develop an empirically-based survey instrument to measure compellingness, and identify the components that define compellingness. An ability to measure and understand the elements of an interface that contribute to its compellingness will enable researchers to evaluate how compellingness interacts with other human performance issues in human-computer interaction.

Compellingness is a concept that appears in many different contexts. In general, compellingness is a description of the influence that something or someone can have over a user’s opinions, beliefs and actions (Collins English Dictionary, 2017). If a person were to be described as being compelled, often they are convinced of something and are inspired to act (Dictionary.com, 2017). If a speech is compelling, it is believable and convincing (Harrison and Gough, 1996). If an idea or concept is compelling, it is interesting, gaining traction, and more people are discussing it (Rodriguez, 2002). If a device or video game is compelling, it captures your attention (Brockmyer, Fox, Curtiss, McBroom, Burkhart & Pidruzny, 2009). If a story is compelling, it draws the reader in and makes the reader feel immersed in the story (Harrison & Gough, 1996).

Common use of the term compelling consists of compelling arguments or stories, or something that convinced you or moved you to believe a fact or story (Wright, Lackner & Dizio, 2006). Compellingness is a descriptor that means being believable and convincing (Collins English Dictionary, 2017). In the digital world, it is more than just having the user believe the interaction with the application feels real, but also includes important factors that enhance the users' interaction with the interface. These factors not only make the user convinced that they are immersed in the environment but also convince the user that the interaction is valuable and directs their attention to proper (or improper) features in order to enhance their experience or performance.

The majority of this research focuses on the development of compellingness in regards to digital displays and applications. From the research that will be presented in Chapter 2, a proposed definition of compellingness in regards to digital displays or applications is as follows:

The amount to which a display or application directs and controls your attention, drives you toward a course of action, aligns with your prior beliefs, values and knowledge, convinces you of facts and immerses you in an experience.

This research also hypothesizes that there are three main factors that make up compellingness and seeks to confirm them via development of a measurement tool. These three factors are categorized as the human, the system, and the interaction. The three factors were derived from literature related to compellingness. For the human category, research on compellingness was linked to the beliefs, knowledge, preferences and ideas that the user brings to an interaction. These are inherent and intrinsic features of humans that influence how they approach an interaction and how they are affected by it. The human factor includes attributes that are important to the user (Moore, Foster, Lemon & White, 2004), information about the user (Lamont, 2003), and the ethics, rationale, reasoning, empathy and beliefs of the user (Maturana, 1988).

The system factor includes invariant features of the display or application. That includes things like design strategies (Dickey, 2006), synchronicity (Warran et al, 1981), display quality including age, resolution and size (McMahan, Bowman, Zielinski & Brady, 2012), display realism and graphics quality (Banos, Botella, Alcaniz, Liano, Guerrero & Rey, 2004), and the consistency of the interface (Tonelli, 2012). It was chosen as a factor because this group of items consisted of objective features associated with the system and its design, and are unlikely to change based on the type of user.

The third factor, the interaction, includes all of the features that are affected based on an interplay of the user and the interface. This includes all of the features that depend on the interaction between the user and. It includes attributes such as the ease of use (Ahuja and Webster, 2001), intensity of flow (Davis and Widenbeck, 2001), engagement (Brockmyer et al, 2009), and complexity (Tractinsky, Katz & Ikar, 2000).

1.2 Effects of Compellingness

While a compelling argument can be beneficial to someone giving a speech or trying to win a debate, a high level of compellingness can have negative consequences as well. It has been shown that well-written or “compelling” statements that include known falsified information can still convince people that the false statement is in fact true (Teigen, 1986). This demonstrates how high levels of compellingness can be distracting and cause people to ignore their prior knowledge.

In human computer interaction, a display is defined as compelling if it is “more likely to cause attention to be drawn to it and possibly captured by it” (Ververs & Wickens, 1998, p. 78). This capturing of attention has been shown to decrease the ability to notice other events (Yeh & Wickens, 2000; Gempler & Wickens, 1998).

Compellingness of displays has been identified as an issue almost from the start of the aviation industry. Hersey (1925) described how “personal prejudices” influence how compelling they find an instrument, despite how “fool proof” it is:

> If the instrument for any reason fails to appeal to the individual pilot, he will take great chances rather than trouble to look at it. On the other hand, if the instrument pleases his fancy, he may grow so attached to it that he will claim he could not fly safely without it, even though the instrument be scientifically known to be incorrect (p. 9).

This is similar to the idea of complacency. If a user believes that a system will always give them correct information, that user may not double check that the information provided was correct (Parasuraman, Molloy and Singh, 1993). Compellingness can also draw a user’s attention elsewhere, distracting a user from their main objective. In one example, pilots were given predictor information that was so compelling that they ignored the aircraft’s current condition and focused on the future events (Gempler & Wickens, 1998).

Positive and negative examples can be found for different levels of compellingness, but there are tradeoffs. Compellingness has been used beneficially by cueing and targeting user’s attention towards the task at hand, but also has been proven to decrease the likelihood and speed of noticing unexpected events (Davison & Wickens, 1999). Tradeoffs such as these impact design decisions. The ability to identify whether an interface is compelling is subjective and has been assumed based on the proportion of the user’s attention drawn to a display (Ververs &Wickens, 1998). However, the ability to control how compelling an interface design is has not been researched in detail and would prove beneficial. In order to control compellingness of an interface, a measurement tool must first be created to assess the level of compellingness of an interface.

1.3 Importance of Compellingness in Human Computer Interaction

Human computer interaction (HCI) can benefit from compellingness research. It is the premise of this work, to be tested in the evaluations described, that the construct of compellingness has contributions from the three factors of HCI: the human, the computer (system), and the interaction between the human and the system. The human factor is crucial because what is highly compelling to one user might not be to another. The beliefs and opinions of people influence how easily persuaded or convinced they are of new ideas. The system factor relates to the influence the design and hardware features have on the compellingness of an interface. The final factor, the interaction, influences the opinions derived from the human’s use of the system.

Because of the influence compellingness has been shown to have in aviation (Thomas & Wickens, 2004), compellingness levels could also have an impact on many resultant variables such as the trust a user has in the system automation, the performance capabilities of pilots, the level of enjoyment users have in interactions with displays and applications, stress levels, knowledge retention, speed of learning, beliefs, and amount of errors. This leads to the idea of being able to control and design the level of compellingness.

An agreed-upon measurement scale of compellingness would enable a new avenue of research into the interplay of compellingness and these human factor issues.

1.4 Previous Compellingness Research

There has been extensive work in the field of attention and cognitive tunneling in aviation and how a compelling feature can direct attention and decrease a pilot's ability to notice other events (Yeh & Wickens, 2000). A display is compelling if it is "more likely to cause attention to be drawn to it and possibly captured by it (p. 78, Ververs & Wickens, 1998)". Additionally, undesired allocation of attention, which can be caused by compellingness, has been shown to be countered using display techniques that involve reorienting attention to more relevant parts of a task (Rizzolatti, Riggi, Dascola, & Umiltá, 1987). There has also been research in the field of audio-visual synchronization where compellingness is referred to the relationship between sensory modalities such as how in sync audio cues are with visual cues (Warren et al., 1981). If there is a perfect sync between the audio and the visual, even if they are coming from two different locations, a user will be compelled to believe that they are related and connected. However, when they are out of sync, a user will notice the difference and the relationship would not be considered compelling since the user could tell the difference.

There are three research question related to compellingness that may benefit from further research: 1) can compellingness be measured? 2) If so, is a measure of compellingness on a single or multi-dimensional, sliding scale? 3) Can a measure of compellingness contribute to the manipulation of compellingness through design? Currently, there is no defined scale of compellingness. However, if participants are able to measure the difference in compellingness from one interface to another, it is possible to quantify the contribution of compellingness to the quality of a design.

1.5 Research Aims

The aim of this study is to develop an empirically-based measurement instrument for the compellingness in relation to electronic displays and applications, provide insight into the factors that affect compellingness, and lay the groundwork for future research to discover how to design different levels of compellingness.

Before compellingness levels can be designed, a better understanding is needed of what it is and how to measure it. The first phase of this research identified what items influence compellingness, and how it is defined. This phase included a review of the literature and an initial user study. The next phase developed a survey tool that allowed designers and experimenters to measure the level of compellingness of a display or application. The survey was developed following established measurement scale development steps (DeVellis, 2012). Research then was done to identify the relationship between the items identified in phase one and converted them into questions, followed by a fielding the questions, and a factor analysis on them to see which questions loaded on which factors, and how much. Additionally, the resultant survey had to be as concise as possible, allowing for full measurement of compellingness, while minimizing the burden on the respondent to complete the survey.

1.6 Developing a Valid and Reliable Survey of Compellingness

When developing a scale of a construct that has little or no conceptual work done on it, the scale and construct often evolve together as the scale is developed (Spector, 1992). Since compellingness has not been discussed at length previously, the development of this scale will allow for future research in the area.

Subjective surveys have been used frequently for measures similar in nature to compellingness such as simulator sickness and workload (Kennedy, Lane, Berbaum & Lilienthal, 1993; Hart and Staveland, 1988). It is a tool used that provides a high level of capability in representing a large population, is low cost to implement, convenient to use, provides good statistical significance, leads to little observer subjectivity and precise results (Sincero, 2012). Since compellingness relies heavily on the user's prior beliefs and knowledge as well as their interaction with the system, a survey tool would be best to quickly measure their thoughts and opinions on the interaction.

In order to develop a measurement tool to answer the question "What are the factors affecting compellingness of an interface?" The idea of compellingness must first be defined. When answering a research question like this, developing a measurement instrument is the most appropriate path (DeVellis, 2012). While it may be much simpler to just ask users "Did you find this compelling?", a yes/no response or a simple 1-10 rating is not acceptable when measuring complex issues (Spector, 1992). Compellingness may have several contributing factors. A concept with several constructs likely requires many questions to reveal their multi-dimensionality (Netemeyer, Bearden, & Sharma, 2003). Having only a yes/no question also does not allow differentiation between the responders within the "yes" or the "no" responses, more dimensions are necessary in order to demonstrate the level of compellingness and the factors that are affecting that value. Therefore, a multi-dimensional scale will be needed to accurately measure compellingness.

The most widely used guidelines for developing a measurement scale were specified by DeVellis (2012) and consist of the eight steps**.** The steps are provided on the left side of **Table 1** and how the methodology was implemented in the development of the Compellingness Survey in this research can be found in the middle column. The final column of **Table 1** shows where each step can be found in this thesis.

Table 1: *Scale Development Methodology and Compellingness Survey Process (DeVellis, 2012)*

Step	Scale Development Methodology	Current Research Method	Location in Thesis
1	Determine what is being measured.	Conducted literature review	Chapter 2
2	Compose item pool.	Generated initial items from literature, Conducted Study 1	Chapter 2 Section 9, Chapter 3
3	Determine scale format.	Compared to current scales and created questions	Chapter 4 Section 4
4	Expert review of initial item pool.	Ad-hoc review of item pool	Chapter 4 Section 2
5	Determine items or scales for testing construct validity.	Created initial draft of survey	Chapter 4 Sections 3&4
6	Administer items to sample of respondents.	Conducted Study 2	Chapter 5
7	Evaluate the items.	Conducted initial assessment and exploratory factor analysis on item pool to test validity	Chapter 5
8	Adjust scale length.	Used Cronbach's alpha to test reliability. Result was Compellingness Survey	Chapter 5

First, a comprehensive literature review was conducted in order to determine key synonyms used in literature as well as any vocabulary and research pertaining to the definition of compellingness. From this, a definition was created to define what was being measured. This is all outlined in Chapter 2. A list of constructs that form an "item pool" was generated from the literature review. This list consisted of words or phrases that were considered to be factors that affect compellingness and can be found in Chapter 2, Section 9.

Chapter 3 details Study 1 in which participants were asked to define compellingness and were asked to rate how much that features in the item pool described compellingness. From their responses, items were changed, added, or eliminated from the item pool. An expert review of the item pool followed, rusting in wording changes and item consolidation. The logic of all the choices that were made is outlined in Chapter 4 Section 2. After the modifications to the item pool, each item was turned into a question to be put in the first draft of the survey. This is outlined in Chapter 4 Sections 3&4.

Study 2 was conducted to test the questions from the item pool and to analyze data to build and reduce the survey. Study 2 can be found in Chapter 5. An initial assessment and exploratory factor analysis was conducted on the results of Study 2 to test the question validity and group questions into main factors Cronbach's alpha was used to test the reliability of the questions and the survey and also allowed questions that did not relate to the survey to be eliminated.

CHAPTER 2

RELATED WORK

2.1 Introduction

Compellingness has been described as a feature in evaluative arguments, narratives, the ventriloquism effect, and displays. The following chapter will provide an overview of related threads of research related to the concept of compellingness, with the ultimate goal of presenting a definition of compellingness in human computer interaction. An initial set of definitions of compellingness will be presented from multiple domains. Research in multiple domains can be informative when developing a definition of compellingness. The chapter will include a discussion of the importance of the persuasion in evaluating arguments, compellingness narratives, writing, and media to understand what how each of these contribute to a user's perception and influence the user's beliefs and opinions on a topic. As the focus of this work is human computer interaction, compellingness in displays can be informed by a review of how the timing of visual and auditory features influence compellingness. The chapter will continue with a review of compellingness in display design and the tradeoffs necessary, including examples of human factors issues that have arisen due to the compellingness of a feature or interaction. Finally, the chapter will conclude with a proposed definition of compellingness in human-computer interaction, which will be used as the starting point in the development of a measurement instrument of compellingness is human-computer interaction.

2.2 Definitions

Dictionary.com defines compelling as “having a powerful and irresistible effect; requiring acute admiration, attention, or respect” as well as “to force or push toward a course of action; overpowering”. These definitions both describe something compelling as being something that causes someone to do or feel something, regardless of their will (Dictionary.com, 2017).

Merriam-Webster defines compelling as “forceful, demanding attention, convincing”, all words again showing strong action (Merriam-Webster, 2017). The American Heritage Dictionary defines compelling as “urgently requiring attention, drivingly forceful” (American Heritage Dictionary, 2017) while the Collins English Dictionary defines compellingness as “arousing or denoting strong interest, especially admiring interest; convincing” (Collins English Dictionary, 2017).

While these four definitions are not identical, they do have similarities in their vocabulary and bring together themes of requiring attention, being convincing, and being drivingly forceful- all leading to a proposed broad definition of compellingness: a descriptor of an object, feature or argument that commands your attention, drives you toward a course of action, and convinces you of facts.

In addition to the dictionary definitions of compellingness, papers used the word compellingness but did not provide a definition. It was used in place of many similar terms such as fascinating, believable, or pleasing. One example of this was a scale of perceived self-motion where the participants rate the “compellingness” of the feeling that their body moved (Wright, Lackner & Dizio., 2006). They describe a “compelling realistic visual scene” and suggest that compellingness may be driven by the “heightened sense of presence elicited by the virtual-environment/real-environment match”.

Essentially, the participant would rate the experience as highly compelling if they were convinced that they had both body displacement and velocity, regardless of whether or not they actually did move. This ties closely into the dictionary definitions as the interface commanded participants’ attention by immersing the user into the virtual environment, drove them toward the feeling of moving and convinced them that they did in fact feel both displacement and velocity.

In another example, Kramer (2003) frames the question “how can we effectively represent this one data variable in the most compelling way? (p. 3)” and implies that beyond attractiveness, a compelling representation of the data would enhance the information-conveying capacity and will reduce listening fatigue and annoyance (Kramer, 2003). The premise is that enhancing the information-conveying capacity, getting the point across more clearly and convincingly, and commanding attention will reduce fatigue and annoyance because of the forced interest the user shows.

There are many ways to influence the beliefs and trust of individuals. Compellingness could help influence the trust a user has in a website or system which is something that many are attempting to convey (Jiang, 2016). Additionally, false trust or coercion could be obtained using compellingness similarly to how researchers have shown how the presentation of data can change the belief of a user (Huff, 2010).

Figure 1 shows a breakdown of some of the most common vocabulary terms used in literature to describe compellingness, based on the discussion above. While each genre of literature used different vocabulary, four branches were created that contain the most commonly used words and are grouped by similarity of the words. Two of the four categories of compellingness vocabulary, the attention and convincing categories, come from dictionary definitions. However, these dictionary definitions only look at the most frequent uses of the word compelling. Attention and distraction are grouped together, for example, because they are antonyms. Value, knowledge and beliefs are grouped together because they are all held by a person and contribute to the users' preferences. These four branches are shown below in **Figure 1** and were used in the following chapter sections to draw connections between the research.

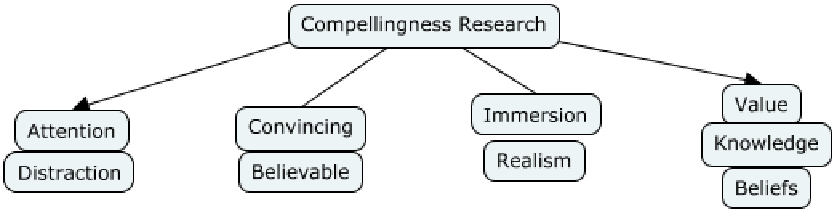


Figure 1*: Vocabulary Categories used in Compellingness Research*

2.3 Compellingness in Narratives

The first three branches of the vocabulary describe aspects of the proposed interaction factor. The amount of attention a user pays to an interface, how convincing and believable the interface is, and the realism of the interaction need both a human user and the computer system interaction. The fourth branch of values, beliefs and knowledge of the user align with the proposed human factor as they are all features of the human.

Compelling narratives, literature, television and writing all require knowledge about the user. This focus on the user can help drive how to design information presentation to make something more compelling, command the user or reader's attention, drive them toward a directed course of action and convince them of facts regardless of the truth.

Creating compelling television requires that three important characteristics be taken into account during the creation process: information about the user, the television program, and the interactive content (Lamont, 2003). Compellingness in an argument is based on the ethics, rationale, reasoning, empathy and beliefs of the listener, and therefore arguments must be tailored around those items (Maturana, 1988). Many of the design aspects of compelling writing and media are all tailored toward a specific audience or user in order to draw in that user group. All of these design factors tie in with the value, beliefs and knowledge category in **Figure 1**, capturing the importance of understanding your user groups' background.

In a discussion on compellingness between Colin Harrison and Philip Gough (1996) in the Conversations series of *Reading Research Quarterly*, they argued that "no matter how timely, brilliantly conceived, carefully constructed, or well-written an article is, if we do not find it compelling, the article will fail in its most important goal, namely to change our view of how things are (p. 335)". Not only should the end user be considered in the writing process, but the interaction between the text and the reader has to be considered as well.

In the end, if an argument or reading is compelling, it can cause people to believe what they read was the truth, regardless of whether it is or not. Fiction compelled many Americans' attitudes towards slavery; journalism may have influenced the withdrawal from Vietnam because of the compellingness of the journalistic accounts of what was occurring, books even change views of modern art (Harrison and Gough, 1996). In short, compelling writing can be quite powerful. Compellingness is centered on a change in one's beliefs, not their knowledge, which influences many of these authors' writings, and a powerful enough change in one's belief can change their view of the entire world. This argument ties into the convincing and believable category of **Figure 1** again, as a compelling argument or book can convince someone of new facts and make that person believe new things.

Designing a compelling narrative to change a person's view of the world is not an easy feat. Compelling narratives are intensely interpretative, but all narratives possess some level of compellingness. Compellingness can be described using vocabulary such as pushing to act, challenging, encouraging, forceful, giving new possibilities and giving new and different ways of understanding and experiencing the world (Rodriguez, 2002).

There are four principle of social realism in writing: recording events in a scene-by-scene construction, recording dialogue in full, making use of a series of I was there perspectives and recording symbolic details of an event or scene in order to evoke entire patterns of life. These principles are often what make for compellingness in case studies and ethnographies in reading research (Harrison & Gough, 1996). These four principles are some of many design strategies for narratives that have been implemented to draw a reader in and make them feel like they are truly immersed in the book. This contributes to the realism and immersion vocabulary in **Figure 1.**

In a more computer-based field, similar game design strategies are being used for the narrative in order to compel learners or players to continue (Brockmyer et. al, 2009). There are many different methods for framing and continuing a story including learning arcs, various roles, and lines to hook and motivate learners to continue playing learning games (Dickey, 2006). These contribute to the realism and immersion a user feels, but also contributes to the direction of the user's attention. Both of these areas are included in **Figure 1**.

2.4 Compellingness in Developing Evaluative Arguments

In 2000, Carenini and Moore developed an equation for Artificial Intelligence or other computer interface to decide which parts of an argument were most relevant to a user and were worth mentioning in an argument. Two measures were defined, the *s-compellingness* and the *s-notably-compelling.* The s-compellingness of an object or attribute is defined as the "measure of its strength in determining the overall value difference between the two alternatives, other things being equal. (p. 50)" The term s-notably-compelling means it is worth mentioning and is considered such it if is an outlier in a population of objectives with respect to compellingness (Carenini & Moore, 2000b). In each of these equations, the user must first create a factor tree of what is important in the decision process and the weights of each. These factors and weights are then assessed by the computer for each potential option and the computer then provides the best option available, as well as the most compelling remaining options in terms of tradeoffs between attributes which are important to the user (Moore et al., 2004).

It is important to know preferences of all of the users present in order to choose the most compelling argument. This work is related to the "value" vocabulary section in **Figure 1** with the idea that user's preferences contribute to what will be the most compelling to them. It also introduces the idea that what is compelling to one user group may not be the same level of compelling to a different user group.

2.5 Visual-Auditory Compellingness

Compellingness has been used in reference to the relationship between the sensory modalities (Warren, Welch & McCarthy, 1981). This use of compellingness focuses only on the synchronization between audio and visual cues. However, in this work the researchers introduce the idea that compellingness is not just present or not present but instead has multiple levels. This supports the premise of the thesis work that compellingness can be measured. We build on this idea to propose that compellingness can be measured and designed on a sliding scale according to which items are manipulated.

The ventriloquism effect describes the mental mapping of the location of an auditory feature and visual display that do not originate from the same location (Warren et al., 1981). Compellingness in the ventriloquism effect is the synchronization between the audio and visual features. The high compelling situation included a video of a person on a screen and their voice being played over the video, the medium compellingness situation included a 150 millisecond lag between the mouth movements and the voice, and the low compellingness had the normal audio but no person on the screen, just tape.

This ventriloquism idea and similar levels of compellingness was also used to look at lip reading. The high compellingness situation had a man’s voice and a man’s image while the low compelling situation had a woman’s voice and a man’s image (Easton & Basala, 1982). It was also used in an experiment where high compellingness was a face and voice and low compellingness had no face and the voice (Warren, McCarthy & Welch, 1983). In each of these cases, compellingness referred to the relationship between the sensory modalities. This research looked only at the compellingness of that specific relationship but does build the groundwork for the idea that compellingness is something with multiple levels and values. The ventriloquism effect research contributes to both the believability as well as the distraction provided by the lag which created a lower compellingness condition, both features in the vocabulary outlined in **Figure 1**.

2.6 Compellingness in Display Design

The potential allocation of attention is an important consideration in display design (Gempler & Wickens, 1998). In aviation, designers must make sure that a pilot's attention is drawn to the right information sources such as warning lights or navigation cues when necessary. Compelling is described as "a characteristic which may influence what information is noticed by the user as well as the level of confidence that users attribute to the validity of that information *whether the display designer intended it to be noticed or not*" (Yeh & Wickens, 2000, p. 3). Since compellingness can affect what information is being noticed by the user, it is important for a display designer to take compellingness into consideration when designing so as to keep control over what information is noticed. The compellingness of an information source can be induced by superimposing information at the same location (Fadden, Ververs, & Wickens, 1998; McCann, Foyle, & Johnston, 1992; Wickens & Long, 1995), presenting cueing information (Yeh, Wickens, & Seagull, 1998; Ockerman & Pritchett, 1998) and increasing realism by using an immersed perspective (Wickens, Olmos, Chudy & Davenport, 1997; Wickens, 1999).

The more information provided in guidance symbology, the more compelling a display becomes and the more attention the operator pays to it (Gempler & Wickens, 1998). This can reduce the attention allocated to the rest of the visual scene. Peripheral cues were found to be so compelling that some subjects were unable to ignore them. Even when subjects were told to ignore them, they were unable to (Jonides, 1981). There is also a phenomenon where operators do not have sufficient attentional capacity to view other visual elements concurrently. Even when the altimeter was not relevant to the task at hand, if it was placed in a specific position, the compellingness of it caused cognitive tunneling and less attention paid to the task at hand (Crawford & Neal, 2006).

The "tunnel-in-the-sky" symbology is designed to keep users focus on the course ahead. However, it has been shown that the tunnel-in-the-sky can be so compelling as to cause pilots to miss in-the-world events that occur outside the tunnel (Thomas & Wickens, 2004). The tunnel provides a more compelling sense of three dimensionality then a mere runway does however the total capture of the pilot's attention comes at the expense of monitoring for and detecting unexpected events (Wickens et al., 2000). Research has been done in simply contrasting the display to create visual enhancement where the designer wants the information to be more compelling (Bossi, Ward & Parkes, 1997). Visual enhancement of a display aids in the performance of tracking but at the cost of detecting targets outside of the visually enhanced section of the display.

2.7 Design Strategies that Induce Compellingness

There are many design strategies that induce compellingness in an information source, such as superimposing information at the same location (Fadden, Ververs, & Wickens, 1998; McCann, Foyle, & Johnston, 1992; Wickens & Long, 1995), presenting cueing information (Yeh, Wickens, & Seagull, 1998; Ockerman & Pritchett, 1998) and increasing realism by using an immersed perspective (Wickens, Olmos, Chudy & Davenport, 1997; Wickens, 1999). **Table 2** outlines the results of various studies where one of these design strategies was used. Some of these studies resulted in accidents while others resulted in a reduction to notice hazards or targets.

Table 2: *Results of Design Strategies that use Compellingness as an Information Source*

Design strategy Category	Design strategy implementation	Task	Description of results	Study
Cueing	Target highlighted in red or with lead-in blinking	During aerial bombing run, identify objects as target or non-target	Highlighting lead to confidence increases in pilots' decisions of whether or not to shoot a target, no increase in accuracy. Pilots allocated less attention to determining presence/absence of other items in the environment	Conejo and Wickens, 1997
Cueing	Target on electronic map and highlighted in visual scene	Simulated exploration mission requiring target avoidance	Cueing led to greater hazard awareness but directed attention away from unexpected events	Davison & Wickens, 1999
Location	Superimposing information at same location- HUD	HUD in simulated low-visibility approaches	More accurate with HUD but less likely to see an aircraft taxiing on the runway	Fischer, Haines, Price, 1980
Symbology	Length of predictor line decreased as time to predicted conflict increased, intruder highlighted in yellow	Avoid traffic conflicts	Predictor information was so compelling that subjects ignored what the aircraft was currently doing and focused on future events	Gempler & Wickens, 1998
Cueing	Presence or absence of cueing	Target detection, identification and location	Cueing resulted in reduced detections of unexpected but high priority targets	Merlo, Wickens, & Yeh, 1999
Cueing	Previous crew told them #1 engine needed to be monitored closely due to wear	Perform preflight inspection (#2 engine damaged)	Crews using paper checklists were more likely to perform the correct task, other crews immediately shut down engine #1 due to compelling misinformation from previous crew	Mosier, Palmer, and Degani, 1992
Modaility of information	Checklists items were either in text or text+picture with a wearable computer	Perform preflight inspection	The higher realism picture system was more compelling and those pilots did not do as thorough a preflight inspection as users followed computer's advice blindly instead of their own knowledge	Ockerman & Pritchett, 1998
Symbology	Tunnel-in-the-sky	Fly simulated path, perform landing, watch out for runway incursion	Pilots responded slower to traffic in the real world such as reporting that the runway was in sight and spotting the runway incursion	Ververs & Wickens, 1998
Perspective	Hand-held miniature representation of virtual environment	Navigation through virtual environment	The icon in the hand-held captures users' attention and they go so far as to orient the viewpoint so that they are looking over the icon's shoulder	Pausch, Burnette, Brockway, & Weiblen, 1995

2.8 Compellingness in Human Computer Interaction

This research proposes that there are three main factors that make up compellingness. These three factors include the human, the system and the interaction. The first factor, "the human", includes the variable prior knowledge and interest which contains the users' view of the world, value of output, and willingness to participate and continue to use the interface. These factors all group together because they are intrinsic properties of the user that have little to no influence from the system design. In a study assessing the practical relevance of clinical research results, Tonelli (2012) looked at what factors determined the compellingness of clinical research results. A few of these focused on the user including their prior knowledge/belief as well as the value of the outcome. Tonelli argued that when research supports the prior understanding and preconceived beliefs people have on a subject matter, they much more readily accept conclusions and reports. The opposite was also seen as true, that when findings counter strongly held beliefs, likely a single study or person will not be found compelling (Tonelli, 2012). This specific variable is related to others such as the willingness to participate and the value the user sees in the information and output provided because the user is likely to believe what they believe, and one interaction with an interface is not going to sway them otherwise.

The second factor, “the system,” has a list of contributing variables that describe features such as the aesthetic quality of the interface, design choices to promote engaged learning, the fidelity of the interface, the goals and feedback provided and the layout design. These variables describe the features of the interface, automation, software and hardware.

In a paper aimed at making UI more compelling, Birnbaum, Horvitz, Kurlander, Lieberman, Marks & Roth (1997) discussed how effort should be focused on “better design of layout, controls, and functionality of user interfaces, and, where necessary, weaving into the designs relatively straightforward pattern matching, similarity metrics and search techniques” in order to increase compellingness of a UI. Salesforce also discusses on their website how their software has a compelling UI because of their standardized and easily understood interface that still has an immense amount of functionality (Compelling UI, 2008). The quality and realism of an environment are also incredibly important features that influence compellingness (Banos et al, 2004).

In order to encourage users to be more meaningfully engaged, authentic activities and interacting with other learners as well as focused goals, challenging tasks, clear standards, affirmation of performance, novelty, choice and challenges can all be provided (Jones, Valdez, Norakowski & Rasmussen, 1994; Kearsley & Shneiderman, 1999; Scardamalia, Bereiter, McLean, Swallow & Woodruff, 1989; Shneiderman, 1992; Schlechty, 1997; Malone, 1981). These activities and many others provide a medium to become more involved in the interaction but do not require any user input to be present, and thus are in “the system” factor. Similarly, variables such as the workload required, completion time necessary and effort necessary all do depend on the user but should be relatively similar on the same interface with a few outliers. The reason variables like these are included in “the system” factor is because they have much more variability between interfaces than between users. From one interface or system to another, the workload may be incredibly different because users are likely completing a different task. However if two users are completing the same task it might be a bit harder for one than the other but not as much as it would be if they were performing different tasks.

The third and final factor, “the interaction”, consists of many variables that involve how the user interprets and reacts to the system such as their sense of control, how desirable they view the system as, whether or not they lose track of time and how immersed they get into the system. These are grouped into the categories of intrinsic motivation, engagement, perceived ease of use, interest and the change in knowledge of the topic. When designing a tool for an animation package, designers replicated the artists' annotation language and interaction techniques to make the experience more fluid and understandable to meet the users' expectations and be more predictable (Vronay and Wang, 2004). It was a great example of how the designers took the user's prior knowledge and designed a feedback and interaction style to meet their needs and make a more compelling tool. This is one example of how a designer might improve their design using variables in "the interaction" factor such as the user knowing what to do, a matchup between the user's expectations and the system and ease of comprehension.

2.9 Definition of Compellingness

The goal of this work is to develop an empirically-based instrument to measure compellingness of human-computer displays. **Figure 1** outlined four themes of the vocabulary found in dictionary definitions and previous literature. Based on this work, the following definition of compellingness is provided as a starting point for this research:

> "The compellingness of display is dependent on *the amount to which a display or application directs and controls your attention, drives you toward a course of action, aligns with your prior beliefs, values and knowledge, convinces you of facts, and immerses you in the experience."*

CHAPTER 3

STUDY 1: ITEM POOL GENERATION AND EXPERT REVIEW

3.1 Introduction

While compellingness can be found in literature in many different fields, it has not yet been developed in the field of electronic displays and applications outside of Wickens' work on attention. Because of this, it is important to verify the proposed definition and constructs presented in this research. DeVellis's (2012) third step in survey development is to conduct an expert review of the item pool.

The objective of Study 1 is to verify the definition created in Chapter 2, to understand common word associations with compellingness, and to identify constructs not uncovered in literature. The end result of Study 1 will be an item pool that will be used to design the compellingness survey.

Participants were asked to define compellingness in their own words. The purpose of the free-response questions were to assess participants' view on the definition of compellingness, and to pick up on any constructs not covered in the semantics question section. Any additional constructs were added to the list in **Table 3**. In addition, participates were asked to rate how strongly compellingness is related to each of the constructs in **Table 3**, Constructs not closely related to compellingness were eliminated. The resultant list was used to generate the questions that made up the compellingness survey to be tested in Study 2.

3.2 Initial Item Pool

DeVellis (2012) developed a set of eight steps for developing a measurement scale. These steps were provided in Chapter 1 in Table 1. After the first step of literature review was completed, the initial items were generated from that literature. From the literature presented in Chapter 2 as well as additional material, both objective and subjective items were identified that either contributed to or were a result of compellingness. These items and their sources can be found in **Table 3**. This is an initial draft of what items contribute to compellingness. Study 1 was conducted to determine how closely each of the items contributed to compellingness when presented to represented users. While some of these items could be measured objectively, others have to do with the user and the interaction between the user and the system which leads to the idea that a subjective survey may be sufficient for a measurement instrument of compellingness.

***Table 3**: List of Initial Contributing Factors to Compellingness*

Contributing Items	**Source**
completion time	Warren, Welch and McCarthy, 1981
deafness/alertness to outside world	Davis and Widenbeck, 2001; Brockmyer, et al., 2009
repetition of content	Tonelli, 2012
prior knowledge of topic	Tonelli, 2012
concentration required	Davis and Widenbeck, 2001; Brockmyer, et al., 2009
negative consequences present	Provenzo, 1991
appreciative feedback from virtual audience	Turkle, 1995
emotional support provided by the system	Scardamalia et al, 1989
dazed and inattentive	Brockmyer, et al., 2009
fear	Brockmyer, et al., 2009
interaction with other users	Blythe, Overbeeke, Monk & Wright, 2008; Schubert, Friedmann & Regenbrecht, 2001
workload	Ahuja and Webster, 2001
view of world is changed	Harrison and Gough, 1996
lose track of time	Davis and Widenbeck, 2001; Brockmyer, et al., 2009
calm/ hyper	Brockmyer, et al., 2009
display size	McMahan et al, 2012
physical interaction with system and interface	Blythe et al, 2008
user takes on a role or persona in order to complete a task	Dickey, 2005
challenging	Kearsley & Shneiderman, 1999
system seems simple/complex	Tractinsky, Katz & Ikar , 2000
age of display	McMahan et al, 2012
user feels tired/energized	Brockmyer, et al., 2009
interface is standardized	Compelling UI, 2008

Table 3 continued.

amount of distraction	Davis and Widenbeck, 2001; Brockmyer, et al., 2009
user feels a sense of being physically present with the environment provided by the system	Brockmyer, et al., 2009
display realism	Banos et al, 2004
sense of control	Davis and Widenbeck, 2001; Brockmyer, et al., 2009
mental engagement	Brockmyer, et al., 2009
user reaction time	Davis and Widenbeck, 2001
actions feel automatic/actions require a lot of thought	Davis and Widenbeck, 2001; Brockmyer, et al., 2009
desirability of system	Karvonen, 2000
story or narrative provided	Dickey, 2005
immersion	Davis and Widenbeck, 2001
feedback is direct	Davis and Widenbeck, 2001
the output matters to the user	Tonelli, 2012
increase in knowledge of topic	Harrison and Gough, 1996
specific goals	Jones et al., 1994
display resolution	McMahan et al, 2012
meaningfulness of information and result	Tonelli, 2012
speed of feedback	Bowman, 1982
order of information	McMahan et al, 2012
user motivation	Jacques, Precce & Carey, 1995; Linnenbrick-Garcia, Rogat and Koskey, 2006
effort necessary to use system	Davis and Widenbeck, 2001
user willingness to use system	Linnenbrick-Garcia, Rogat and Koskey, 2006
clearness of goals	Bowman, 1982
matchup between user's expectations and the system	Vronay and Wang, 2004
number of choices	Schlechty, 1997; Malone, 1981
interesting dialogue	Harrison and Gough, 1996
visually appealing	Tractinsky, Katz & Ikar, 2000
quality of graphics	Banos et al, 2004
information quality	McMahan et al, 2012
ease of navigation	Ahuja and Webster, 2001
ease of comprehension	Ahuja and Webster, 2001
know what to do	Davis and Widenbeck, 2001
legibility of instructions	Tractinsky, Katz & Ikar, 2000
consistency in interface	Tonelli, 2012
convenience of display location	McMahan et al, 2012
understandability	Ahuja and Webster, 2001
ease of use	Tonelli, 2012; Ahuja and Webster, 2001
system is interesting	Tractinsky, Katz & Ikar, 2000
functionality	Birnbaum et al, 1997, Compelling UI, 2008
satisfaction	Bowman, 1982
response time	Jack and Thurlow, 1973
time delay between visual and audio	Warren, Welch and McCarthy, 1981; Radeau and Bertelson, 1977

3.3 Method

Participants

This study was approved by the Iowa State Institutional Review Board (IRB #16-581). Students, faculty and staff at a Midwest university were invited to participate in the online survey via sources such as flyers, emails and word of mouth. The compellingness survey is developed to help researchers study the human factors of interface design. Thus the chosen demographic of participants was chosen to represent the types of participants often involved in assessing interfaces. The survey was started by 576 people and completed by 238 participants (140 identified as female, 132 identified as male, 9 identified as other and 2 chose not to answer). The average age of participants was 24 (SD = 6.2). Participants' highest education received included 1 participant with some high school, 24 with a high school diploma, GED or similar, 164 with some college, 16 with an associate's degree, 48 with a bachelor's degree, 24 with a master's degree, 4 with a doctorate and 2 with other. Of the fields the participants work in or are studying, 46 are in Agriculture and Life Sciences, 27 are in Business, 14 are in Design, 87 are in Engineering, 31 are in Human Sciences, 61 are in Liberal Arts and Sciences, 7 are in Veterinary Medicine and 10 are in Other.

Measures

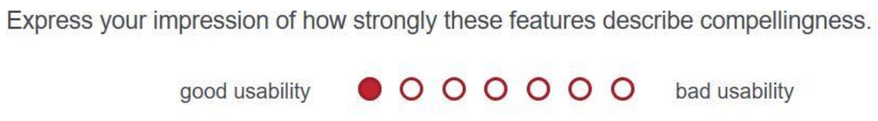
Study 1 consisted of three separate sets of measures grouped into sections as can be seen in Appendix A. The first section consisted of free response and multiple choice questions that asked users to define compellingness and assessed their use of different types of technology. The second section consisted of a review of the item pool where participants were asked to rate how well each item is related to compellingness. Section three consisted of open ended questions that assessed what participants believed were examples of high and low compellingness interfaces and what features contributed to their level of compellingness.

Definitions and frequency of use questions

Participants were asked to answer a series of questions asking them to define compellingness. Participants were asked to define, in the own words, compellingness in general, compellingness in relation to interactive electronic displays, and compellingness in relation to applications. They were also asked how often participants used interactive electronic displays (tablets, laptops, computers, phones) and applications (video games, learning software, office software, online news or shopping sites, social media, phone apps, navigational software). Finally, participants were asked what would make them choose one video game over another? These questions can be found below in Appendix A.

Item review

In order to review the 67 item constructs, participants were asked to rate how strongly each described compellingness. An example is provided in **Figure 2**. This 7-point scale from -3 to +3 was centered on 0 with a 0 meaning that the feature does not describe compellingness at all. The endpoints were chosen to be positive and negative as each of the two sides of the semantics questions had a positive and negative description of a feature. If the participant was unsure they were asked to leave the question blank. Blank answers are not counted towards the average score.



Express your impression of how strongly these features describe compellingness.

good usability ● ○ ○ ○ ○ ○ ○ bad usability

Figure 2*: Example of Semantics Question*

<u>Open ended questions</u>

Finally, participants were asked which displays they did and did not consider compelling. They were first asked to think about an application on an interactive electronic display that they considered compelling. They were asked to describe it and what features it had that made it compelling. They were then asked to think of an application on an interactive electronic display that they did not consider compelling. They were again asked to describe it and the features that made it not compelling. The survey in its entirety can be found in Appendix A.

Procedure

Participants received a link via email, flyer, social media or word of mouth, where they were directed to a Qualtrics survey in the comfort of their own environment. Due to the electronic nature of the study, the participants were able to take the study wherever they were most comfortable, including on mobile devices. Each participant was asked to follow a link to the survey. They electronically signed a consent form, and verified that they were over the age of 18. If they consented to participate and were over the age of 18 they then received an intro of the study and instructions followed by each of the questions found in Appendix A. To avoid making respondents conscious and aware of their identifying characteristics and introducing a bias, participants filled out the demographics questions after completing the survey. At the end they were thanked for their participation and were given the option to enter their email addresses for a gift card drawing.

Data analysis plan

The free response questions yielded paragraphs of answers which were analyzed by looking at the frequency of word use and the context the most frequent words were used in. Word clouds were created to aid in visualization of these frequencies. The context of these responses aided in the addition of questions to the Compellingness Survey. If a word was used frequently but the context it was used in was not addressed in one of the semantics questions developed from the item pool, a new question was created to address it.

For the three questions that asked participants to write out a definition of compellingness, word clouds were created that show the frequency with which a word was used from all the responses, denoted by word size. For instance, if the word “interest” was used 100 times but the word “persuasive” was used 50 times, “interest” will show in a font size twice as large as “persuasive”. The word clouds were used as a visual representation of frequency but actual frequency numbers were recorded as well to rank words by their frequency. The top 20-30 words used to answer each question were defined as being used with high frequency and were compared against the current list of questions on the first draft of the Compellingness Survey. If the words from the responses describe features of compellingness not yet included in the Compellingness Survey, they were be added.

A few questions asked responders to describe why they would choose one phone or video game over another as well as what electronic displays they considered compelling and not compelling. For each of these free response questions, word clouds were again used to discover any parts of the compellingness defined in responses that were not detailed in literature.

The semantics scale questions resulted in an average rating ranging from -3 to 3 in describing how well the construct was related to compellingness. The absolute values of the mean responses were analyzed since high correlation was desired but direction was not important, just power. The closer the average absolute value of the score was to 3, the more related the construct was to compellingness. The closer the average was to 0, the less. The constructs with the lowest averages were looked at and analyzed as to whether they just needed rewording or should have been eliminated from the final list of questions. The cutoff threshold can be defined as the point at which every construct with a mean below that value was eliminated. It was chosen based on the distribution of the means and where the data naturally appeared to break. Any questions below that cutoff threshold were eliminated from the list and the questions just above that threshold were evaluated for wording changes.

Limitations and assumptions

Due to the location of the researchers, only Midwest university students and faculty were sampled which does not provide a world-wide, diverse view of the definition of compellingness. It is likely that in other countries or other parts of the globe, people may view the word and its definition differently and that was not captured in the sampled population.

DeVellis' (2012) Step 4 calls for an expert review of the item pool which was accomplished in this case by conducting Study 1 on a representative population of participants, as well as an expert review conducted by the principle investigators in Chapter 4 Section 3.

3.4 Results

Definitions and frequency of use questions

The first free response question, Question 1, asked, “In your own words, please tell me what you think *compellingness* means.” The resulting word cloud is presented in Error! Reference source not found.. The most frequent words used were: action (34 times) attention (18 times), interest (36 times), drive (18 times) feel (33 times), persuasive (33 times) and willing (23 times). These words were assessed against the semantic difference item pool and action, attention, interest, drive, feel, and willing were all verified on the list. No vocabulary similar to persuasive was in the item pool so it was added.

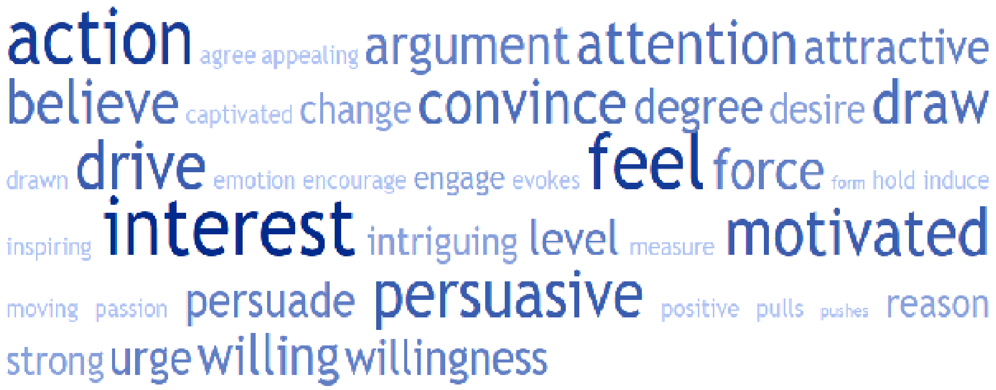


Figure 3*: Word Cloud for Question 1: "In your own words, please tell me what you think compellingness means."*

Questions 2-5 asked how often participants use various electronic devices. The results are displayed in **Figure 4.** Participants used a cell phone the most frequently with 276 of the 283 participants saying they used it a few times a day or more. Participants used a tablet the least frequently with only 32 participants saying they used it a few times a day or more and 201 participants saying they used it never or less than once a week.

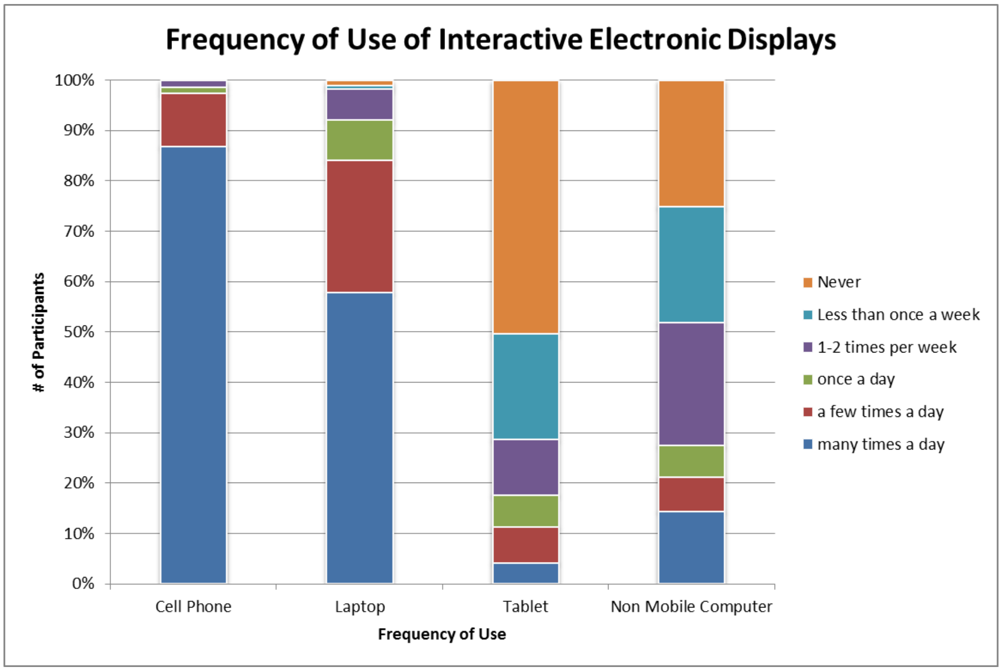


Figure 4*: Graph of how Often Participants use Various Interactive Electronic Displays*

The second free response question, Question 6, asked, "In your own words, please tell me what compellingness means to you in relation to interactive electronic displays (such as tablets, laptops, computers or phones)." The resulting word cloud is presented in **Figure 5**. The most frequent words used were: interactive (35 times), feel (38 times), interest (16 times) and attention (13 times). These words were assessed against the semantic difference item pool and interactive, feel, interest and attention were all verified on the list.

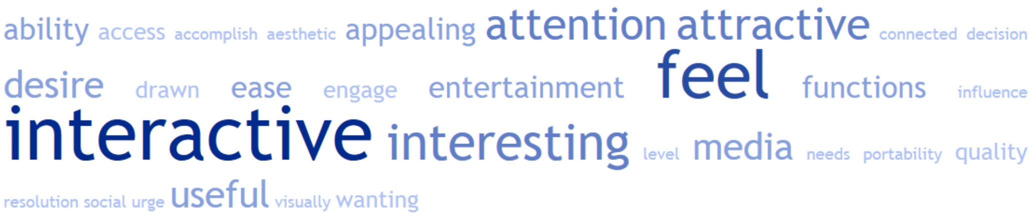


Figure 5*: Word Cloud for Question 6: In your own words, please tell me what compellingness means to you in relation to interactive electronic displays (such as tablets, laptops, computers or phones).*

The third free response question, Question 7, asked, “Think about smart phones and their display screens. What would make you choose one phone over another?” The resulting word cloud is presented in **Figure 6**. The most frequent words used were: phone (114 times), display (70 times), size (72 times), quality (33 times), clarity (23 times), large (38 times) and ease/easy (73 times). These words were assessed against the semantic difference item pool and phone, display, size, quality, clarity and large were all verified on the list.

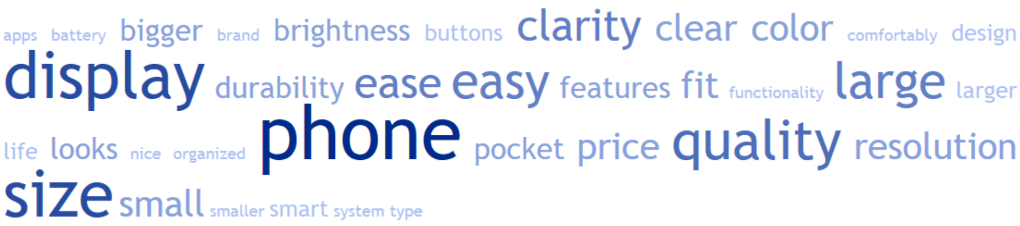


***Figure 6**: Word Cloud for Question 7: Think about smart phones and their display screens. What would make you choose one phone over another?*

Questions 8-15 asked how often participants use various applications. The results are displayed below in **Figure 7.** Participants used phone apps the most frequently with 246 of the 283 participants saying they used it a few times a day or more. Participants used online shopping sites the least frequently with only 13 participants saying they used it a few times a day or more and 172 participants saying they used it never or less than once a week.

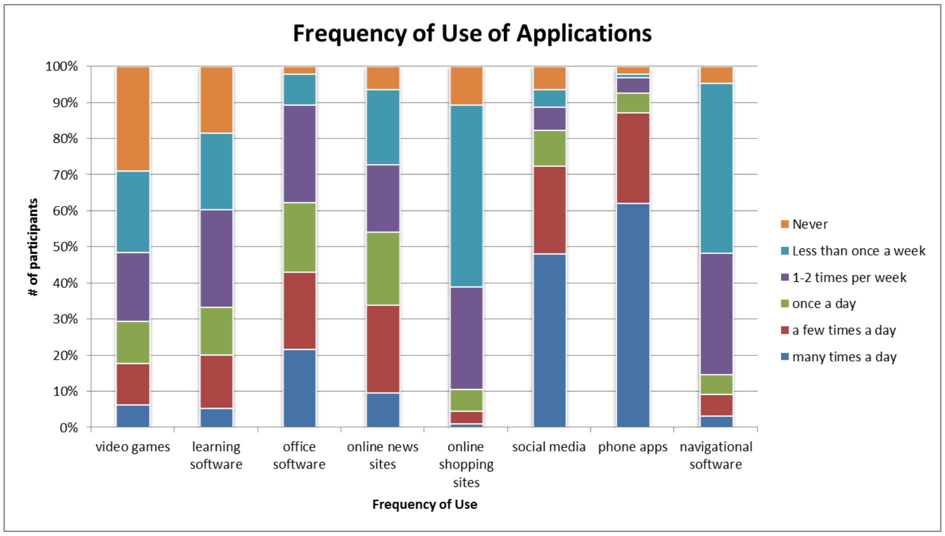


***Figure 7**: Graph of how often participants use various applications*

The fourth free response question, Question 16, asked, “In your own words, please tell me what compellingness means to you in relation to applications (such as video games, learning software, office software, online news or shopping sites, social media, phone apps or navigational software).” The resulting word cloud is presented in

. The most frequent words used were: easy (78 times), social (37 times), media (32 times), interesting (25 times), navigational (18 times) and entertainment (17 times). These words were assessed against the semantic difference item pool and easy, interesting, navigational, and entertainment were all verified on the list. No vocabulary similar to social or media was in the item pool so they were added.

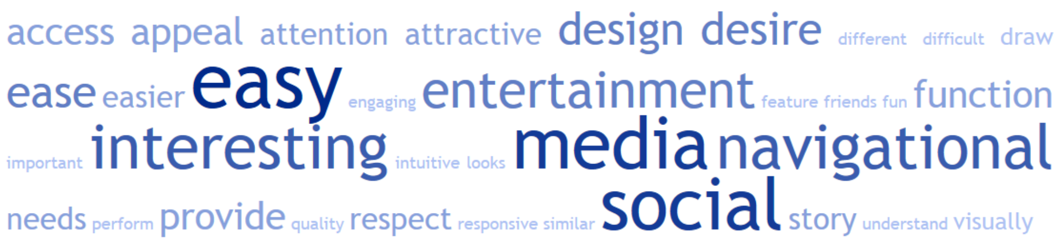


***Figure 8**: Word Cloud for Question 16: In your own words, please tell me what compellingness means to you in relation to applications (such as video games, learning software, office software, online news or shopping sites, social media, phone apps or navigational*

The fifth free response question, Question 17, asked, “Think about video games and their content. What would make you choose one video game over another?” The resulting word cloud is presented in **Figure 9.** The most frequent words used were: story (86 times), graphics (48 times), interesting (40 times), reviews (30 times), fun (34 times), type (22 times) and content (24 times). These words were assessed against the semantic difference item pool and story, graphics, interesting, fun, type and content were all verified on the list. No vocabulary similar to reviews was in the item pool so it was added.

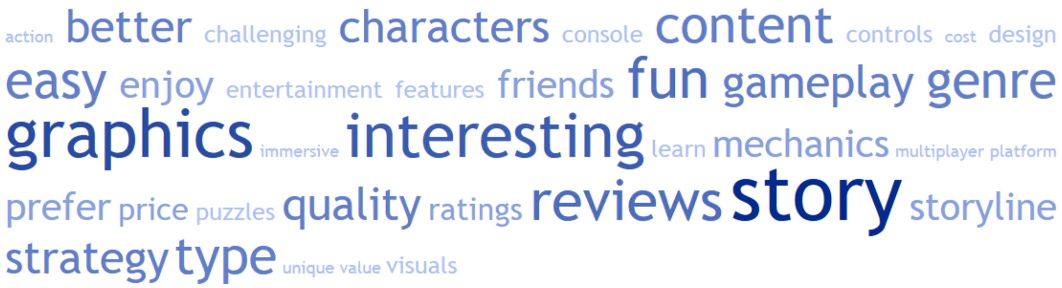


***Figure 9**: Word Cloud for Question 17: Think about video games and their content. What would make you choose one video game over another?*

Item review

After the initial 17 questions were asked, participants were then given the semantics scale questions. **Table 4** below summarizes all features’ mean scores (sorted smallest to largest) as well as the standard deviations. Three of the questions were asked in reverse, so the absolute value captures the strength of the relationship between the concept and compellingness.

***Table 4**: Semantics Questions Results*

Endpoint	Endpoint	mean	std. dev.
time delay between visual and audio	no time delay between visual and audio	2.56	0.91
system response time is long	system response time is short	2.55	0.88
low satisfaction	high satisfaction	2.46	0.89
low functionality	high functionality	2.44	0.98
system is uninteresting	system is interesting	2.38	1.01
low ease of use	high ease of use	2.36	1.05
interface is not easily understood	interface is easily understood	2.33	1.00
display located inconveniently	display located conveniently	2.31	0.99
inconsistency in interface	consistency in interface	2.19	1.08
illegible instructions	legible instructions	2.13	1.10
user will not know what to do	user will know what to do	2.12	1.10
system is hard to comprehend	system is easy to comprehend	2.09	1.09
user has difficulty navigating system	user is able to navigate the system easily	2.08	1.16
low information quality	high information quality	2.08	1.09
low quality graphics	high quality graphics	2.06	1.10
system is not visually appealing	system is visually appealing	2.03	1.25
uninteresting dialogue	interesting dialogue	2.02	1.13
user does not have choices to make	user has choices to make	2.01	1.24
user's expectations do not match system	user's expectations match system	1.99	1.15
goals are unclear	goals are clear	1.99	1.24
low user willingness to use system	high user willingness to use system	1.97	1.13
high effort necessary to use system	low effort necessary to use system	1.95	1.33
low user motivation	high user motivation	1.94	1.23
information is presented in random order	information is presented in order	1.90	1.33
delayed feedback	immediate feedback	1.88	1.24
information and result are not meaningful	information and result are meaningful	1.88	1.30
low display resolution	high display resolution	1.87	1.18
un-specific goals	specific goals	1.85	1.18
no increase in knowledge of topic	increased knowledge of topic	1.83	1.19
the output does not matter to the user	the output matters to the user	1.80	1.25
feedback is indirect	feedback is direct	1.80	1.18
user does not become immersed	user becomes immersed	1.74	1.47
no story or narrative provided	story or narrative provided	1.74	1.40
low desirability of system	high desirability of system	1.73	1.44

Table 4continued.

actions require a lot of thought	Actions feel automatic	1.64	1.42
user reaction time is slow	user reaction time is fast	1.61	1.26
low mental engagement	high mental engagement	1.60	1.33
user has full sense of control	user has little sense of control	1.55	1.82
low display realism	high display realism	1.54	1.38
user does not feel a sense of being physically present with the environment provided by the system	user feels a sense of being physically present with the environment provided by the system	1.50	1.44
high amount of distraction	low amount of distraction	1.48	1.52
interface is not standardized	interface is standardized	1.47	1.41
user feels energized	user feels tired	1.44	1.50
old technology display	new technology display	1.40	1.29
system seems complex	system seems simple	1.34	1.52
not challenging	Challenging	1.34	1.43
user does not take on a role or persona in order to complete a task	user takes on a role or persona in order to complete a task	1.23	1.54
low amount of physical interaction with system and interface	high amount of physical interaction with system and interface	1.04	1.54
small display size	large display size	0.99	1.35
user is hyper	user is calm	0.94	1.45
user does not lose track of time	user loses track of time	0.91	1.76
view of world is not changed	view of world is changed	0.91	1.49
high workload	low workload	0.85	1.44
user has no interaction with other users	user interacts with other users	0.82	1.71
user feels fear	user does not feel fear	0.81	1.71
user does not get dazed and inattentive	user gets dazed and inattentive	0.79	1.79
little or no emotional support provided by the system	large amount of emotional support provided by the system	0.73	1.61
no appreciative feedback from virtual audience	appreciative feedback from virtual audience	0.72	1.69
no negative consequences present	negative consequences present	0.64	1.80
low concentration required	high concentration required	0.45	1.53
user has a lot of prior knowledge of topic	user has little prior knowledge of topic	0.25	1.58
no repetition of content	repetition of content	0.20	1.66
user is alert to the outside world	user becomes deaf to the outside world	0.09	1.92
shorter completion time than normal	longer completion time than normal	0.06	1.78

Figure 10 shows a graph of each of the above responses from lowest mean value to highest mean value. From the combination of **Table 4** and **Figure 10**, the questions with a mean value of lower than 1.25 were cut from the question list due to little connection to compellingness. This cut-off point was decided by looking at **Figure 10** to find a gap in the

data or an inflection point. There was one large gap at 1.25 and an inflection point at 0.85. After examining the semantics questions between those two points and seeing that they included many features not mentioned by participants in the free response questions, the cutoff point of 1.25 was chosen and is depicted with a red line on the graph. The only feature kept that was under the 1.25 cutoff was losing track of time. It kept was due to the association of the word in prior word clouds and free responses provided by participants. The other 17 features under that cutoff point were removed from the item pool.

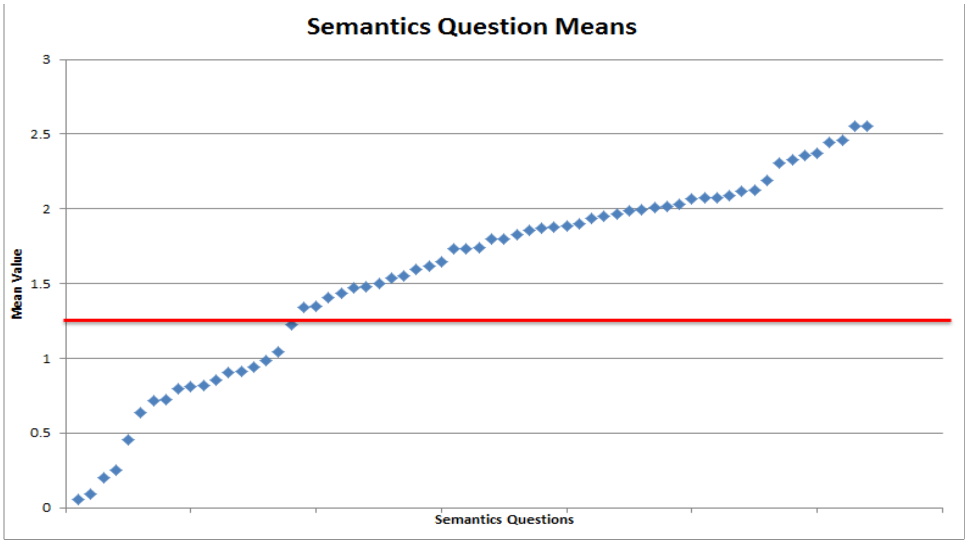


***Figure 10**: Mean Values of Responses for Semantics Questions, with 1.25 Mean Value Question Cutoff*

Open ended questions

After the semantics questions, participants were asked two additional free response questions to gauge the features that make an interactive electronic display compelling and not compelling. These questions were asked after the semantics questions in order to get the participant thinking about possible features before answering the questions.

The first of the two final free response question asked, “Think about an application on an interactive electronic display that you consider compelling. What is it and what features make it compelling?" The resulting word cloud is presented in **Figure 11**. The most frequently words used were: easy (79 times), interactive (26 times), information (20 times), simple (18 times), story (19 times) and news (19 times). These words were assessed against the semantic difference item pool and easy, interactive, information, simple, and stories were all verified on the list. No vocabulary similar to "news" was in the item pool so it was added to the list of items to be analyzed.

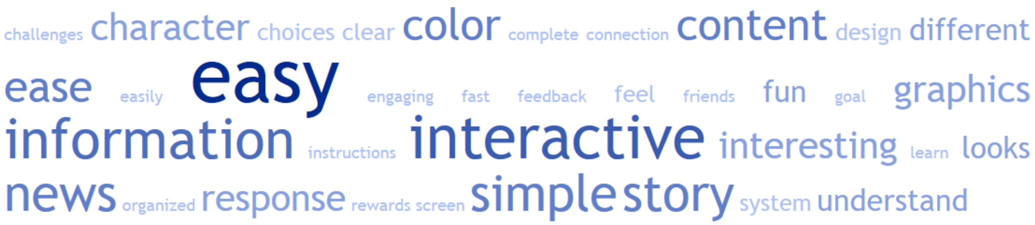


Figure 11*: Word Cloud for Question 18: Think about an application on an interactive electronic display that you consider compelling. What is it and what features make it compelling?*

The second free response question asked, "Think about an application on an interactive electronic display that you do *not* consider compelling. What is it and what features make it *not* compelling?" The resulting word cloud is presented in **Figure 12**. The most frequent words used were: hard (24 times), difficult (18 times), functionality (14 times), boring (11 times), interactive (12 times), slow (15 times) and ads (10 times). These words were assessed against the semantic difference item pool and hard, difficult, functionality, boring, interactive, and slow were all verified on the list. No vocabulary similar to "ads" was in the item pool so it was added to the list of items to be analyzed.

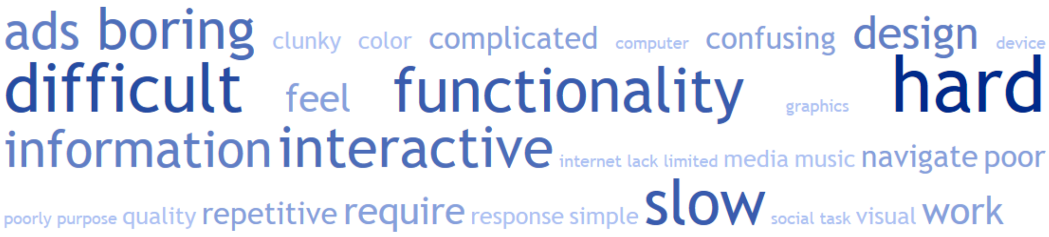


***Figure 12**: Word Cloud for Question 19: Think about an application on an interactive electronic display that you do not consider compelling. What is it and what features make it not compelling?*

3.5 Discussion

The objective of Study 1 was to understand common word associations with compellingness and identify any missed constructs not covered in literature. From the definitions provided by participants from the free response questions, all portions of the definition created in Chapter 2 were frequently used by participants.

The missed constructs that were identified from the free responses of users consisted of the words “reviews”, “social”, “ads” and “media.” These construct were all used to describe the influences in life that manipulate a user’s motivation. Many users reported wanting to play a video game because of good reviews that they have heard about or talk amongst their social network. The media also influenced their decisions and ads were mentioned with a negative connotation in responses reporting that “too many ads” made an application not compelling.

Analysis of responses led to the identification of an item that captures the idea that extraneous information not relevant to the task at hand can distract participants and cause their attention to be focused elsewhere. A review of the meaning behind each of these constructs led to a deeper look into the constructs of motivation, persuasion and attention. Ultimately, the questions “I am willing to continue with this task,” “After interacting with this interface I am persuaded to take an action,” and “This interface was able to hold my attention" were added with responses ranging from strongly disagree to strongly agree. These were chosen to supplement the already existing constructs.

The item pool originally consisted of the items in **Table 3** and those items were used in the semantics questions in order to understand word association. Study 1 identified four words that identified and described two additional items to this list from the free response question as well as removed non-associated words because of the semantics question responses. The result of Study 1 is a new, updated item pool that more closely represents all the factors that go into compellingness. This revised item pool can be seen below in **Table 5** and was used to create the initial compellingness survey.

Table 5*: Final Item Pool*

Items	Items	Items
visual and audio sync	uninteresting dialogue	story or narrative
Length of system response time	number of choices to make	desirability of system
satisfaction	match between user expectations and system	actions require a lot of thought
functionality	clarity of goals	user reaction time
system is uninteresting	user willingness	mental engagement
ease of use	effort necessary to use system	sense of control
understandability	user motivation	display realism
convenience of display location	order of information	sense of being physically present with the environment provided by the system
interface consistency	speed of feedback	amount of distraction
legibility of instructions	meaningfulness of information and result	standardization of interface
knowing what to do	display resolution	user feels energized
comprehension of system	specificity of goals	age of technology display
navigation of system	increase in knowledge of topic	system complexity
information quality	output meaning to the user	challenges present
quality of graphics	directness of feedback	Track of time
visual appeal of system	immersion	

CHAPTER 4

INITIAL SURVEY DEVELOPMENT

4.1 Theoretical Groupings

Objective

The objective of this chapter was to analyze all of the items in the item pool, group them into categories, remove any repetitive items, and develop a final question list that included each of the items. The question list was then tested in Study 2. The objective of this first section was to group the items in the item pool into categories known as factors. This Chapter includes Devellis' (2012) Steps 3-5 including determining a scale format, an expert review of the initial item pool, and determining the items or scales for testing construct validity.

Methods

A card sorting method was used to analyze the relationship between the items in the item pool. Similar items were grouped together into small groupings and then similar groupings were also grouped together by their similarity. These categories were then displayed on a concept map to visualize their relationships.

Results

Through the card sorting, 11 groups were defined: prior knowledge and interest, intrinsic motivation, engagement, perceived ease of use, interest, knowledge state, aesthetic quality, engaged learning, fidelity, goals/feedback, and layout design (see Figure 13). Further discussion of the initial groupings from the card sorting exercise revealed relationships between many of the groupings and thus three hypothesized overarching factors were created. These three factors were: (1) the user’s beliefs and intentions with which they approach the situation, (2) the features of the system such as the fidelity and information provided, and (3) the interaction between the user and the system that affects things such as the user’s sense of control or the perceived desirability of the system. Those three categories or “factors” were labeled: the *human*, the *system*, and the *interaction*. Each of the small initial groupings of items fell under one of these three factors and they became the second level headers in the concept map found in **Figure 13.** Each of the small groupings of items were given a title or overarching theme descriptor that is displayed above them. The computer factor was renamed to “the system” to account for not just the computer itself, but also the automation and the interface.

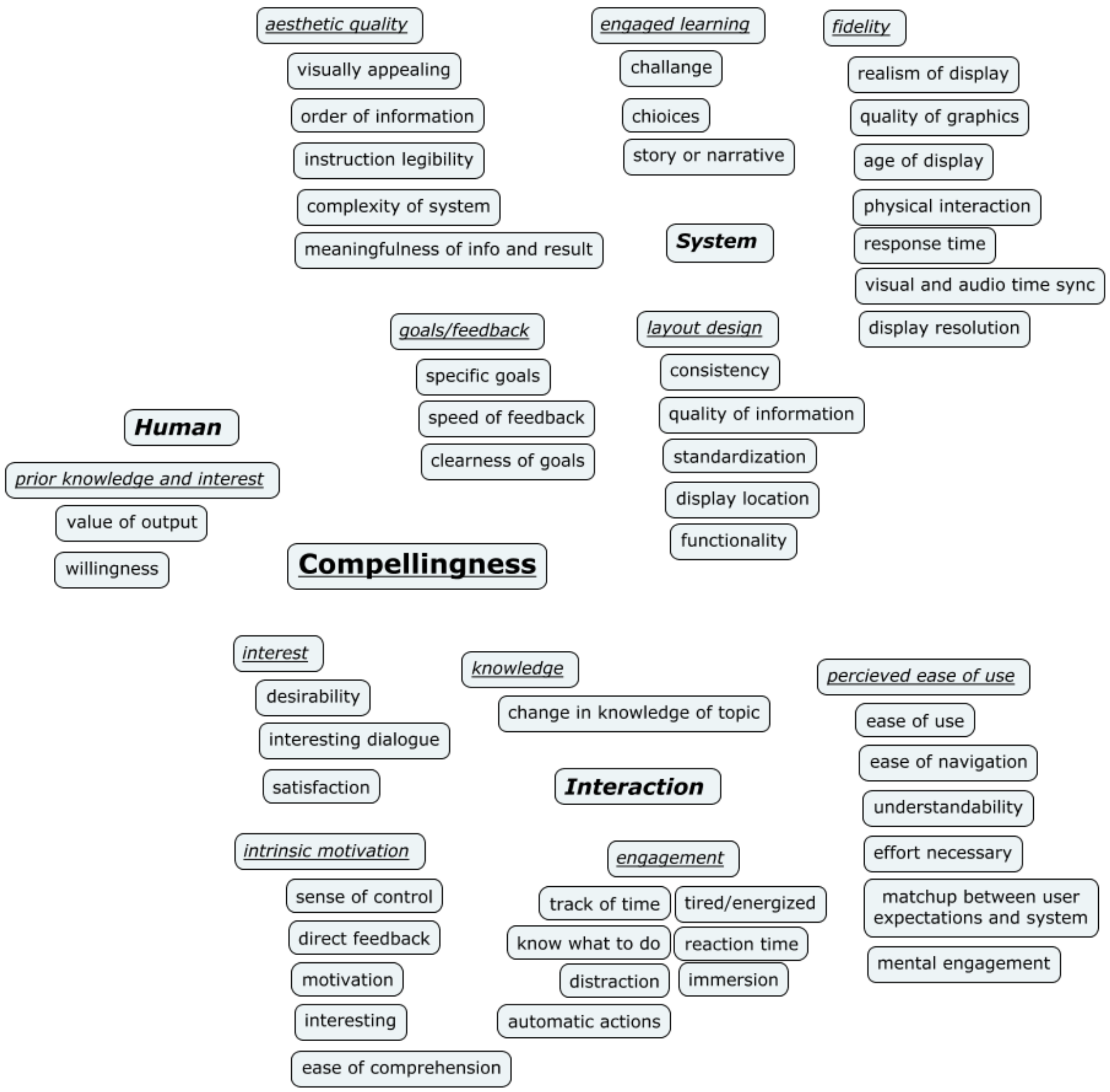


Figure 13*: Concept Map of Compellingness, its 3 factors, 11 groupings and 47 items*

Discussion

The factor structure that resulted from the card sorting was a two level structure consisting of three overarching factors of human, system and interaction. This highlights the importance of not just the system itself, but also what the user brings and the interaction between the two. The second level consisted of 11 groupings identified in the card sorting, each with their own items from the initial item pool. This concept map was then put through a second expert review of the item pool to assess if there was remaining redundancy in the item pool or opportunities to condense the survey.

4.2 Second Expert Review of Item Pool

Objective

From these initial groupings, a second expert review was performed to assess if there was any remaining redundancy in the words used, a common level of abstraction among the item pool, and if there were opportunities to condense the survey. The goal was to develop the most efficient set of question in the initial survey that still covered all the principal concepts.

Methods

The principle investigators then examined each of the individual factors to decide which should be combined. The principle investigators looked for any redundancy as well as the number of questions that were asked per item and per grouping. Items that described the same concept were combined and items that seemed vague or could be interpreted incorrectly were re-phrased.

Results

To start, factors were grouped together that were extremely similar such as the responsiveness which consisted of the response time, direct feedback, visual and audio time sync, reaction time and speed of feedback factors. The ease of comprehension was also eliminated because of its similarities to the understandability and the mental engagement was removed because of its similarity to immersion. The meaningfulness of info and result was combined with the value of the output in the Human grouping. Functionality and standardization were also removed as they seemed to be covered by the ease of use, ease of navigation and understandability. Desirability seemed interesting but since the idea of the survey is to assess the users' view of the compellingness of the interface after the fact, satisfaction, value of the output and willingness all seemed to cover the desirability.

The change in knowledge of the topic appeared too vague to assess and was similar to the idea that the information provided is not what makes an interface compelling, it's the way that information is provided (Harrison and Gough, 1996). Because of this idea, coupled with the idea that the display and application were the focus of this research, all topics regarding the information and hardware not associated with the display were removed including the age of the display, the quality of the information, the interesting dialogue and the display location. The age of the display was redundant with the graphics quality and display resolution as those were two key features that often already indicated age.

While the Game Engagement Questionnaire (Brockmyer et al, 2009) provided many questions to help measure engagement, the features of challenges and choices present as well as a story or narrative were too specific to games and could not be applied across many other applications and thus were removed from the item pool. The effort necessary also seemed less relevant to compellingness, as it is instead a feature of workload and thus was removed (Hart and Staveland, 1988).

The final factor eliminated was the matchup between the user expectations and the system. The system is designed with the user in mind so that when the user goes to interact with the system, they do not have to think too much or get confused by the system or interface, they can get right to performing the task (Gilbert, 2017). The ease of use, ease of navigation and understandability of the system as well as the satisfaction of the user all cover the matchup between the user expectations and the system.

The thinning of the question list contributes to DeVellis' (2012) step of the expert review of the item pool. With the additional review of each individual factor, underlying constructs could be identified and redundant questions were removed to allow for a shorter to be administered in Study 2. The final item pool of 28 items was used to create a question for each constructs. This process is documented in the following section.

Twenty-eight of the forty-seven items remain after the expert review conducted in this section. The remaining 28 items sorted into their groupings under the three factors can be found in **Figure 14**.

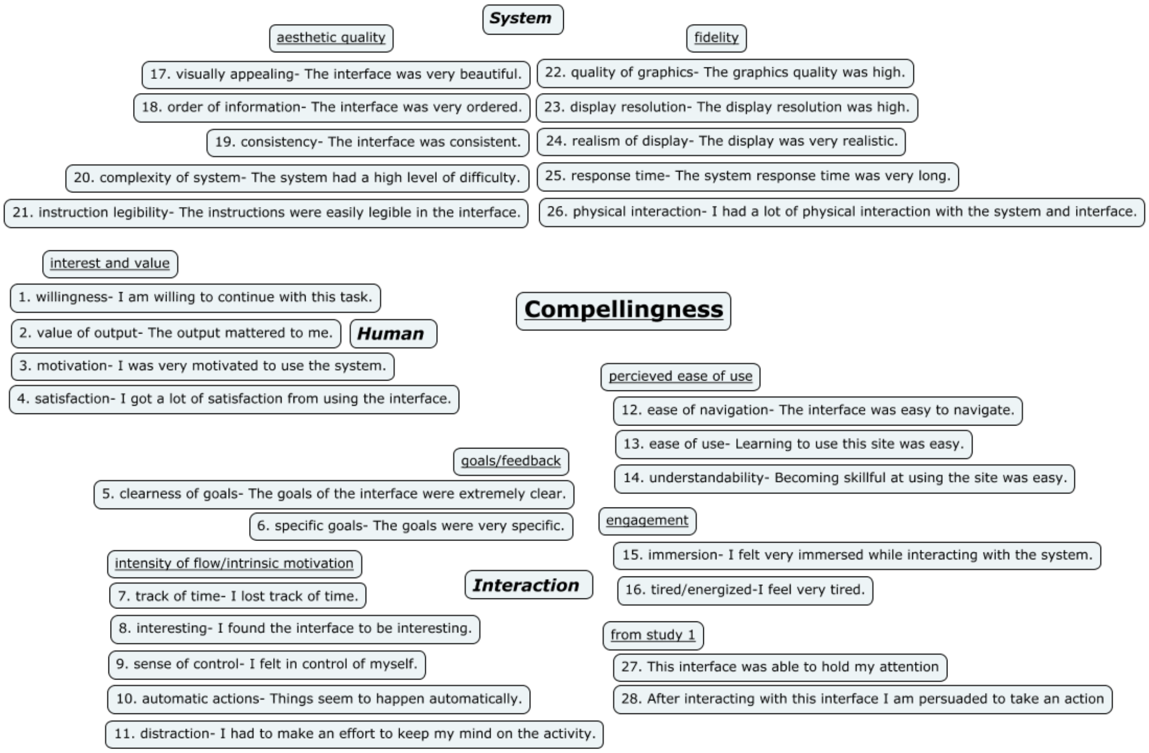

System
aesthetic quality
fidelity
17. visually appealing- The interface was very beautiful.
18. order of information- The interface was very ordered.
19. consistency- The interface was consistent.
20. complexity of system- The system had a high level of difficulty.
21. instruction legibility- The instructions were easily legible in the interface.
22. quality of graphics- The graphics quality was high.
23. display resolution- The display resolution was high.
24. realism of display- The display was very realistic.
25. response time- The system response time was very long.
26. physical interaction- I had a lot of physical interaction with the system and interface.
interest and value
1. willingness- I am willing to continue with this task.
2. value of output- The output mattered to me.
Human
3. motivation- I was very motivated to use the system.
4. satisfaction- I got a lot of satisfaction from using the interface.
Compellingness
percieved ease of use
12. ease of navigation- The interface was easy to navigate.
13. ease of use- Learning to use this site was easy.
14. understandability- Becoming skillful at using the site was easy.
goals/feedback
5. clearness of goals- The goals of the interface were extremely clear.
6. specific goals- The goals were very specific.
engagement
15. immersion- I felt very immersed while interacting with the system.
16. tired/energized-I feel very tired.
intensity of flow/intrinsic motivation
7. track of time- I lost track of time.
Interaction
8. interesting- I found the interface to be interesting.
9. sense of control- I felt in control of myself.
10. automatic actions- Things seem to happen automatically.
11. distraction- I had to make an effort to keep my mind on the activity.
from study 1
27. This interface was able to hold my attention
28. After interacting with this interface I am persuaded to take an action

***Figure 14**: Concept Map after expert review*

4.3 Question Development

Objective and method

In order to measure each of the 28 items within 8 groupings under the 3 factors, literature was referenced to find pre-designed survey questions for as many constructs as possible. For the constructs where no relevant measure was already established, a question was designed to assess the construct.

Similar surveys that obtain frequent use include the NASA TLX for workload (Hart and Staveland, 1988), simulator sickness (Kennedy, Lane, Berbaum & Lilenthal, 1993), trust (Jian, Bisantz & Drury, 2000) and the USE questionnaire (Lund, 2001). These questionnaires ranged from four options to twenty and each had a negative to positive scaling with similar or identical endpoints used for all questions. Because of this, a similar Likert scale was chosen with the scale ranging from Strongly Disagree to Strongly Agree. Only five points were selected in order to give the participant enough of a range to answer clearly, but not so much to not be able to distinguish between two points on a scale. Points were labeled on the scale that have been shown to be equally spaced.

Human Factor Questions

The “human” factor consists of the value the user has in the output, their motivation, their satisfaction, and the willingness of the user to participate and interact with the interface. These are completely to do with the user and will vary from user to user. The willingness is measured by asking the user “I am willing to continue with this task” with options ranging from strongly disagree to strongly agree in order to gauge how much they want to continue to participate. Similarly, motivation was asked using a question similar to “How motivated were you to use the system?" The value the user has in the output is measured by asking "How much did the output matter to you?" and satisfaction was measured by an outright question as well.

System Questions

The aesthetic quality grouping under the "system" factor includes visual appeal, order of information, consistency, complexity of the system, and instruction legibility. Schaik and Ling (2009) assessed five psychometric scales that can be used to measure the quality of human computer interactions in websites. These scales consisted of a 9-item flow scale developed by Davis and Widenbeck (2001) as a measure of intrinsic motivation, perceived ease of use, perceived usefulness and disorientation scales by Ahuja and Webster (2001), and a 7-item aesthetics scale developed by Tractinsky, Katz & Ikar (2000). The 7-item scale they chose to use to judge the appearance of the webpage developed by Tractinsky, Katz & Ikar in 2000 can be seen in **Table 6.**

Table* 6: Aesthetics Scale (Tractinsky, Katz & Ikar, 2000)*

Q#	Question
1	I judge the Web page to be Very complex 1 2 3 4 5 6 7 very simple
2	I judge the Web page to be Very illegible 1 2 3 4 5 6 7 very legible
3	I judge the Web page to be Very disordered 1 2 3 4 5 6 7 very ordered
4	I judge the Web page to be Very ugly 1 2 3 4 5 6 7 very beautiful
5	I judge the Web page to be Very meaningless 1 2 3 4 5 6 7 very meaningful
6	I judge the Web page to be Very incomprehensible 1 2 3 4 5 6 7 very comprehensible
7	I judge the Web page to be Very bad 1 2 3 4 5 6 7 very good

Six of the seven questions in the aesthetic quality scale addressed an item in the item pool and were chosen to be used in the compellingness survey. The first question of the aesthetic quality scale addressed the item “complexity of the system”, the second addressed the item “legibility of the system”, the third addressed the item “order of the information”, the fourth addressed how “visually appealing” the system was, the fifth addressed the “value of the output”, the sixth addressed the “comprehension of the system”, and seventh did not measure an item originally identified in this study and appeared too vague to address the compellingness of the web page.

The other grouping within the system factor is the fidelity of the system which can be defined as “the objective degree of exactness with which real-world experiences and effects are reproduced by a computing system” (McMahan et al, 2012, p. 1). This grouping includes the realism of the display, quality of graphics, physical interaction, response time of system, and display resolution. This grouping consists of objective constructs that can easily be measured on a 5-point Likert scale gauging the realism, quality, amount of interaction, and resolution.

Interaction Factor Questions

The “interaction” factor contains four groupings including the intrinsic motivation, engagement, perceived ease of use and goals/feedback. The intensity of flow is commonly measured using a 9-item flow scale developed by Davis and Widenbeck (2001) as a measure of intrinsic motivation. This scale is broken into two categories, involvement and control. The control category measures the factors of the sense of control the user feels, the interest and the ease of comprehension using the questions found in **Table *7*.** Questions were created for each of these groupings based on the Flow Scale (Davis and Widenbeck, 2001). Birnbaum et al. (1997) argues that effective and interesting dialogues are what make a UI more compelling. In fact, Birnbaum et al. (1997) interchanges the word interesting for the word compelling when describing how to make a compelling UI.

Table* 7*: Flow Scale developed by Davis and Widenbeck (2001)

Q #	Questions
1	I thought about other things
2	I had to make an effort to keep my mind on the activity
3	I was aware of distractions
4	I was aware of other problems
5	Time seemed to pass more quickly
6	I knew the right things to do
7	I felt like I received a lot of direct feedback
8	I felt in control of myself
9	I felt in harmony with the environment

Intrinsic motivation and engagement each contain many overlapping concepts. These concepts had a question measuring them in both the flow scale (Davis and Widenbeck, 2001) and in the Game Engagement Questionnaire **(**Brockmyer et al, 2009). One concept, for example, is “losing track of time. In the flow scale, question 5 asks “time seemed to pass more quickly”. Similarly, in the Game Engagement Questionnaire, question 1 asked “I lose track of time”. Both questions measured the ability of the user to be aware of the amount of time that had passed, but for the purpose of the compellingness survey, one of the two questions had to be chosen. The overlapping concepts that can be found in both constructs and that were also in the item pool included losing track of time, knowing what to do, distraction, and automatic actions which could be measured using either the flow survey questions #5, 6, 3 and 6 again from **Table 7** or questions #1, 15, 6 and 2 from the game engagement questionnaire found below in **Table 8**. The flow survey questions were selected for the items “knowing what to do” and “being aware of distractions” and the Game Engagement Questionnaire questions were chosen for “losing track of time” and “automatic actions”. Along with the overlapping questions, engagement also includes the items “tired/energized” and “immersion”. Questions 4, 5, 9, 13, 14, 16, 17 and 18 from **Table 8** each represented a way to gauge immersion, but were combined to form the question “I feel very immersed while interacting with this system.” To gauge how tired or energized the user was, question 11 was selected from the Game Engagement Questionnaire for the compellingness survey.

Table* 8*: *Game Engagement Questionnaire developed by Brockmyer et al (2009)*

Q #	Questions
1	I lose track of time
2	Things seem to happen automatically
3	I feel different
4	I feel scared
5	The game feels real
6	If someone talks to me, I don’t hear them
7	I get wound up
8	Time seems to kind of stand still or stop
9	I feel spaced out
10	I don’t answer when someone talks to me
11	I can’t tell that I’m getting tired
12	Playing seems automatic
13	My thoughts go fast
14	I lose track of where I am
15	I play without thinking about how to play
16	Playing makes me feel calm
17	I play longer than I meant to
18	I really get into the game
19	I feel like I just can’t stop playing

Perceived ease of use consists of the ease of use, ease of navigation, and understandability. Ahuja and Webster created a perceived ease of use scale in 2001 that can be found in **Table 9.** This scale provides measures of the perceived ease of use and covers the ease of use, ease of navigation and understandability. All three of these questions were used in the compellingness survey to represent the ease of use, ease of navigation, and understandability items.

Table* 9: Perceived Ease of Use Scale developed by Ahuja and Webster (2001)*

Q#	Questions
1	Learning to use this site was easy
2	Becoming skillful at using the site was easy
3	The site was easy to navigate

The final grouping in the interaction factor is the goals/feedback section which consists of having specific goals and the clearness of the goals. Educational books ask “How clear were the goals of this web site?” (p. 43) and “How clear were the tasks you did today?” (Johnson, Maddux and Ewing-Taylor, 2003, p. 43). Since this category consists of more subjective measures, asking the participants’ opinion of the clearness of the goals and how specific they were was the best route. Thus, the participants were asked the following questions with responses ranging from strongly disagree to strongly agree: “The goals of the interface were extremely clear” and “The goals were very specific”.

4.4 Final Question List

Due to the nature of the survey and its future uses, it is important that it is easy and quick to use. Each of the questions chosen in Chapter 4 Section 3 could have been asked in many different ways, but in order to encourage consistency, all were asked in a way in which the participant could respond along a 5-point Likert scale of strongly disagree, disagree, neutral, agree, and strongly disagree. The questions were also worded to sound consistent and avoid confusion. For example, questions that started with “I judge this web page to be…”

such as I judge the web page to be…" ranging from very beautiful to very ugly was changed to "The interface was very beautiful" ranging from strongly disagree to strongly agree. This change was made since the interface the participant would be interacting with may not be a web page. The final question list is presented in **Table 10**.

***Table* 10:** *Initial Question List for the Compellingness Survey*

Q#	Question	Item	Source
1	I am willing to continue with this task.	Willingness	New question developed
2	The output mattered to me.	Value of output	Tractinsky, Katz & Ikar, 2000
3	I was very motivated to use the system.	Motivation	New question developed
4	I got a lot of satisfaction from using the interface.	Satisfaction	New question developed
5	The goals of the interface were extremely clear.	Clearness of goals	Johnson, Maddux and Ewing-Taylor, 2003
6	The goals were very specific.	Specific goals	Johnson, Maddux and Ewing-Taylor, 2003
7	I lost track of time.	Track of time	Brockmyer et al, 2009
8	I found the interface to be interesting.	Interesting	Davis and Widenbeck, 2001
9	I felt in control of myself.	Sense of control	Davis and Widenbeck, 2001
10	Things seemed to happen automatically.	Automatic actions	Brockmyer et al, 2009
11	I had to make an effort to keep my mind on the activity.	Distraction	Davis and Widenbeck, 2001
12	The interface was easy to navigate.	Ease of navigation	Ahuja and Webster, 2001
13	Learning to use this site was easy.	Ease of use	Ahuja and Webster, 2001
14	Becoming skillful at using the site was easy.	Understandability	Ahuja and Webster, 2001
15	I felt very immersed while interacting with the system.	Immersion	Brockmyer et al, 2009
16	I feel very tired.	Tired/energized	Brockmyer et al, 2009
17	The interface was very beautiful.	Visually appealing	Tractinsky, Katz & Ikar, 2000
18	The interface was very ordered.	Order of information	Tractinsky, Katz & Ikar, 2000
19	The interface was consistent.	Consistency	Tonelli, 2012
20	The system had a high level of difficulty.	Complexity of system	Tractinsky, Katz & Ikar, 2000
21	The instructions were easily legible in the interface.	Instruction legibility	Tractinsky, Katz & Ikar, 2000
22	The graphics quality was high.	Quality of graphics	New question developed
23	The display resolution was high.	Display resolution	New question developed
24	The display was very realistic.	Realism of display	New question developed
25	The system response time was very long.	Response time	New question developed
26	I had a lot of physical interaction with the system and interface.	Physical interaction	New question developed
27	This interface was able to hold my attention.	Study 1	Study 1
28	After interacting with this interface I am persuaded to take an action.	Study 1	Study 1

CHAPTER 5

STUDY 2

5.1 Introduction

The aim of this chapter was to empirically determine the validity and reliability of the survey through Cronbach's Alpha and to investigate the variable relationships in the concept of compellingness through factor analysis. These statistical analyses methods were used statistically assess which questions should remain in a final draft of the survey. The result of Study 2 is an empirically-based compellingness survey instrument that can be used to assess the level of compellingness of an interface.

5.2 Methods

Research objectives

Based on an extensive literature review and expert judgment, 28 initial questions were formulated as contributors to overall compellingness, as described in Chapter 3-4. The objective of this step in the research was to refine a survey that measures compellingness down to its most parsimonious form. A factorial experiment was designed that manipulated factors to create different interfaces to test. These factors were manipulated to create interface conditions with different levels of compellingness. The resulting data set can be used to study the cohesiveness and reliability of the survey questions. This study executes the final three steps in DeVellis's (2012) survey development: administer items to sample of respondents, evaluate the items, adjust scale length. A factor analysis and Cronbach's Alpha were run on the data set to evaluate the items by grouping them into sub-factors with like constructs, and to adjust the scale length by eliminating questions that do not load on the factors or survey as a whole. These results were used to create a final survey that can be used to measure compellingness. Additionally, ANOVA results were analyzed to see if the manipulation of aspects of the display resulted in differing ratings of compellingness as scored by the final survey.

Participants

This study was approved by the Iowa State Institutional Review Board (IRB #17-052). Students, faculty and staff at a Midwest university as well as working professionals were invited to participate in an on-campus study via sources such as flyers, emails, and word of mouth. Participants were compensated with a chance to win one of 3 $50 gift cards. Sixty participants completed the study in its entirety.

Of those 60, 23 identified as female, 37 identified as male, 0 identified as other and 0 chose not to answer. The average age of participants was 35.6 with a standard deviation of 14.9. Participants' highest education received included 0 participants with some high school, 9 with a high school diploma, GED or similar, 12 with some college, 5 with an associate's degree, 21 with a bachelor's degree, 12 with a master's degree, 0 with a doctorate and 1 with other. Of the fields the participants work in or are studying, 6 are in Agriculture and Life Sciences, 11 are in Business, 1 are in Design, 18 are in Engineering, 2 are in Human Sciences, 7 are in Liberal Arts and Sciences, 0 are in Veterinary Medicine and 15 are in Other (mainly IT).

Participants were also asked how many hours per week that they spent their time on the computer. The majority of respondents, 41, said 25+, 6 said 21-25, 4 said 16-20, 3 said 11-15, 1 said 6-10 and 3 said less than 5 hours per week.

Tasks and scenarios

Participants completed two map-based tasks, each requiring them to navigate between four pre-loaded destinations. These included a “home” location, a “friend’s house” location, an “accident” location and a final destination location that was either “restaurant” or “movie theater.” They were then read the scenario about how they needed to pick up gas, then their friend, avoid the accident, and get to their final destination as fast as possible with as few left turns as possible. The map locations consisted of cities in Nevada and Tennessee to avoid any location familiarity for the Midwestern participants.

The locations were chosen such that stopping for gas would make the route longer and so would picking up their friend. The accident was chosen along the most likely route the participant would choose which required them to make additional turns and decisions. If the participant followed all of the instructions and met all of the requirements, their route would have a minimum of 10 turns.

The constraint that they needed to make as few left turns as possible was added to better immerse the participant in the task. Instead of being able to use the optimal route that Google Map provides (in some conditions), participants had to consider each and every turn that they made to determine whether it was a left or a right turn. If it was a left turn, they then problem solved to figure out how to avoid it. They were also told that they needed to get there as fast as possible so that participants did not take a long, scenic route with no left turns. In both cases, participants were told that each of the requirements weighed equally on their scoring so they needed to find a balance between the number of left turns and the distance travelled. This required more planning and thought on the participants’ part.

Independent variables

The experiment had three independent variables, each with two levels (low, high): motivation, display realism, and interactivity. Each of these three independent variables were selected from one of the three hypothesized factors of compellingness, one from each. The independent variables are summarized in **Table *11***.

Table* 11*:* *Study 2 Independent Variables

Factor	Variable	Low	High
Human	Motivation	Chances of winning a gift card is not tied to performance	Higher performance results in higher chance to win gift card
System	Display realism	Map view	Satellite view
Interaction	Interactivity	Route guidance allowed, participants choose where to deviate from the route	No route guidance allowed, participant makes all turn-by-turn decisions

Motivation

The human factor consisted of the following items: willingness, value of output, motivation and satisfaction. Motivation was chosen as the independent variable to manipulate since the willingness of the users would be expected to be related to the motivation, and extrinsic motivation can be manipulated. The value of the output and the satisfaction would be hard to control for participant groups. Intrinsic motivation of participants is often difficult to manipulate and even more difficult to measure (Wiersma, 1992). Because of this, an external monetary motivation was chosen to provide a greater amount of motivation to college participants (Ariely, Brach & Meier, 2007).

In the low motivation condition, participants were told that their performance on the task would determine how many entries into the gift card drawing they would get. If they were in the top 10% of participants, they would receive ten entries, if they were in the 80th to 90th percentiles, they would receive nine entries and so on. The bottom 10% of participants would only receive one entry. This competition was to encourage a higher motivation to perform well and was expected to result in a higher level of compellingness.

In the low motivation condition, participants were told that numbers were randomly selected to receive one to ten entries into the gift card drawing and their number was selected to only receive one entry. In this low motivation condition, they received only one entry and their number of entries was not tied to their performance. They were also led to believe that other participants got more gift card entries than they did. Therefore, it was expected that the participants would try less and be less motivated.

Display realism

The System factor was manipulated through the display realism. The display realism was chosen for manipulation sinceit would not affect the task, but could cause a noticeable difference in the display for the participant. Participants were either presented a map in "map" view or "satellite" view of the city where they were to determine the route. The two views can be seen in **Figure 15**. In the low display realism condition, the background was light gray and only roads, water and parks were illuminated in a color. In the map view, it was much easier for participants to see all of the roads and turns on the map. In the high display fidelity condition, the map was in "satellite" view where the map background was satellite imagery of the location. The satellite view presented higher resolution imagery of the landscape.

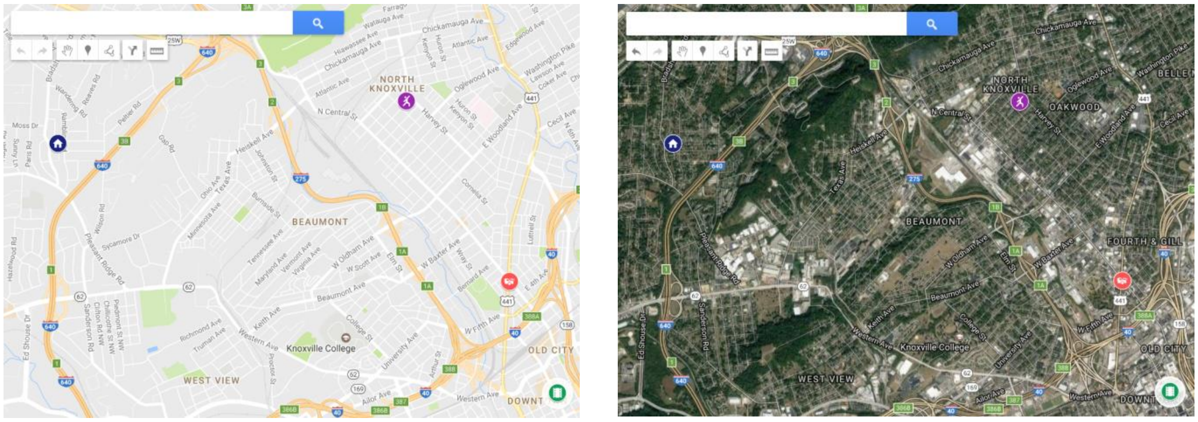


Figure 15: *(left) Map View of Task- Low Display Realism; (right) Satellite View of Task- High Display Realism*

Interactivity

The third factor consisted of different features of the interaction that takes place between the user and the interface. Interactivity is in part determined by levels of automation used by the system (Sheridan & Verplank, 1978). Thus the factor was manipulated by providvind the user with different levels of automation assistance in the navigation planning task. Participants were asked to either complete the task using navigational assistance or no navigational assistance. In the low interactivity condition shown in **Figure 16**, participants were required to use route guidance where a blue “optimal route” was displayed on the map that showed the fastest way to get to their final destination. This blue route was considered a level 4 in the Levels of Automation (Parasuraman, Sheridan & Wickens, 2000) where the computer “suggests one alternative”. This route, however, led them right through the accident and had left turns so the participant was asked to indicate what route they would take and where they would deviate from the blue route. This was the low interactivity condition since participants were provided a route and were asked to make just a few decisions about where they wanted to change the path. They had to interact with the interface only a few times in those locations where they wanted to deviate from the path provided.

In the high interactivity condition shown in **Figure 16**, participants were not allowed to use route guidance and were instead forced to make every turn-by-turn decision themselves. This was considered a level 1 on the Levels of Automation (Parasuraman, Sheridan & Wickens, 2000) where the computer "offered no assistance and the human must take all decisions and actions". Participants were expected to have a higher amount of interaction with the interface in order to make every decision at every intersection.

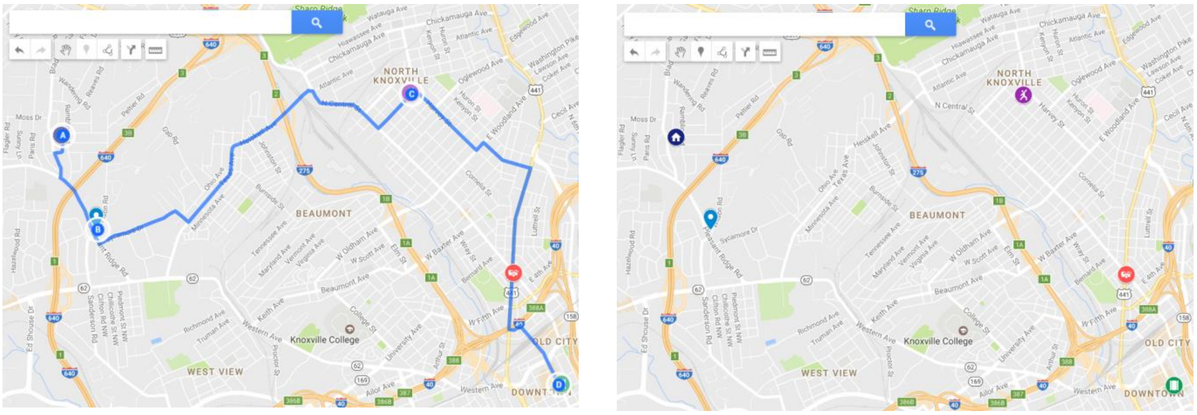


***Figure 16**: (left) Low Interactivity Condition; (right) High Interactivity Condition*

Dependent variables

The dependent variables measured were the responses to the compellingness survey developed in **Table 10**, the participants' responses to NASA TLX questions that measure workload, completion time for each of the two tasks, and demographics including how often participants spend on a computer in a week. Each of these variables were measured using an online Qualtrics survey that participants took on the same IPad that they performed the task on.

Experimental design

This is a 2 (motivation: low, high) x 2 (display fidelity: low, high) x 2 (interactivity: low, high) fractional factorial, mixed design. Eight trails were created using a high and low value for each of the three measures of motivation, interaction and display realism. Participants were grouped into one of four groups (A-D), each group conducting the two tasks indicated in **Table *12*.**

Table* 12: Distribution of Participants in Study 2 Experimental Design*

Motivation: Low		
	Realism: Low	Realism: High
Interaction: Low	D	B
Interaction: High	B	D

Motivation: High		
	Realism: Low	Realism: High
Interaction: Low	C	A
Interaction: High	A	C

The first 30 participants were grouped into group A and completed one scenario in each of two experimental conditions. These conditions counterbalanced the order participants saw the variable manipulations and also the locations of the maps. Participants 31-60 were grouped into group B and completed one scenario in each of two experimental conditions. Scenario order was counterbalanced between participants, as well as the trial order of the two conditions.

Procedure

The participants were asked to come in for a one hour time slot and completed all tasks on a Generation 2 IPad. Their time spent was separated into two parts, the first 20 minutes consisted of signing the paper consent form, being walked through a tutorial and example task and completing a NASA TLX training and survey. The tutorial consisted of the principle investigator explaining features of the Google Maps program MyMaps to the participant, and asking them to interact with it. The script for the tutorial and the rest of the participant guide can be found in Appendix B. The features of the program highlighted were how to open and close the legend, how to create locations, how to get driving directions, how to hide layers, how to add lines, how to edit lines and how to plan a route along roads with as few left turns as possible.

After the tutorial, participants were read a short training on the NASA TLX survey and then took a practice NASA TLX survey on how much workload the training was. After the survey, participants were read one of two prompts to manipulate their motivation. One prompt explained to participants that they were competing for their number of entries into a drawing for one of three $50 gift cards and the other prompt told them that participants were randomly selected to receive 1-10 entries into the gift card drawing and they were selected to only receive one.

The last 40 minutes consisted of being read the prompt for their first scenario, completing their first scenario, the compellingness survey, a NASA TLX survey, being read the prompt for their second scenario, completing the second scenario, the compellingness survey, a NASA TLX survey, and finally, a demographics survey.

Data analysis plan

Four statistical methods were used to test the validity and reliability of a questionnaire measuring compellingness: sampling adequacy, exploratory factor analysis, Cronbach’s Alpha, and Confirmatory Factor Analysis (Field, 2009; Bornstedt, 1977; Rattray & Jones, 2007). Once the compellingness survey instrument is finalized, an analysis of the 2 x 2 x 2 interface experiment data was conducted. Since the compellingness was hypothesized to be the result of three factors (human, system, and interaction), the data analysis was run on each of the factors as well as the total survey. For each factor, analysis was run to identify sub-factors and questions that are candidates for elimination. The data analysis will be presented in a three-step process of initial analysis and results, elimination decisions, and a final analysis and results of the reduced question list for the factor.

Sampling adequacy

A reliable factor analysis requires two things: that the sample size be large and that the variables are measured at an interval level (Field, 2009). In order to determine if the sample size is large enough, the Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) was used (Field, 2009). If the KMO is close to zero, it will be difficult to extract factors but the closer it is to one, factors can likely be extracted. All questions were measured on a Likert scale which should be interpreted as an interval scale (Rattray & Jones, 2007).

For the Kaiser-Meyer-Olkin measure of sampling adequacy, Kaiser (1974) put the following values on the results:

- 0.00 to 0.49 unacceptable.
- 0.50 to 0.59 miserable.
- 0.60 to 0.69 mediocre.
- 0.70 to 0.79 middling.
- 0.80 to 0.89 meritorious.
- 0.90 to 1.00 marvelous.

In addition to the KMO, Bartlett’s test (Snedecor and Cochran, 1983) is used to test if the samples have equal variances. It is also sensitive to departures from normality and can identify if the samples come from non-normal distributions (Nist, 2017). KMO and Bartlett’s Test were reported for each of the three factors as well as the entire survey.

Exploratory factor analysis

Exploratory factor analysis was the first step used in order to achieve a multi-dimensional measure that holds up under cross-validation. Factor analysis allows the testing of construct validity of a questionnaire, meaning that if the questionnaire is considered construct valid, all questions together represent the underlying construct well (Bornstedt, 1977; Rattray & Jones, 2007). Exploratory factor analysis is meant to detect the patterns and constructs (or factors) that underlie a question set based on the correlation between the questions (Field, 2009; Tabachnik & Fidell, 2001; Rietveld & Van Hout, 1993). Factors that explain the most variance represent the underlying constructs (Hof, 2012).

Factor extraction produces a correlation matrix with eigenvectors that are a linear representation of the variance that variables share (Field, 2009; Tabachnik & Fidell, 2001; Rietveld & Van Hout, 1993). In order to decide how many factors to keep there are three possible data analysis: the default of statistical packages keeps any eigenvalue over one, the screeplot can be examined and all factors with values at the break point or below are eliminated, or a likelihood factor analysis in R can be run. In this case, the screeplot will be examined, any factor with an eigenvalue over one will be considered. When all factors with eigenvalues over one are kept, it may lead to too many factors being retained (Costello & Osborn, 2005), therefore the factor groupings with the most logical sense will be selected. Additionally, the factor analysis will be re-run with chosen questions removed to confirm that the correct number of factors was selected.

It may be confusing to think of a factor analysis on a factor but note that the factors being identified through the factor analysis are actually second level factors (or sub-factors) of the three proposed factors. In this work the term “factors” always refers to the three top level factors (human, system, interaction), and "sub-factors" refers to any groupings of questions under each of the three factors. When there are many extracted factors, sometimes the same question loads on multiple factors, and it becomes difficult to determine the construct the question represent. In factor analysis, the factors are rotated towards some constructs and away from others. Rotation is a mathematical process where the axes of factors is rotated within the multidimensional variable space to fit the actual data points better and to make the factors more easily interpretable. There are two different types of rotation, orthogonal which is used when factors are assumed to be independent, and oblique when the factors are assumed to correlate (Field, 2009; Tabachnik & Fidell, 2001; Rietveld & Van Hout, 1993). Since it can be assumed that all items in the questionnaire measure compellingness an oblique rotation is expected to be appropriate and the factor analysis was run with an oblique rotation. To be safe, an orthogonal and non-rotated factor analysis were also run to visualize any differences between the rotations.

After running a factor analysis, a table of factor loadings is given. Factor loadings are the correlations between a question and a factor and can range from -1 to 1 however the sign does not matter. Often, factor loadings are considered high if they are greater than 0.6 and moderately high if they are greater than 0.3. Any loadings lower than 0.3 show that the questions doesn't load on that factor and will likely either load on a different factor or is not related (Kline, 2014).The questions that do load on the factor are grouped together. If a question loads on two factors it can be grouped into the factor on which it loads higher.

Cronbach’s Alpha

Cronbach’s Alpha will be used to remove unnecessary questions. Cronbach’s Alpha is used to measure the internal consistency and reliability of a survey. The reason it was chosen as an analysis tool is that we can use it to see if all of the questions in the survey reliably measure the same variable of compellingness. It will be used to get an overall alpha value of the entire survey to get a big picture of if all the questions reliably measure compellingness, but it will also be used on each of the principle components defined by the factor analysis. Both of these analyses will identify questions that do not positively contribute to the reliability of the questionnaire and are candidates for removal.

The output of running Cronbach’s Alpha produces a correlation matrix that shows how each variable is related to each other. The output also includes an alpha value for the entire set of questions as well as an alpha value for each of the individual questions. The alpha value next to each of the individual questions represents what the entire set’s alpha value would be if that question were to be eliminated. The closer an alpha value is to one, the closer related the questions are so if an individual question’s alpha value is greater than the alpha value of the entire set, that question should be considered for removal since it is bringing down the correlation within the entire set.

Confirmatory Factor Analysis

A Confirmatory Factor Analysis was run to directly test the hypothesized model which exploratory factor analysis does not have the ability to do (Harrington, 2009). A Confirmatory Factor Analysis compares a hypothesized model to the data to see how well the model describes the data. Resultant model fit statistics diagnose how good of a fit the specified model is.

For Confirmatory Factor Analysis, sample sizes between 25 and 400 can be considered small and the percentage of proper solutions, the accuracy of parameter estimates, the appropriateness of the X^2 test statistic, and the sampling variability in parameter estimates were all influenced favorably by larger sample sizes (Boomsma & Hoogland, 2001; Gerbing & Anderson, 1993). It is recommended that the sample size be at least 100 but 200 would be more desirable (Boomsma, 1982). Convergence toward proper solutions and accuracy of estimates is also positively influenced by increasing *N*, increasing the number of times each variable is measured, and having higher factor loadings (Velicer & Fava, 1998; Marsh, Hau, Balla & Grayson, 1998). With this study only running 60 participants, it was not likely to find strong results for any proposed model. However it can be informative to conduct a preliminary confirmatory factor analysis at this early stage to provide useful guidance for future work.

Multiple model fit statistics were analyzed to determine the goodness of a fit twoproposed survey models:Root Mean Squared Error of Approximation (RMSEA), Comparative Fit Index (CFI), Tuker-Lewis Index (TLI), Akaike’s Information Criterion (AIC), Bayesian Information Criterion (BIC), and Standardized Root Mean Square Residual (SRMR). **Table 13** summarizes these six model fit statistics, whether or not they are absolute statistics that can be analyzed or comparative statistics that require multiple models to compare the values, and what the success criteria are for each.

***Table 13**: Confirmatory Factor Analysis Model Fit Statistics*

Metric	**Statistic**	**Absolute or Comparative?**	**Criteria**
Chi Square Goodness of Fit	X^2	Absolute	$p < .05$
Root Mean Squared Error of Approximation	RMSEA	Absolute	0-0.01 excellent 0.01-0.05 good 0.05-0.08 mediocre 0.08-0.10 poor
Comparative Fit Index	CFI	Absolute	CFI > 0.9 satisfactory
Tuker-Lewis Index	TLI	Absolute	TLI > 0.9 satisfactory
Akaike's Information Criterion	AIC	Comparative	Lower indicates better fit
Bayesian Information Criterion	BIC	Comparative	Lower indicates better fit
Standardized Root Mean Square Residual	SRMR	Absolute	0 perfect fit SRMR < 0.08 good fit

RMSEA is an absolute measure of fit based on the non-centrality parameter. A lower value of the RMSEA is more desired. Commonly used cutoffs include 0.01 as excellent, 0.05 as good, 0.08 as mediocre, and 0.10 as poor (MacCallum, Browne and Sugawara, 1996).

The CFI and TLI are also based on the non-centrality measure but are incremental measures between zero and one. They are often not reported or computed if the RMSEA of the null model is less than 0.158 because one will obtain too small a value of the CFI (Kenny, 2014). A CFI and TLI value greater than 0.9 is considered a satisfactory fit (Awang, 2012).

The AIC and BIC are both comparative measures of fit and are only meaningful when estimating two different models. Lower values indicate a better fit so the model with the lowest AIC or BIC is the best fitting model however there are no cutoff values for the AIC or BIC of an individual model. The SRMR is an absolute measure of fit and is the standardized difference between the predicted correlation and the observed correlation. Because it is an absolute measure of fit, zero indicates perfect fit and a value less than 0.08 is generally considered a good fit (Hu & Bentler, 1999).

Analysis of experimental manipulations

To highlight whether or not the manipulations made in the study were strong enough to make a noticeable and significant difference in participants' responses, t-tests were run on each of the three independent variables for the questions that corresponded to the independent variable. The purpose of manipulating three independent variables was to attempt to exercise the survey to its full extent to get participant responses across the full range of scores. However, the data can also be analyzed to assess whether the different experimental manipulations resulted in different levels of compellingness, workload, and performance (time). Potential variables of completion time, gender of participant and task order were assessed to see if they had any effect on the results. Additionally, NASA TLX response scores were assessed to see if there was any difference in workload required for each of the conditions.

A repeated measure analysis of variance (ANOVA) was used for the normally distributed data. Since only half (four) of the combinations of the three independent variables were conducted, it is not possible to do a complete factorial 2x2x2 ANOVA. The dependent variables were thus analyzed using a one-way ANOVA with four levels (the four combinations of the independent variables that were run). Results are reported as significant for alpha <.05, and marginally significant for alpha <.10 (Gelman, 2013). The abbreviation "ns" is used to denote non-significant results. Tukey post-hoc tests determined significance between pairwise comparisons of normally distributed data groups. Results will present letters above each group; the letters indicate significant (at the .05 level) pairwise differences between groups when they do not share a letter. Cohen's d calculated an effect size and provides a standard measure that expresses the mean difference between two groups in standard deviation units. Cohen's d results are reported as small effects for .20 < d <.50, medium effects for .50 < d <.80, and large effects for d >.80.

Limitations and assumptions

A limitation of this study was the limited types of interfaces this survey was tested on. There is a very large array of devices, software and interfaces that this survey is developed to be used on however this study only assessed one program on a single type of device conducting a single task. Future work should look at a wider range of application of the survey. Additionally, sixty participants were run, which is adequate for an exploratory factor analysis but is considered a low number for confirmatory factor analysis and has been shown negatively influence many model fit statistics (Boomsma & Hoogland, 2001; Gerbing & Anderson, 1993).

Testing environment

The evaluation was conducted in both a private conference room and a private laboratory. Up to two participants were able to participate at the same time and two iPad Generation 2 models were used to conduct the evaluation. Participants were told to interact with the IPad using only the stylus provided to them on the back of their pens. All maps and surveys were conducted on the IPad in a Google Chrome browser. The map-based tasks were conducted in a Google Maps program called MyMaps and the surveys were conducted in Qualtrics.

5.3 Results

The results are split into five sections, the first three containing the analysis on each of the three factors (human, system and interaction), the fourth containing the analysis of the whole survey, and the final section reporting the results of the manipulations of the independent variables. Each of the first three sections will be presented in a three-step process of initial results and analysis, elimination decisions, and finally a follow-up analysis of the results of the remaining items. This will be followed by the fourth section which contains a review of the entire resultant survey after eliminations.

Human predicted factor

The “Human” predicted factor was one of three initial predicted factors from the card sorting exercise in Chapter 4.1. This factor consisted of questions 1-4 that can be found in **Table 10**.

Sampling adequacy

The Kaiser-Meyer-Olkin measure of sampling adequacy for the predicted human factor had a value of 0.764. Using the results values presented by Kaiser (1974), the resulting KMO of 0.764 is middling and can be considered high enough that factor analysis can be run on this data. The Bartlett’s Test of Sphericity, which tests the overall significance of all the correlations within the correlation matrix, was significant ($\chi^2(6) = 154.253$, $p < .05$) and thus the assumption of equal variances is valid and indicating that it was appropriate to use the factor analytic model on this set of data.

Full Cronbach's Alpha

Cronbach's Alpha for the entire set of questions in the Human factor was 0.800 The Alpha value for each of the four questions can be found in **Table 14.**

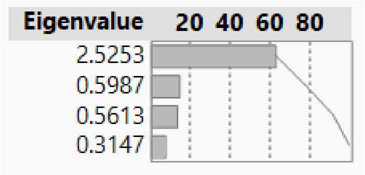
Table 14*: Output of Cronbach's Alpha on Full Human factor questions*

Question Number	Alpha Value
Q1	0.784
Q2	0.765
Q3	0.694
Q4	0.751

From the Cronbach's Alpha it can be seen that none of the questions have alpha values higher than that the overall alpha value of 0.800, therefore, none of the four questions should be considered for removal.

Full exploratory factor analysis

First, a plot of the eigenvalues was created during the factor analysis. It is typical to say that the number of eigenvalues whose value is greater than one is equivalent to the number of factors that make up the list of questions. The eigenvalues for the Human factor can be found below in **Figure 17**.



Eigenvalue	20 40 60 80
2.5253	
0.5987	
0.5613	
0.3147	

Figure 17: *Eigenvalues of Full Human Factor*

From the eigenvalues in **Figure 17**, it can be seen that one factor would likely describe the data. However, eigenvalues are not the only way to determine how many factors the questions break into so a look at the variance explained by each factor and the factor loadings were also included in the analysis. The solution for one factor was examined. The results of the principle components factor analysis, including the factor loadings, can be seen in **Table 16**.

Table 15: *Factor Loadings for 1 Factor in the Full Human Factor*

Questions	**Factor Loadings on Interest and Value sub-factor**
I am willing to continue with this task.	0.73
The output mattered to me.	0.77
I was very motivated to use the system.	0.87
I got a lot of satisfaction from using the interface.	0.80

In this case, since there is only one expected factor, there was no need to rotate how the questions loaded on the factors so the un-rotated factor loadings were used. All four questions load on the single proposed factor much higher than the 0.6 “moderately high” cutoff and thus are well described by that factor. Additionally, a large percentage (63.13%) of the variance in responses can be described using just the one factor. As a result, one sub-factor was chosen and no questions were eliminated for the proposed Human factor. The start of the factor tree for compellingness can be seen in **Figure 18**

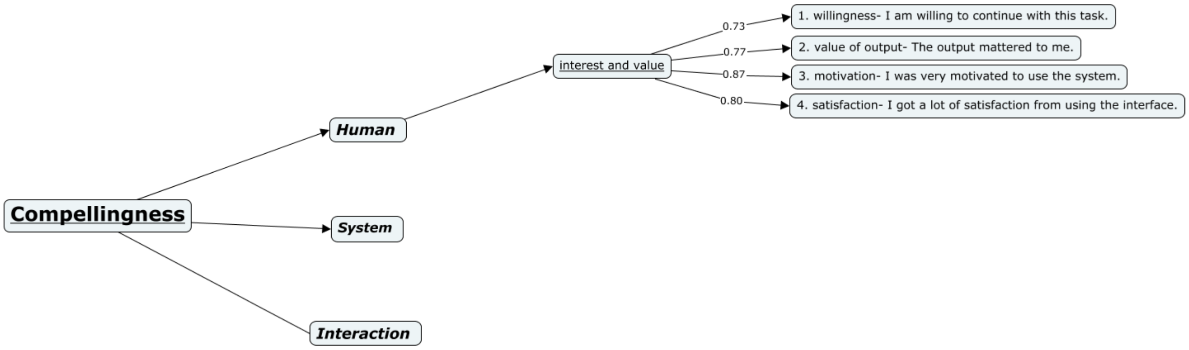

Compellingness
Human
System
Interaction
interest and value
0.73
0.77
0.87
0.80
1. willingness- I am willing to continue with this task.
2. value of output- The output mattered to me.
3. motivation- I was very motivated to use the system.
4. satisfaction- I got a lot of satisfaction from using the interface.

***Figure 18**: Factor Tree for Compellingness including H*

System predicted factor

The “System” predicted factor was the second of three initial predicted factors from the card sorting exercise in Chapter 4.1. This factor consisted of questions 17-26 that can be found in **Table 10**.

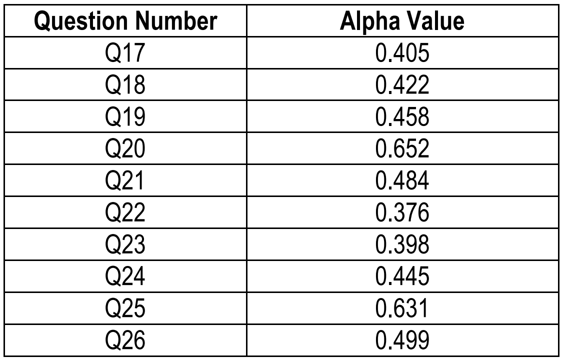
Sampling adequacy

The Kaiser-Meyer-Olkin measure of sampling adequacy for the predicted system factor had a value of 0.767. The resulting KMO of 0.767 is middling Kaiser (1974) and can be considered high enough that factor analysis can be run on this data. The Bartlett’s Test of Sphericity was significant ($\chi^2(45) = 370.430$, $p < .05$) and thus the assumption of equal variances is valid and indicated that it was appropriate to use the factor analytic model on this set of data.

Full Cronbach’s Alpha

From the Cronbach's Alpha, the overall alpha value for the full system factor is mediocre at 0.517. Two of the questions from **Table 16**had higher alpha values: Q20 at 0.652 and Q25 at 0.631. Each of these alpha values means that if that question were to be eliminated, the resultant alpha value would increase to the corresponding number. An alpha value was not given for the case of eliminating both questions, however, a second Cronbach's Alpha will be run after questions are eliminated. As a result of this analysis, Q20 and Q25 were strongly considered for elimination.

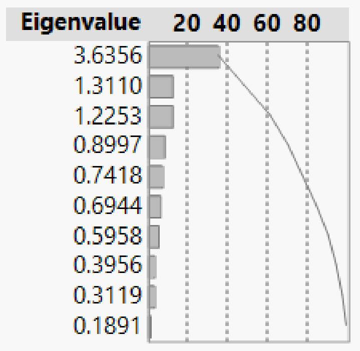
***Table 16**: Output of Cronbach's Alpha on Full System Factor*



Question Number	Alpha Value
Q17	0.405
Q18	0.422
Q19	0.458
Q20	0.652
Q21	0.484
Q22	0.376
Q23	0.398
Q24	0.445
Q25	0.631
Q26	0.499

Full exploratory factor analysis

Exploratory Factor Analysis was used on the proposed System factor to see if there were any sub-factors that contributed to the factor. The KMO was high enough to confidently say that the data is fit for factor analysis. First, a plot of the eigenvalues was created during the factor analysis and can be found in **Figure 19**.



Eigenvalue
3.6356
1.3110
1.2253
0.8997
0.7418
0.6944
0.5958
0.3956
0.3119
0.1891

***Figure 19**: Eigenvalues of Full System Factor*

The eigenvalues in **Figure 19** suggest that up to three factors can be used to group the questions in the System factor. However, eigenvalues are not the only way to determine how many factors the questions break into, so a look at the variance explained by each factor, the factor loadings, and which questions were grouped together were also included. Solutions for one, two and three factors were each examined using Promax and Quartimin rotations of the factor loading matrix. The two factor solution, which explained 56.63% of the variance and can be found in **Table 17**, was preferred because of: (a) its previous theoretical support from the card sorting in chapter 4.1; (b) the 'leveling off' of eigenvalues on the scree plot after two factors; and (c) the insufficient number of primary loadings and difficulty of interpreting the one or three factor solutions. Note that **Table 17** only contains the factor loadings that are above 0.35 since factor loadings below that value mean that the question does not load very much on the factor. There was little difference between the two factor Promax and Quartimin solutions, thus both solutions were examined in subsequent analyses before deciding to use a Quartimin rotation for the final solution.

***Table 17:** Factor Loadings (>.35) for 2 Factors in the Full System Factor. Factor loadings <.35 are suppressed.*

Q#	Question Wording	Factor Loadings on Aesthetic Quality	Factor Loadings on Fidelity sub-factor

		sub-factor	
17	The interface was very beautiful.	0.40	0.51
18	The interface was very ordered.	0.73	
19	The interface was consistent.	0.83	
20	The system had a high level of difficulty.	-0.81	
21	The instructions were easily legible in the interface.	0.40	
22	The graphics quality was high.		0.79
23	The display resolution was high.		0.84
24	The display was very realistic.		0.62
25	The system response time was very long.	-0.51	
26	I had a lot of physical interaction with the system and interface.		

From the card sorting method in Chapter 4.1, questions 17-21 were originally identified in a grouping called "aesthetic quality" and questions 22-26 were originally in a grouping called "fidelity." The two factor groupings mirror that grouping almost perfectly except that question 25 switched from fidelity to aesthetic quality and question 26 did not load on either factor. Additionally, question 17 loaded on both factor one and two but was chosen to be grouped into factor one, even though it loaded higher on factor two in this case.

Two factors described a good portion (56.63%) of the variance in responses as well. As a result, two sub-factors were chosen and question 26 was considered for elimination for the proposed System factor. The first sub-factor, consisting of questions 17-21 and 25 was named aesthetic quality to match the naming of the grouping from the card sorting in Chapter 4.1. The second sub-factor consisted of questions 22-24 and 26 and was named fidelity to match the card sorting title.

Elimination decisions

From the Cronbach's Alpha analysis, two questions were identified that would raise the overall alpha value a large amount. Question 20 (The system had a high level of difficulty) was identified that its elimination would raise the alpha value by 0.135, and question 25 (The system response time was very long) was identified to raise the alpha value by 0.115 if it was eliminated. Both of these are large increases in the alpha value and therefore both questions were chosen to be eliminated. Question 20 loaded surprisingly high on the first factor, however it increased the alpha value too much to be kept. Question 25 loaded relatively low on both factors which confirmed the decision to eliminate it.

From the full exploratory factor analysis, 2 sub-factors were chosen to most accurately describe the breakout of questions in the System factor. One question was found to not fit with the two chosen sub-factors and thus must be considered for elimination. Question 26 (I had a lot of physical interaction with the system and interface) loaded low on both factors and would barely decrease the Cronbach's Alpha value (0.017) if it were to be eliminated and therefore was eliminated.

Reduced Cronbach's Alpha

After eliminating questions 20, 25 and 26, Cronbach's Alpha was conducted on the remaining questions to get a view of how well the new set of questions relate to each other. This analysis can be found in **Table 18**.

Table 18: *Output of Cronbach's Alpha on Reduced System Factor*

Question Number	Alpha Value
Q17	0.747
Q18	0.744
Q19	0.752
Q21	0.811
Q22	0.731
Q23	0.744
Q24	0.794

The alpha value of the entire set originally was 0.517 before eliminating questions. After elimination, it became 0.789. Analysis of this second Cronbach's Alpha shows two additional questions would increase the alpha value a small amount. Question 21 (The instructions were easily legible in the interface) would increase the alpha value by 0.022 and question 24 (The display was very realistic) would increase the alpha value by 0.005. Both of these questions would increase the alpha value, but that increase would be quite small and therefore both questions were kept.

Reduced exploratory factor analysis

After eliminating questions 20, 25 and 26, an exploratory factor analysis was conducted on the remaining questions to see if these new factors would be identified as the only two factors contributing to the data. The eigenvalues for this analysis can be found in **Figure 20**.

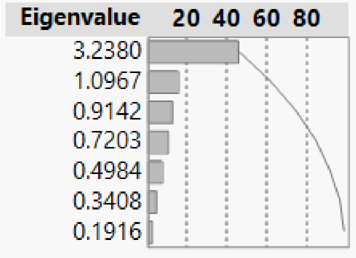


Figure 20*: Eigenvalues of Reduced System Factor*

These eigenvalues identify two factors being the ideal number of factors for this group of questions. The factor loadings can be seen in **Table 19**.

Table 19*: Factor Loadings for 2 Factors in the Reduced System Factor. Factor loadings <.35 are suppressed.*

Q#	Question Wording	Factor Loadings on Fidelity sub-factor	Factor Loadings on Aesthetic Quality sub-factor
17	The interface was very beautiful.	0.53	0.38
18	The interface was very ordered.		0.72

19	The interface was consistent.		0.77
21	The instructions were easily legible in the interface.		0.69
22	The graphics quality was high.	0.87	
23	The display resolution was high.	0.92	
24	The display was very realistic.	0.57	

The factors have switched sides, but the same questions still remain in each of the two factors and each question has similar factor loadings to the previous factor analysis. The factor loadings for questions 22 and 23 both increased. This confirms the two sub-factor selection choice. The resultant sub-factors and their loadings, after eliminating the three questions identified through Cronbach's Alpha and the Exploratory Factor Analysis can be seen in the factor tree for compellingness in **Figure 21**.

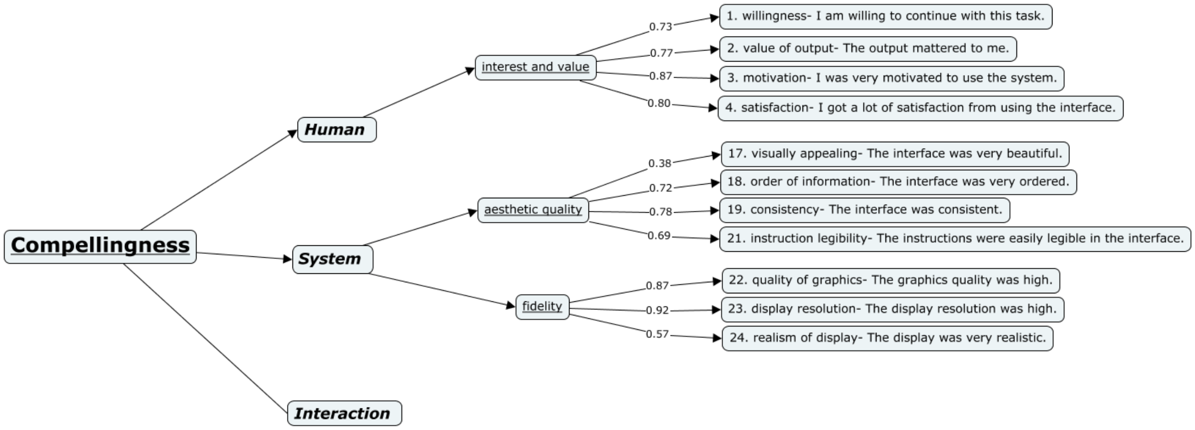

Compellingness
Human
System
Interaction
interest and value
aesthetic quality
fidelity
0.73
0.77
0.87
0.80
1. willingness- I am willing to continue with this task.
2. value of output- The output mattered to me.
3. motivation- I was very motivated to use the system.
4. satisfaction- I got a lot of satisfaction from using the interface.
0.38
0.72
0.78
0.69
17. visually appealing- The interface was very beautiful.
18. order of information- The interface was very ordered.
19. consistency- The interface was consistent.
21. instruction legibility- The instructions were easily legible in the interface.
0.87
0.92
0.57
22. quality of graphics- The graphics quality was high.
23. display resolution- The display resolution was high.
24. realism of display- The display was very realistic.

Figure 21*: Factor Tree for Compellingness including H and S*

Interaction predicted factor

The "Interaction" predicted factor was the final of three initial predicted factors from the card sorting exercise in Chapter 4.1. This factor consisted of questions 5-16 and 27-28 that can be found in **Table 10**.

<u>Sampling adequacy</u>

The Kaiser-Meyer-Olkin measure of sampling adequacy for the predicted interaction factor had a value of 0.799. Using the results values presented by Kaiser (1974), the resulting KMO of 0.799 is middling and can be considered high enough that factor analysis can be run on this data. The Bartlett's Test of Sphericity, which tests the overall significance of all the correlations within the correlation matrix, was significant ($\chi^2(91) = 633.92$, $p < .05$) and thus the assumption of equal variances is valid and indicating that it was appropriate to use the factor analytic model on this set of data.

Full Cronbach's Alpha

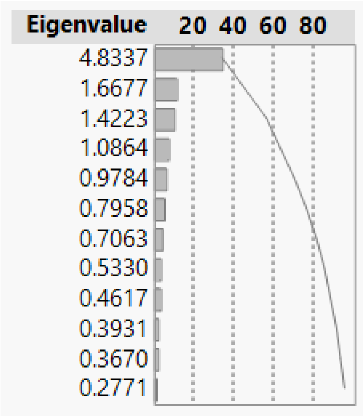
From the Cronbach's Alpha the overall alpha value for the full interaction factor is high at 0.728. Four of the questions from **Table 20** had higher alpha values: Q7 at 0.756, Q10 at 0.730, Q11 at 0.772 and Q16 at 0.771. As a result of this analysis, Q7, Q11 and Q16 were strongly considered for elimination and Q10 was considered as well.

Table 20: *Output of Cronbach's Alpha on Full Interaction Factor*

Question Number	Alpha Value
Q5	0.706
Q6	0.717
Q7	0.756
Q8	0.683
Q9	0.688
Q10	0.730
Q11	0.772
Q12	0.674
Q13	0.684
Q14	0.682
Q15	0.684
Q16	0.771
Q27	0.692
Q28	0.696

Full exploratory factor analysis

Exploratory Factor Analysis was used on the proposed Interaction factor to see if there were any sub-factors that contributed to the factor. The KMO was high enough to confidently say that the data is fit for factor analysis. First, a plot of the eigenvalues was created during the factor analysis and can be found in **Figure 22**.



Eigenvalue
4.8337
1.6677
1.4223
1.0864
0.9784
0.7958
0.7063
0.5330
0.4617
0.3931
0.3670
0.2771

***Figure 22**: Eigenvalues of Full Interaction Factor*

From the eigenvalues in **Figure 22**, it can be seen that up to four factors can be used to group the questions in the Interaction factor. However, eigenvalues are not the only way to determine how many factors the questions break into, so a look at the variance explained by each factor, the factor loadings, and which questions were grouped together were also included. Solutions for one, two, three and four factors were each examined using Promax and Quartimin rotations of the factor loading matrix. The three factor solution, which explained 62.351% of the variance, was preferred because of: (a) its previous theoretical support from the card sorting exercise in Chapter 4.1; (b) the ‘leveling off’ of eigenvalues on the scree plot after three factors; and (c) the insufficient number of primary loadings and difficulty of interpreting the one, two and four factor results. Again, factor loadings less than .35 were not included in the table to better visualize which questions actually loaded on which factors. There was little difference between the three factor Promax and Quartimin solutions, thus both solutions were examined in subsequent analyses before deciding to use a Quartimin rotation for the final solution found in **Table 21**.

Table 21*: Factor Loadings (>.35) for 3 Factors in the Full Interaction Factor. Note, Factor loadings <.35 are suppressed*

Q#	Question Wording	Factor Loadings on perceived ease of use sub-factor	Factor Loadings on interest and attention sub-factor	Factor Loadings on goals and actions sub-factor
5	The goals of the interface were extremely clear.			0.64
6	The goals were very specific.			0.76
7	I lost track of time.		0.72	
8	I found the interface to be interesting.		0.62	
9	I felt in control of myself.	0.68		
10	Things seemed to happen automatically.	0.47		-0.60
11	I had to make an effort to keep my mind on the activity.		-0.49	-0.42
12	The interface was easy to navigate.	0.76		
13	Learning to use this site was easy.	0.82		
14	Becoming skillful at using the site was easy.	0.80		
15	I felt very immersed while interacting with the system.		0.73	
16	I feel very tired.			
27	This interface was able to hold my attention.	0.46	0.62	
28	After interacting with this interface I am persuaded to take an action.	0.56		

The original card sorting method had the questions split into five groupings: goals/feedback (Q5-6), intrinsic motivation (Q7-11), perceived ease of use (Q12-14), engagement (Q15-16), and questions added from study 1 (Q27-28). While the three factor option does not keep all of the items together in their original groupings, groupings such as the perceived ease of use remained together in the same factor. Question 16 (I feel very tired) did not load on either factor and thus was considered for elimination.

Three factors described a good portion (62.35%) of the variance in responses as well. As a result, three sub-factors were chosen and question 16 was considered for elimination for the proposed Interaction factor. The first sub-factor, consisting of questions 9, 12-14 and 28 was named perceived ease of use to match the title given to questions 12-14 in Chapter 4.1's card sorting exercise. The second sub-factor consisted of question 7-8, 11, 15 and 27 and was named interest and attention. The third and final factor consisted of questions 5-6 and 10 and was named goals and actions.

Elimination decisions

From the Cronbach's Alpha analysis, three questions were identified that would raise the overall alpha value a large amount and one a small amount. Question 7 (I lost track of time) was identified that is elimination would raise the alpha value by 0.0282, question 10 (Things seemed to happen automatically) was identified to raise the alpha value by 0.0020, question 11 (I had to make an effort to keep my mind on the activity) was identified to raise the alpha value by 0.0442, and question 16 (I feel very tired) was identified to raise the alpha value by 0.0434 if it was eliminated. Questions 7, 11 and 16 all resulted in moderate increases in the alpha value and were eliminated.

Reduced Cronbach's Alpha

After eliminating questions 7, 11 and 16, Cronbach's Alpha was conducted on the remaining questions to get a view of how well the new set of questions relate to each other. This analysis can be found in **Table 22**.

***Table 22**: Output of Cronbach's Alpha on Reduced Interaction Factor*

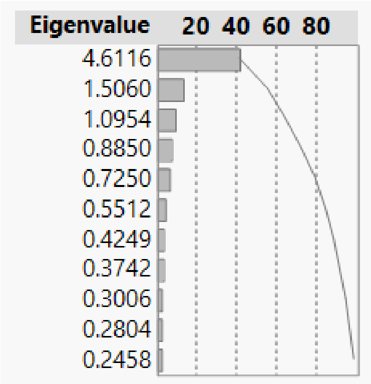
Question Number	Alpha Value
Q5	0.841
Q6	0.846
Q8	0.830
Q9	0.826
Q10	0.862
Q12	0.818
Q13	0.826
Q14	0.826
Q15	0.830

Q27	0.829
Q28	0.839

The alpha value of the entire set originally was 0.728 before eliminating questions. After elimination, it became 0.847. As expected, analysis of this second Cronbach's Alpha shows one additional question would increase the alpha value a small amount. Question 10 (Things seemed to happen automatically) would increase the alpha value by 0.015 however that increase would be small and therefore question 10 was kept.

Reduced exploratory factor analysis

After eliminating questions 7, 11 and 16, an exploratory factor analysis was conducted on the remaining questions to see if these new factors would be identified as the only three factors contributing to the data. The eigenvalues for this analysis can be found below in **Figure 23**.



Eigenvalue
4.6116
1.5060
1.0954
0.8850
0.7250
0.5512
0.4249
0.3742
0.3006
0.2804
0.2458

Figure 23*: Eigenvalues of Reduced Interaction Factor*

These eigenvalues identify three factors being the ideal number of factors for this group of questions. The factor loadings can be seen in **Table 23**.

Table 23*: Factor Loadings for 3 Factors in the Reduced Interaction Factor. Note, factor loadings <.35 are suppressed*

Q#	Question Wording	Factor Loadings on perceived ease of use sub-factor	Factor Loadings on interest and attention sub-factor	Factor Loadings on goals and actions sub-factor
5	The goals of the interface were extremely clear.	0.50		0.57
6	The goals were very specific.			0.81
8	I found the interface to be interesting.		0.66	
9	I felt in control of myself.	0.65		
10	Things seemed to happen automatically.			-0.61
12	The interface was easy to navigate.	0.70		
13	Learning to use this site was easy.	0.91		
14	Becoming skillful at using the site was easy.	0.82		
15	I felt very immersed while interacting with the system.		0.94	
27	This interface was able to hold my attention.		0.91	
28	After interacting with this interface I am persuaded to take an action.		0.58	

The same questions remain in each factor except question 28 (After interacting with this interface I am persuaded to take an action) which has switched from the ease of use factor to the interest and attention factor. The questions also have similar factor loadings and the factor loadings for questions 5, 6, 8, 10, 13, 14, 15, 27 and 28 (all but 9 and 12) all increased. This confirms the three sub-factor selection choice. The resultant sub-factors and their loadings after eliminating the three questions identified through Cronbach’s Alpha and the Exploratory Factor Analysis can be seen in the factor tree for compellingness in **Figure 24**.

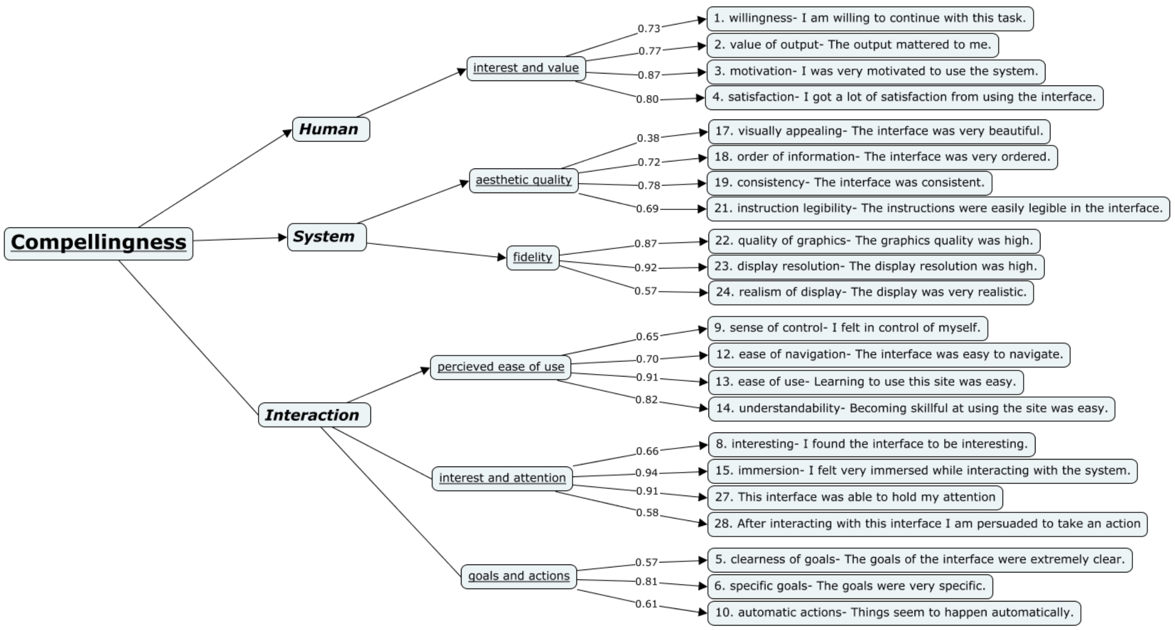

Compellingness
Human
interest and value
0.73
1. willingness- I am willing to continue with this task.
0.77
2. value of output- The output mattered to me.
0.87
3. motivation- I was very motivated to use the system.
0.80
4. satisfaction- I got a lot of satisfaction from using the interface.
System
aesthetic quality
0.38
17. visually appealing- The interface was very beautiful.
0.72
18. order of information- The interface was very ordered.
0.78
19. consistency- The interface was consistent.
0.69
21. instruction legibility- The instructions were easily legible in the interface.
fidelity
0.87
22. quality of graphics- The graphics quality was high.
0.92
23. display resolution- The display resolution was high.
0.57
24. realism of display- The display was very realistic.
Interaction
percieved ease of use
0.65
9. sense of control- I felt in control of myself.
0.70
12. ease of navigation- The interface was easy to navigate.
0.91
13. ease of use- Learning to use this site was easy.
0.82
14. understandability- Becoming skillful at using the site was easy.
interest and attention
0.66
8. interesting- I found the interface to be interesting.
0.94
15. immersion- I felt very immersed while interacting with the system.
0.91
27. This interface was able to hold my attention
0.58
28. After interacting with this interface I am persuaded to take an action
goals and actions
0.57
5. clearness of goals- The goals of the interface were extremely clear.
0.81
6. specific goals- The goals were very specific.
0.61
10. automatic actions- Things seem to happen automatically.

Figure 24: *Final Factor Tree for Compellingness*

Complete survey analysis with eliminated factors

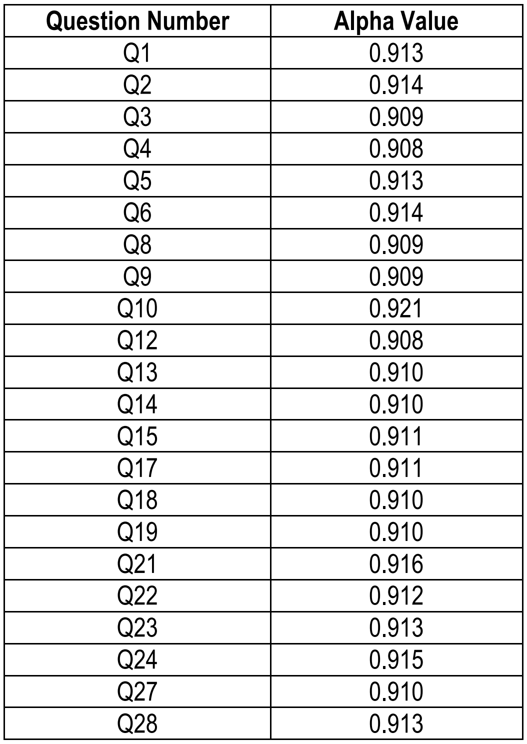
Sampling adequacy

The Kaiser-Meyer-Olkin measure of sampling adequacy for the entire survey minus the six eliminated questions had a value of 0.866. The resulting KMO of 0.866 is meritorious Kaiser (1974) and can be considered high enough that factor analysis can be run on this data. The Bartlett's Test of Sphericity was significant ($\chi^2(231) = 1447.451$, $p < .05$) and thus the assumption of equal variances is valid and indicating that it was appropriate to use the factor analytic model on this set of data.

Reduced Cronbach's Alpha

The overall alpha value of the entire reduced survey from Cronbach's Alpha was high at 0.916. As can be seen in **Table 24**, two questions just barely had higher alpha values than the overall: Q10 at 0.921 and Q21 at 0.916. The increases are miniscule at 0.005 and 0.0002 and do not warrant elimination.

***Table 24**: Output of Cronbach's Alpha on Reduced Full Survey*



Question Number	Alpha Value
Q1	0.913
Q2	0.914
Q3	0.909
Q4	0.908
Q5	0.913
Q6	0.914
Q8	0.909
Q9	0.909
Q10	0.921
Q12	0.908
Q13	0.910
Q14	0.910
Q15	0.911
Q17	0.911
Q18	0.910
Q19	0.910
Q21	0.916
Q22	0.912
Q23	0.913
Q24	0.915
Q27	0.910
Q28	0.913

Confirmatory Factor Analysis: First Order Model

Based on the results of the EFA, the first order model was constructed as show in **Figure 25**.

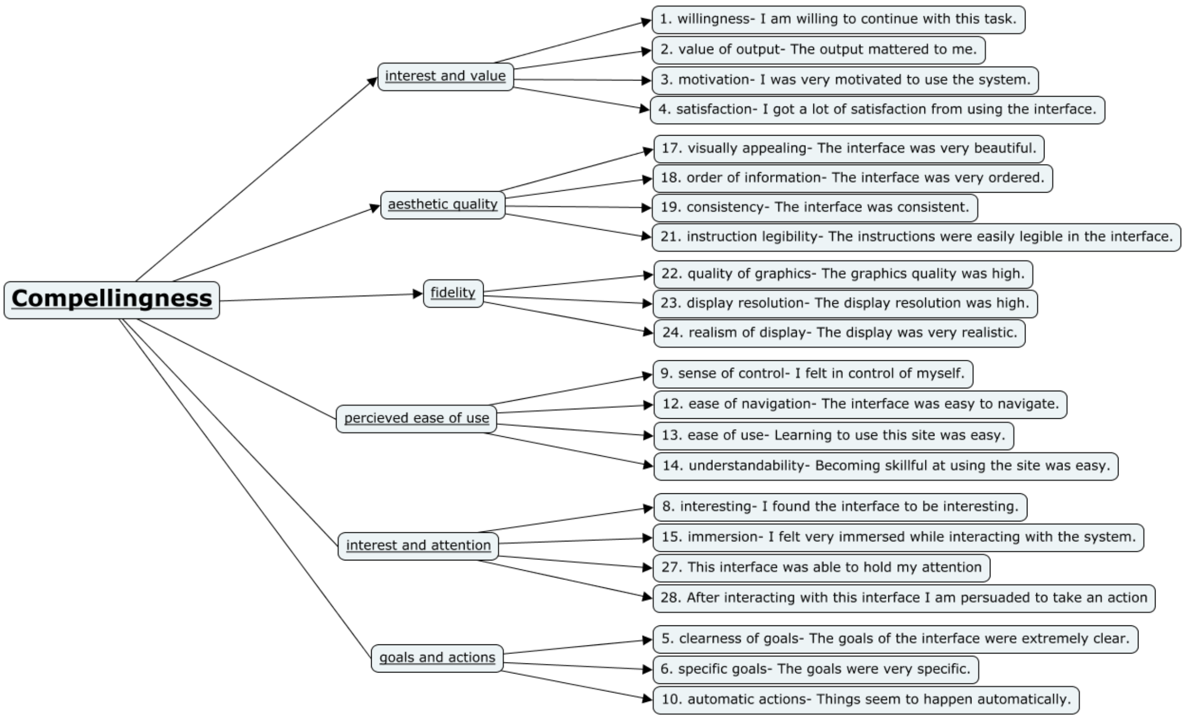

Compellingness
interest and value
1. willingness- I am willing to continue with this task.
2. value of output- The output mattered to me.
3. motivation- I was very motivated to use the system.
4. satisfaction- I got a lot of satisfaction from using the interface.
aesthetic quality
17. visually appealing- The interface was very beautiful.
18. order of information- The interface was very ordered.
19. consistency- The interface was consistent.
21. instruction legibility- The instructions were easily legible in the interface.
fidelity
22. quality of graphics- The graphics quality was high.
23. display resolution- The display resolution was high.
24. realism of display- The display was very realistic.
percieved ease of use
9. sense of control- I felt in control of myself.
12. ease of navigation- The interface was easy to navigate.
13. ease of use- Learning to use this site was easy.
14. understandability- Becoming skillful at using the site was easy.
interest and attention
8. interesting- I found the interface to be interesting.
15. immersion- I felt very immersed while interacting with the system.
27. This interface was able to hold my attention
28. After interacting with this interface I am persuaded to take an action
goals and actions
5. clearness of goals- The goals of the interface were extremely clear.
6. specific goals- The goals were very specific.
10. automatic actions- Things seem to happen automatically.

Figure 25: *First Order Factor Model*

A chi-square test of goodness-of-fit was performed to determine whether the six first order factors were equally distributed. Responses to the six first order factors was not equally distributed in the population, X^2 (194) = 415.53, $p < .0001$. The Chi Square goodness of fit statistic suggests that the model may not fit the data all that well. However, the rest of the goodness of fit statistics can provide more information.

From the model fit statistics of this model, the CFI = .834, the TLI = .803, and the RMSEA = .098. The RMSEA was in the mediocre range but very close to the poor range. Since the RMSEA was less than 0.158, the CFI and TLI are not very useful but were both not in the satisfactory fit range. The AIC = 6287.818 and the BIC = 6513.60. Since these are both comparative measures, they do not have cutoff values but will be compared to the alternative model. The SRMR = 0.091 which is much higher than the 0.08 cutoff for a good fitting model. From these model fit statistics, there are no statistics that say that this model is a good fit for the data.

Confirmatory Factor Analysis: Second Order Model

Based on the results of the EFA, the second order model was constructed as shown in **Figure 26**.

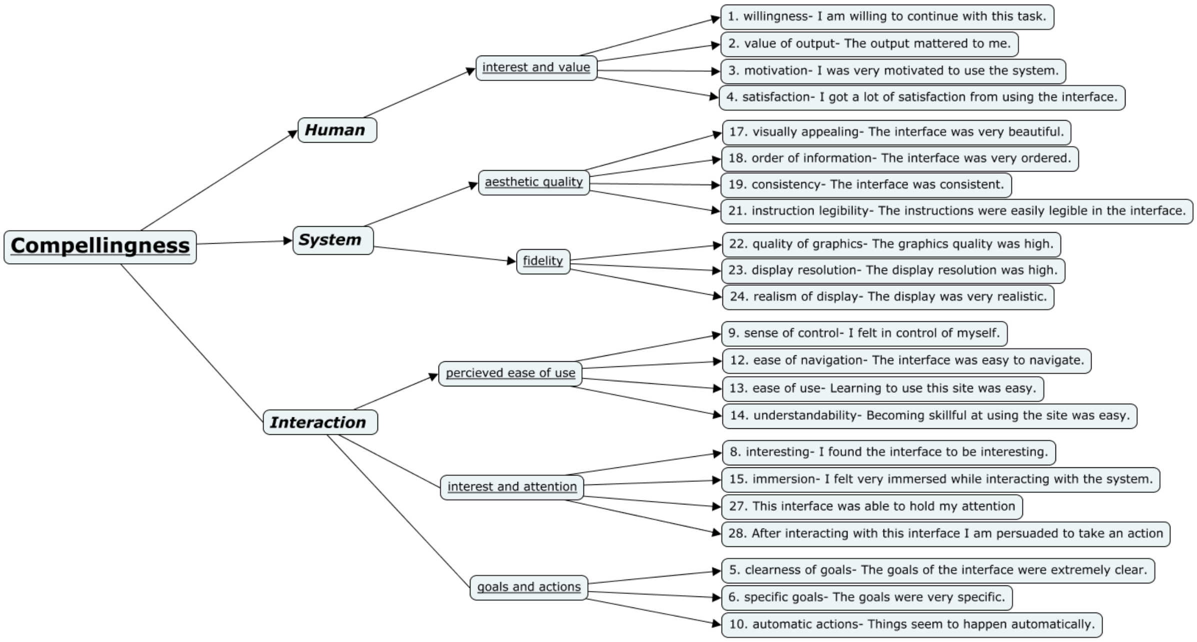

Compellingness
Human
System
Interaction
interest and value
aesthetic quality
fidelity
percieved ease of use
interest and attention
goals and actions
1. willingness- I am willing to continue with this task.
2. value of output- The output mattered to me.
3. motivation- I was very motivated to use the system.
4. satisfaction- I got a lot of satisfaction from using the interface.
17. visually appealing- The interface was very beautiful.
18. order of information- The interface was very ordered.
19. consistency- The interface was consistent.
21. instruction legibility- The instructions were easily legible in the interface.
22. quality of graphics- The graphics quality was high.
23. display resolution- The display resolution was high.
24. realism of display- The display was very realistic.
9. sense of control- I felt in control of myself.
12. ease of navigation- The interface was easy to navigate.
13. ease of use- Learning to use this site was easy.
14. understandability- Becoming skillful at using the site was easy.
8. interesting- I found the interface to be interesting.
15. immersion- I felt very immersed while interacting with the system.
27. This interface was able to hold my attention
28. After interacting with this interface I am persuaded to take an action
5. clearness of goals- The goals of the interface were extremely clear.
6. specific goals- The goals were very specific.
10. automatic actions- Things seem to happen automatically.

Figure 26*: Second Order Factor Model*

A chi-square test of goodness-of-fit was performed to determine whether the six first order and three second order factors were equally distributed. Responses to the six first order factors was not equally distributed in the population, X^2 (201) = 440.22, p < .0001. This suggests that the model may not fit the data all that well. However, the rest of the goodness of fit statistics can provide more information.

From the model fit statistics of this model, the CFI = .821, the TLI = .794, and the RMSEA = .100. The RMSEA was in the poor fit range. Since the RMSEA was less than

0.158, the CFI and TLI are not very useful but were both not in the satisfactory fit range. The AIC = 6298.513 and the BIC = 6504.788. The AIC value was larger than the previous model and the BIC as smaller than the previous model. Both of these are comparative measures and can be used to compare alternative models. Seeing as the AIC and the BIC were not both higher for one model and the other model fit statistics were all poor for both models, it can be concluded that neither of these models is a good fit for the data. The standardized root mean square residual (SRMR) = 0.096 which is much higher than the 0.08 cutoff for a good fitting model. From these model fit statistics, there are no statistics that say that this model is a good fit for the data.

Analysis of experimental manipulations

The purpose of manipulating three independent variables was to attempt to exercise the survey to its full extent to get participant responses across the full range of scores. Responses were received for all questions across the full range of values from -3 to 3, however the manipulations of the three independent variables was subtle and an analysis must be run to determine whether there was a significant difference between the trials. Analysis of Variance (ANOVA) was used to determine if the independent variable manipulations actually did make a difference.

Variable checks

To begin, a check was done to see if there were any affects due to the location the task took place (Nevada or Tennessee), the gender of the participant (Male or Female), or the

Trial Order (first or second). This analysis was conducted using 2-way ANOVA tests to ensure that there were no underlying variables that cause variability in the data. The main effect of location of the tasks was not significant, *F*(1,56) = 2.89, *p* = .095 ns. Participants did not rate the study significantly differently between the Nevada and Tennessee locations.

The main effect of trial number was also not significant, *F*(1,56) = 2.91, *p* = .093 ns. Participants did not perform significantly differently in the same task when it was performed either first or second. The main effect of gender was not significant, *F*(1,56) = 2.26, *p* = .14 ns. This meant that there was not a significant difference in responses between male and female respondents.

NASA TLX

Figure 27 shows a graph of the means and standard error for separate analysis of each of the size NAS TLX scales. For each scale, post hoc Tukeys analysis determined if any of the four conditions were significantly different from each other. When two results (for an individual question scale) do not share a letter, then they are significantly different from each other. Only the four conditions for each NASA TLX can be compared, each of the six scales displayed in **Figure 27** are a separate analysis. For example, the first two columns for the mental demand question can be compared against each other but they cannot be compared to the first to columns of the physical demand question.

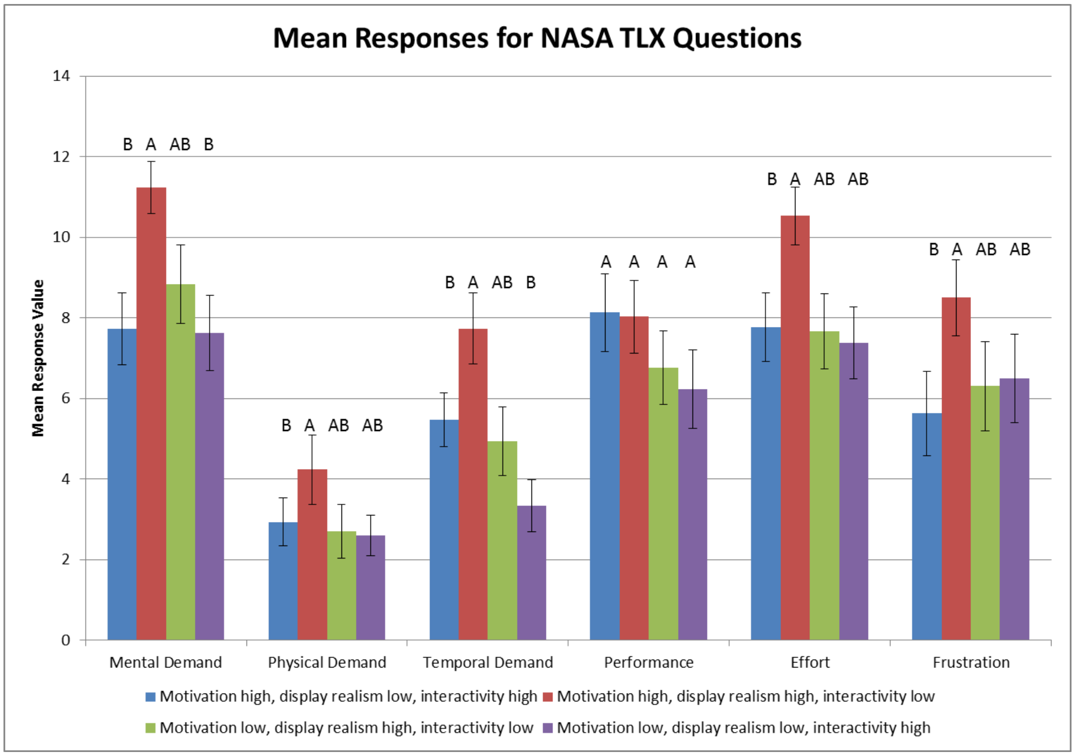


***Figure* 27**: Mean Responses *and Standard Errors* for each NASA TLX Question and I*ndependent Variable Manipulation* Condition

The letters above the bars indicate which conditions are significantly different from each other. If two or more bars do not share a letter, they are significantly different from each other. In this case, two levels of conditions were significantly different for mental demand, *F*(78.16) = 7.81, *p* < .001. In the case of high motivation, two levels of conditions were found to be significantly different between the high display realism, low interactivity condition and the low display realism, high interactivity condition for completion time, *p* = .023. Additionally, a significant difference was found between the high motivation, high display realism, low activity condition and the low motivation, low display realism, high interactivity condition, *p* < .001.

Two levels of condition were found to be significantly different for physical demand, *F*(78.16) = 3.50, *p* = .019. A significant difference was found for the case of high motivation, high display realism and low interactivity and high motivation, low display realism and high interactivity, *p* = .015.

Two levels of condition were found to be significantly different for temporal demand, *F*(78.16) = 7.70, *p* < .001. A significant difference was found for the case of high motivation, high display realism and low interactivity and high motivation, low display realism and high interactivity, *p* = .007. Additionally, a significant difference was found in the case of high motivation, high display realism and low interactivity and low motivation, low display realism and high interactivity, *p* < .001.

No significant difference of condition was found on performance, *F*(78.16) = 0.73, *p* = 0.54 ns. A significant difference of condition was found on effort, *F*(78.16) = 4.34, *p* = .007. A significant difference was found in the case of high motivation, high display realism and low interactivity and high motivation, low display realism and high interactivity, *p* = .009.

No significant difference of condition was found on frustration, *F*(78.16) = 2.51, *p* = .06, however a significant difference of condition was in the case of high motivation, high display realism and low interactivity and low motivation, low display realism and high interactivity, *p* = .041.

Task completion time

A main effect of condition on the resulting task completion time was significant, *F*(3,78.2) = 8.71, *p* < .001. Post-hoc Tukey’s Test was conducted to identify which conditions were significantly different than each other. The letters above the bars indicate which conditions are significantly different from each other. If two or more bars do not share a letter, they are significantly different from each other. The four conditions can be seen in **Figure 28**, which shows the means, error bars and results of Tukey's Test for the 1-way ANOVA of completion time and condition.

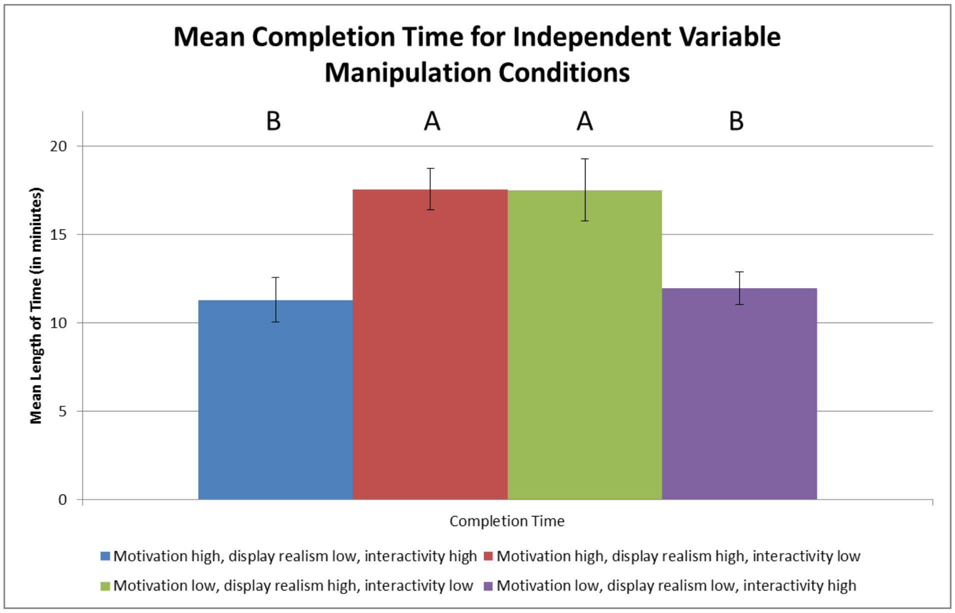


Figure 28*: Mean Completion Times and Standard Error for each Independent Variable Manipulation Condition*

In the case of high motivation, a main effect was found between the high display realism, low interactivity condition and the low graphics quality, high interactivity condition for completion time, *p* = .001. A main effect was also found for the high motivation, high display realism and low interactivity condition and the low motivation, low display realism, high interactivity condition, *p* = 0.017. Two more main effects were also found, one between the low motivation, high display realism, low interactivity condition and the high motivation, low display realism, high interactivity condition, *p* = .006; the other between the low motivation, high display realism, low interactivity condition and the low motivation, low display realism, high interactivity condition, *p* = .006.

Independent variable manipulations

To highlight whether or not the manipulations made in the study were strong enough to make a noticeable and significant difference in participants' responses, t-tests were run on each of the three independent variables for the questions that corresponded to the independent variable. The main effect of motivation was not significant on the average scores of the human factor questions of the survey, *t*(58) = 0.71, *p* = 0.48 ns, d = 0.17. Participants between the high motivation and low motivation manipulation conditions did not differ on the reported responses to the human factor questions. The main effect of display realism was also not significant *t*(58) = -0.71, *p* = .48 ns, d = 0.08. Participants between the map view and satellite view display realism manipulation conditions did not differ on the reported responses to the system factor questions.

The main effect of interactivity was significant on the average scores of the interaction factor questions of the survey, *t*(58) = -2.67, *p* = .010, d = .35. Participants between the high interactivity and low interactivity manipulation conditions differed on the reported responses to the interaction factor questions.

Additionally, Tukey's test was run for each of the groupings of questions identified in Chapter 4's human, system and interaction factors. The purpose of the ANOVA was to see if there was a significant difference in responses to certain types of questions between the independent variable conditions. One analysis was run for each of the three first-level factors as well as a fourth analysis run for the mean response across all questions in all factors. The results of these Tukeys are summarized in **Figure 29**.

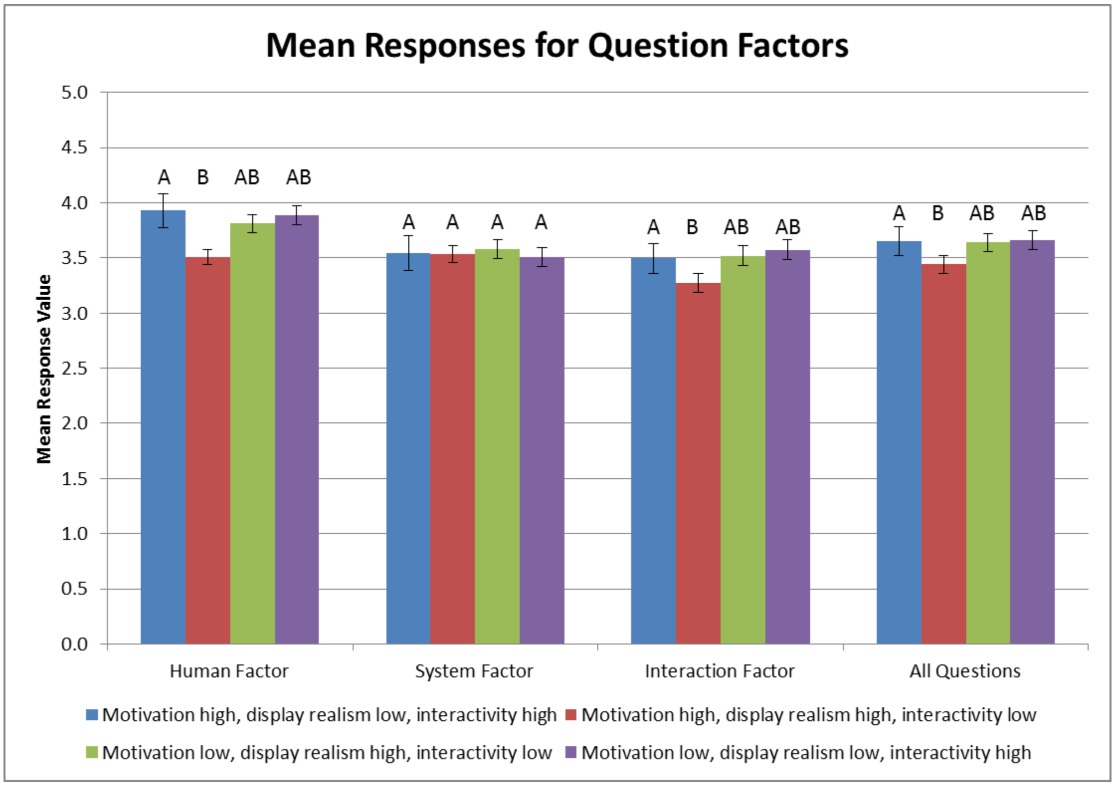


Figure 29*: Mean Responses and Standard Error for each Factor Question Grouping*

Each independent variable condition is the same as reported before. The letters above the bars indicate which conditions are significantly different from each other. If two or more bars do not share a letter, they are significantly different from each other. Bars between factor questions groupings cannot be compared. For example, results in the human factor cannot be compared to results in the interaction factor. In this case, a main effect of condition was found for all question categories, *F*(78.16) = 4.33, *p* = .007. Additionally, a main effect was found for the case of high motivation, high display realism and low interactivity and high motivation, low display realism and high interactivity, *p* = .004.

For the human factor category questions, a main effect of condition was found, *F*(78.16) = 5.06, *p* = .003. Additionally, a main effect was found for the case of high motivation, high display realism and low interactivity and high motivation, low display realism and high interactivity, *p* = .002.

For the system factor category questions, a main effect of condition was not found, *F*(78.16) = 0.43, *p* = 0.73 ns. For the interaction factor category questions, a main effect of condition was found, *F*(78.16) = 4.07, *p* = .010. Additionally, a main effect was found for the case of high motivation, high display realism and low interactivity and high motivation, low display realism and high interactivity, *p* = .015.

5.4 Discussion

Through research on the construct and a card sorting exercise, a two-level survey was proposed for compellingness consisting of three main factors (human, system and interaction) split into eight original sub-factors. Through factor analysis on each of the three factors, six resultant sub-factors were identified and categorized that very similarly matched the original proposed eight from the card sorting exercise in Chapter 4. Figure 24 shows the breakdown of the factor structure for compellingness.

Through the data analysis process, six questions were identified for elimination. These questions were identified because of how low they loaded on the factor structure, how much sense they made in context with the proposed factor structures, and how little they loaded with the other questions in their respective factor. Two additional questions were identified as potentials for elimination but were kept since they made since with the other factors or loaded moderately on one of the identified factors.

After eliminating each of the six questions, a resultant survey was analyzed to confirm that by eliminating the six questions, the remaining survey questions are better related to each other. The Cronbach's Alpha overall alpha value was found to be 0.916 which was much larger than any of the factors' alpha values. This demonstrates that the questions fit together better as an entire survey and that there are interrelated questions in the three identified factors.

The data analysis run in this study included only internal factor development and assessed internal validity. The factor structure that was proposed through the exploratory factor analysis was run through the confirmatory factor analysis internally with the same set of data to confirm its validity; however external validity will be an important part of future work. With the external validity, the proposed factor structure can be tested against a new data set including new manipulations and can also be compared to similar scales.

From initial internal confirmatory factor analysis and based on the results of the model fit statistics, it can be concluded that the model created does not fit the 60 participants worth of data well. Results show that the fully specified six factor model is not supported by the current data set. It has been shown that multiple goodness of fit statistics do not indicate a good model of fit or often produce non-significant results with low sample sizes (Hoyle, 2000). Because of this, it was expected that any proposed model would result in mediocre findings at best and there is the potential that not enough data was gathered to properly assess the model fit. Thus futire work should run the remaining 60 participants to complete the 2x2x2 experimental design. Additional work may also include a more extensive expert review into the remaining questions and different groupings of the questions.

The results of the CFA and the EFA contradict each other. The EFA results show a high Cronbach's Alpha value of the resultant survey, indicating that the questions are all highly related and are likely measuring the same construct of compellingness. However, the fact that the Alpha value of the entire survey was higher than each of the individual factors' Alpha values suggests that there may be errors in the structure of the two-factor model due to the restrictions that were put on it. The CFA results were insufficient to draw a definitive conclusion.

A potential cause for the poor model fit statistic results and the difference between the CFA and EFA results is that the process used to create the model involved restricting question items to each of the three factors. In the exploratory factor analysis process, the factor that each question item belonged to was determined in the card sort and expert item review and then was restricted to that factor during the exploratory factor analysis. This did not allow analysis to see how question items from different factors loaded on each other and therefore could have hidden the possibility of different factor structures.

This research focused its findings on the second level sub-factor analysis. Future work should be conducted to determine the relationship between the first level factors of compellingness and to confirm the second-level groupings developed in this section. This can be done through an external confirmatory factor analysis which has the ability to directly test specific hypotheses, unlike exploratory factor analysis (Harrington, 2009). This confirmatory factor analysis is proposed to be run as future research with more distinct differences in the independent variable conditions. A higher number of participants would be suggested for a confirmatory factor analysis as many measures of fit such as Chi-Square and Standardized Root Mean Square Residual (SRMR) do not indicate a good model of fit or often produce non-significant results with low sample sizes (Hoyle, 2000).

The manipulations that were conducted on the three independent variables for this study included a difference in the motivation of the participant, the realism of the display and the interactivity in the interface. The purpose of these three manipulations was to exercise all ranges of the compellingness survey. Ideally, results would show responses from participants who found the same task to be very lowly compelling all the way up to extremely compelling. To get that range, a manipulation was chosen in each of the three proposed first level factors to try to get variation across responses.

An evaluation of each of the manipulations was conducted to see how similarly to expectations the manipulations actually performed. It was expected that the mean response to the human factor questions (questions 1-4) would change due to the motivation manipulation. The same was expected for both the interactivity manipulation on the interaction questions and the display realism manipulation on the system questions.

No significance was found to exist for the motivation manipulation on the human factor questions or for the display realism manipulation on the system factor questions. The lack of significant difference in the motivation manipulations was expected since many of the participants in the high motivation condition commented on how the gift card did not matter to them. Many participants mentioned signing up to participate in the study because of their interest in the research or their desire to help the principle investigators. An additional gift card drawing likely did not matter to many of the participants as they came in with their own intrinsic motivation. This was true of both the high and low motivation conditions and thus the “competition” aspect was not enough of a motivator in this study to provide a significant difference. The gift card was also mentioned before the reading of the prompt for each of the tasks and was likely forgotten about as the participants started to strategize their plan for the activity.

For the display realism manipulation, it was originally intended for the satellite view to be the “low” manipulation of the system factor, however halfway through running participants, it was discovered that it was in fact the “high” manipulation of display realism. This led to the opposite four conditions being run than were planned and led to results that were closer together and harder to interpret. For example, the two conditions run in the high motivation condition were planned to be [high system factor, high interaction factor] and [low system factor, low interaction factor]. Because of the switching of the display manipulations, the high system factor, low interaction factor and low system factor, high interaction factor were run and resulted in closer data sets, since each data set had one factor high and one factor low.

The questions found in the human factor all relate to intrinsic properties of the human being and likely would be better influenced by intrinsic motivation. However, the motivation manipulation that was chosen was extrinsic as it was the more easily measureable and easy to manipulate type of motivation. Because of this, it is possible that intrinsic motivation of participants was not affected using the IV manipulation, and resulted in non-significant results.

Between the conditions chosen to be run and the strength of the manipulations, strong differences in the results because of these manipulations was not seen. That does not mean, however, that the factor analysis is not valid. The purpose of the manipulations was to exercise different levels of compellingness so the factor analysis was not tailored to only a high or low compelling interface. Through the activity and manipulations, a range of responses were gathered that provided enough variation to get good results. The KMO for each of the factors and the survey overall were also each middling or above which showed that the data was fit for factor analysis.

Since all eight conditions were not run for the experiment, an exact breakdown of each of the independent variable manipulations and how they affected the results cannot be completed. Initial analysis, however, points to evidence that some combination of the display realism and interactivity conditions had an effect on the data. For five of the six measures of workload in the NASA TLX survey as well as for completion time of a task and the human factor questions, interaction factor questions and all questions, there was a significant difference between the high motivation, high display realism, low interactivity and high motivation, low display realism, high interactivity conditions. Because almost every analysis has shown a difference between these two variable conditions, it can confidently be said that there is some combination of the display realism manipulation and the interactivity manipulation that causes a significant difference in the resultant compellingness score.

Factor analysis was conducted to group the initial 28 questions of the survey into factors of similar concepts. The original expectation presented in Chapter 4 was that the questions should naturally split into three groups: The Human, The System, and The Interaction. This was very similar to the results from the factor analysis where 4 questions were split into a factor that was similar to the hypothesized Human factor, 7 questions were split into a factor that was similar to the hypothesized System factor, 11 questions were split into a factor that was similar to the hypothesized Interaction factor, and 6 questions were eliminated.

The final survey found in Figure 24 is split into 3 factors and 6 sub-factors identified by the factor analysis. A resultant score can be calculated from the final survey as a whole, and also for each of the individual factors. This provides a way to not only compare interfaces’ compellingness levels against each other, but also allows for better knowledge of why an interface’s compellingness level is where it is. A low resultant score for any factor could show that the items in that factor are lacking and design changes can be focused in that area.

CHAPTER 6

CONTRIBUTIONS AND FUTURE WORK

6.1 Final Compellingness Scale

***Table 25**: Final Compellingness Scale*

Q#	Question	Factor	Item	Source
1	I am willing to continue with this task.	Human	Willingness	New question developed
2	The output mattered to me.	Human	Value of output	Tractinsky, Katz & Ikar, 2000
3	I was very motivated to use the system.	Human	Motivation	New question developed
4	I got a lot of satisfaction from using the interface.	Human	Satisfaction	New question developed
5	The goals of the interface were extremely clear.	Interaction	Clearness of goals	Johnson, Maddux and Ewing-Taylor, 2003
6	The goals were very specific.	Interaction	Specific goals	Johnson, Maddux and Ewing-Taylor, 2003
8	I found the interface to be interesting.	Interaction	Interesting	Davis and Widenbeck, 2001
9	I felt in control of myself.	Interaction	Sense of control	Davis and Widenbeck, 2001
10	Things seemed to happen automatically.	Interaction	Automatic actions	Brockmyer et al, 2009
12	The interface was easy to navigate.	Interaction	Ease of navigation	Ahuja and Webster, 2001
13	Learning to use this site was easy.	Interaction	Ease of use	Ahuja and Webster, 2001
14	Becoming skillful at using the site was easy.	Interaction	Understandability	Ahuja and Webster, 2001
15	I felt very immersed while interacting with the system.	Interaction	Immersion	Brockmyer et al, 2009
17	The interface was very beautiful.	System	Visually appealing	Tractinsky, Katz & Ikar, 2000
18	The interface was very ordered.	System	Order of information	Tractinsky, Katz & Ikar, 2000
19	The interface was consistent.	System	Consistency	Tonelli, 2012
21	The instructions were easily legible in the interface.	System	Instruction legibility	Tractinsky, Katz & Ikar, 2000
22	The graphics quality was high.	System	Quality of graphics	New question developed
23	The display resolution was high.	System	Display resolution	New question developed
24	The display was very realistic.	System	Realism of display	New question developed
27	This interface was able to hold my attention.	Interaction	Study 1	Study 1
28	After interacting with this interface I am persuaded to take an action.	Interaction	Study 1	Study 1

6.2 Summary

Compellingness describes how likely something is to capture attention and influence opinions, beliefs and actions. In the realm of Human-Computer Interaction, compellingness affects where attention is focused and thus can lead to potential human factors risks. The aim of this thesis was to develop an empirically-based survey instrument to measure compellingness, and decompose compellingness into sub-constructs.

The Scale Development Methodology (DeVellis, 2012) was followed including a literature review to determine what was being measured and to compose the initial item pool. An initial Study 1 and an expert review of the item pool narrowed it down and created 28 questions for testing construct validity. The 28 questions were administered to a sample of respondents in Study 2 and were evaluated using exploratory factor analysis and Cronbach's Alpha. Through the process of creating and refining this survey, a resultant survey of 22 questions was created that can be used to measure the level of compellingness an interface or device design.

This initial development of the compellingness survey provides the first steps towards developing a robust, usable future survey. The current survey requires additional data analysis but can currently be used as a single use survey. However, if the survey can be condensed, it is the goal to be able to use it in real time to assess whether or not compellingness can fluctuate throughout the use of an application or device. It is hyppthesized that some factors may be invariant (e.g. system), while others may fluatcue moment-to-moment (e.g. human). Currently the survey contains questions, especially in the system factor, that are not dynamic and do not change from moment to moment, however it contains others that could, such as the distractions felt by the user or the level of immersion.

This research provides a first step toward future research including: further data collection and confirmatory factor analysis, deeper analysis into the factor structure, validation of the survey and analysis against measures such as trust or usability as well as across different interfaces. Future research can help develop this survey with more internal validation as well as external validation.

While two of the three independent variable manipulations were not found to have made a significant difference in the results, all levels of compellingness were still reached and exercised for the survey and allowed for proper data analysis. This measurement tool can allow for better variable manipulation and can also be used to help meet design requirements such as the amount of attention allocation necessary for design features.

6.3 Future Work

This study presented an introduction of a survey instrument with means to measure compellingness levels. Sixty participants completed trials that manipulated three different variables, but only four of the eight possible combinations were executed during the course of Study 2. Additional trials including more participants and the other four combinations could provide clearer insight into the effects of the independent variables.

There was not enough evidence to reject the hypothesis that the four trials with manipulations of the three independent variables were different. The manipulations were too subtle and did not produce as dramatic of a difference as expected. It is suggested that future work be done to exercise the full range of the survey to validate the results found within this study. Only the manipulations in the interaction independent variable were found to be significant, so rather than complete the final four combinations, the results suggest that stronger manipulations be made across a different interface to gain more significant differences in responses.

The data analysis run in this study included only internal factor development and only assessed internal validity. The factor structure that was proposed through the exploratory factor analysis was run through the confirmatory factor analysis internally with the same set of data to confirm its validity; however external validity will be an important part of future work. With the external validity, the proposed factor structure can be tested against a new data set including new manipulations and can also be compared to similar scales. . Ideally, a new analysis with new manipulations of the three factors (human, system and interaction) will also be conducted and a CFA would be performed. The CFA would analyze the proposed factor structure from this research but will be testing it on a new sample of the population to determine how the three factors load on each other.

Model fit statistics from multiple models can be compared to determine which models are a better fit for the data than others. For the purpose of this study, a six factor first order model of the proposed groupings was compared to a three factor, six sub-factor second order model. Neither of the two models were found to be a good fit for the data however the exploratory factor analysis and Cronbach's Alpha results indicate that more data may be necessary to get a better picture of fit using CFA.

Future research includes running the final 60 participants, running a secondary CFA, and diagnosing whether the problem was the sample size or something else such as the model structure. This study presented an exploratory factor analysis of items that make up the second order of the factor tree and an educated hypothesis of the appearance of the first order. Confirmatory factor analysis can be conducted to identify the loadings that each of the human, system and interaction factors had on each other as well as how well the sub-factors identified in this survey properly fit the population data as a whole.

To further validate the survey, potential future work includes exercising it on interfaces that are thought to have different levels of compellingness to ensure that the survey can pick up on those differences. This study only analyzed one task in one program on one device however this survey has wider application.

Additionally, compellingness can be evaluated in conjunction with such factors as trust, attention allocation, performance, error and workload to discover the relationship between the factors. The following is provided as an example of a human factors study that can utilize a scale of compellingness. In this example, the compellingness survey can be used to study the design of heads up displays of real-time weather. These heads up displays are currently being designed to allow pilots to navigate in weather more accurately. It is expected that different levels of compellingness in the display of the data will affect the path that pilots choose to take. The compellingness level of the interface could affect the risks the pilots are willing to take as well as how much trust they have in the display.

In sensory-based displays for pilots, all the sensory cues of aircrafts are given on a display instead of visually out a window. Since these displays are the only cues the pilot has to what is going on outside the aircraft, the displays need to be designed properly so that the correct amount of information is displayed, the information is displayed in locations that are useful and intuitive to the pilot, and the information has the right amount of compellingness at the right time in order to cue the pilots' attention toward it.

Through the use of the compellingness survey in research areas such as developing these sensory-based displays, design changes can now be made to see if compellingness results in different situational awareness, attention, knowledge retention or trust. By measuring the level of compellingness that the interface has, the responses to the survey can highlight in what areas design decisions should be made in to get the results desired.

6.4 Contribution

This research has developed an empirically-based measurement scale of compellingness. Additionally, it identified three contributing factors with six total sub-factors. Research prior was limited to binary assessment for compellingness (e.g. an interface was compelling or not compelling). With this research, researchers will now have a continuous scale for compellingness. Furthermore, this work has defined compellingness as a multi-dimensional construct, which is reflected in the two-levels of factors in the survey instrument. This will enable to researchers to be more specific in quantifying in what way an interface is compelling.

Much of the work that currently exists for compellingness research lies in the field of attention in aviation. A compelling feature can direct attention to that feature and decrease a pilots' ability to notice other events (Yeh & Wickens, 2000). A feature can be so compelling that a pilot can claim to not be able to fly without it (Hersey, 1925). Additionally, display techniques have been created that involve reorienting attention in order to counter unwanted allocation of attention (Rizzolatti, Riggi, Dascola, & Umiltá, 1987). This all leads to the need for a measurement tool to gauge the expected level of compellingness of an interface or feature before implementation so that measures to counteract effects of compellingness do not have to exist.

This survey can be used to gauge the level of compellingness of an interface when in the beginning stages of design. It can assist in the design process to balance the compellingness levels of instrumentation in tasks that require divided attention and can be used to gauge which more important features need a higher level of compellingness to attract the correct amount of attention desired.

Overall, this study has contributed an empirically-based measurement scale of compellingness that consists of three contributing factors and six sub-factors whose items make up the survey. This survey will benefit many research areas throughout the realm of Human-Computer Interaction and can further research in fields such as trust, attention allocation, performance, error and workload.

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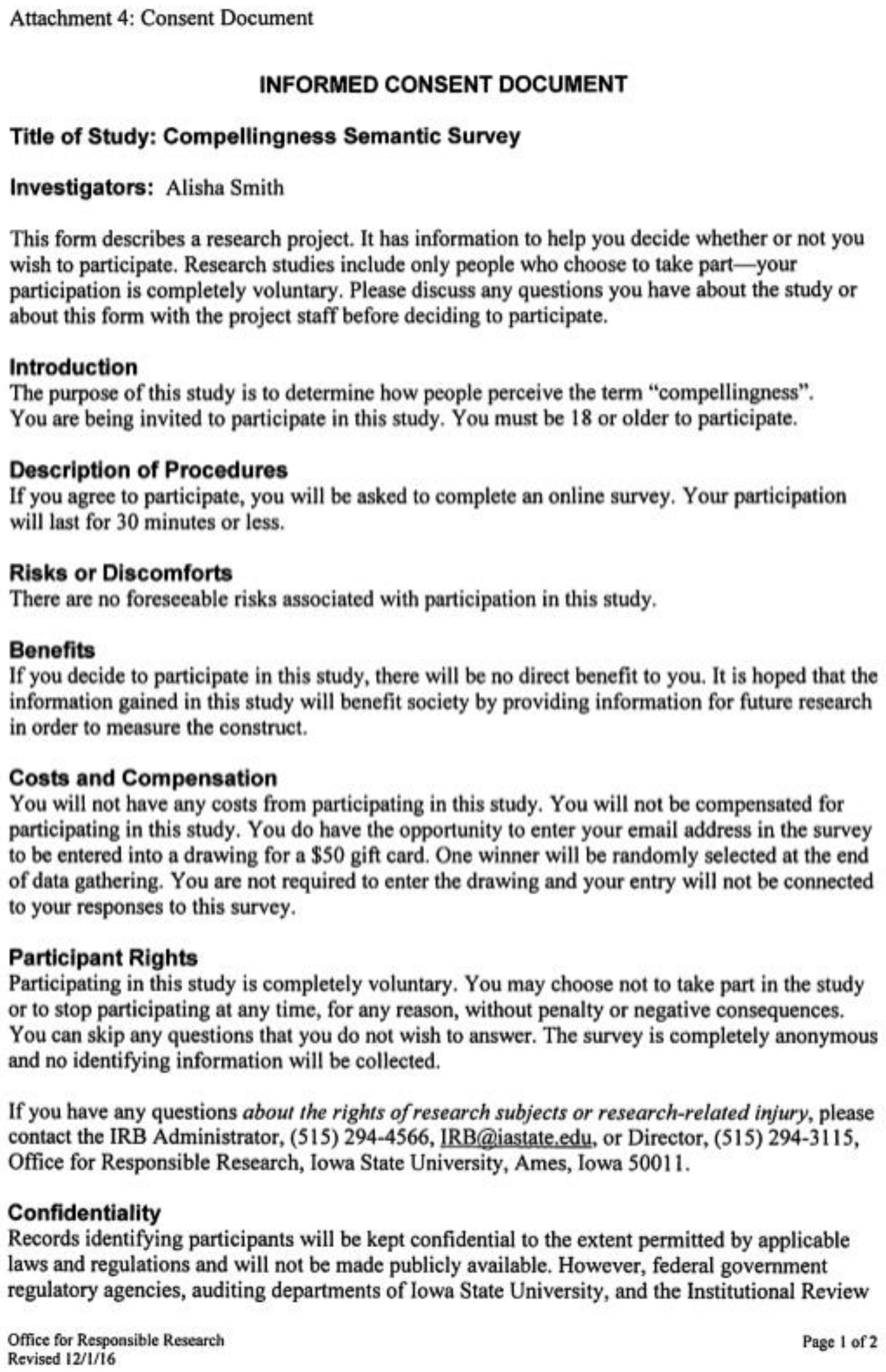
APPENDIX A

STUDY 1 SURVEY



Attachment 4: Consent Document

INFORMED CONSENT DOCUMENT

Title of Study: Compellingness Semantic Survey

Investigators: Alisha Smith

This form describes a research project. It has information to help you decide whether or not you wish to participate. Research studies include only people who choose to take part—your participation is completely voluntary. Please discuss any questions you have about the study or about this form with the project staff before deciding to participate.

Introduction

The purpose of this study is to determine how people perceive the term "compellingness". You are being invited to participate in this study. You must be 18 or older to participate.

Description of Procedures

If you agree to participate, you will be asked to complete an online survey. Your participation will last for 30 minutes or less.

Risks or Discomforts

There are no foreseeable risks associated with participation in this study.

Benefits

If you decide to participate in this study, there will be no direct benefit to you. It is hoped that the information gained in this study will benefit society by providing information for future research in order to measure the construct.

Costs and Compensation

You will not have any costs from participating in this study. You will not be compensated for participating in this study. You do have the opportunity to enter your email address in the survey to be entered into a drawing for a $50 gift card. One winner will be randomly selected at the end of data gathering. You are not required to enter the drawing and your entry will not be connected to your responses to this survey.

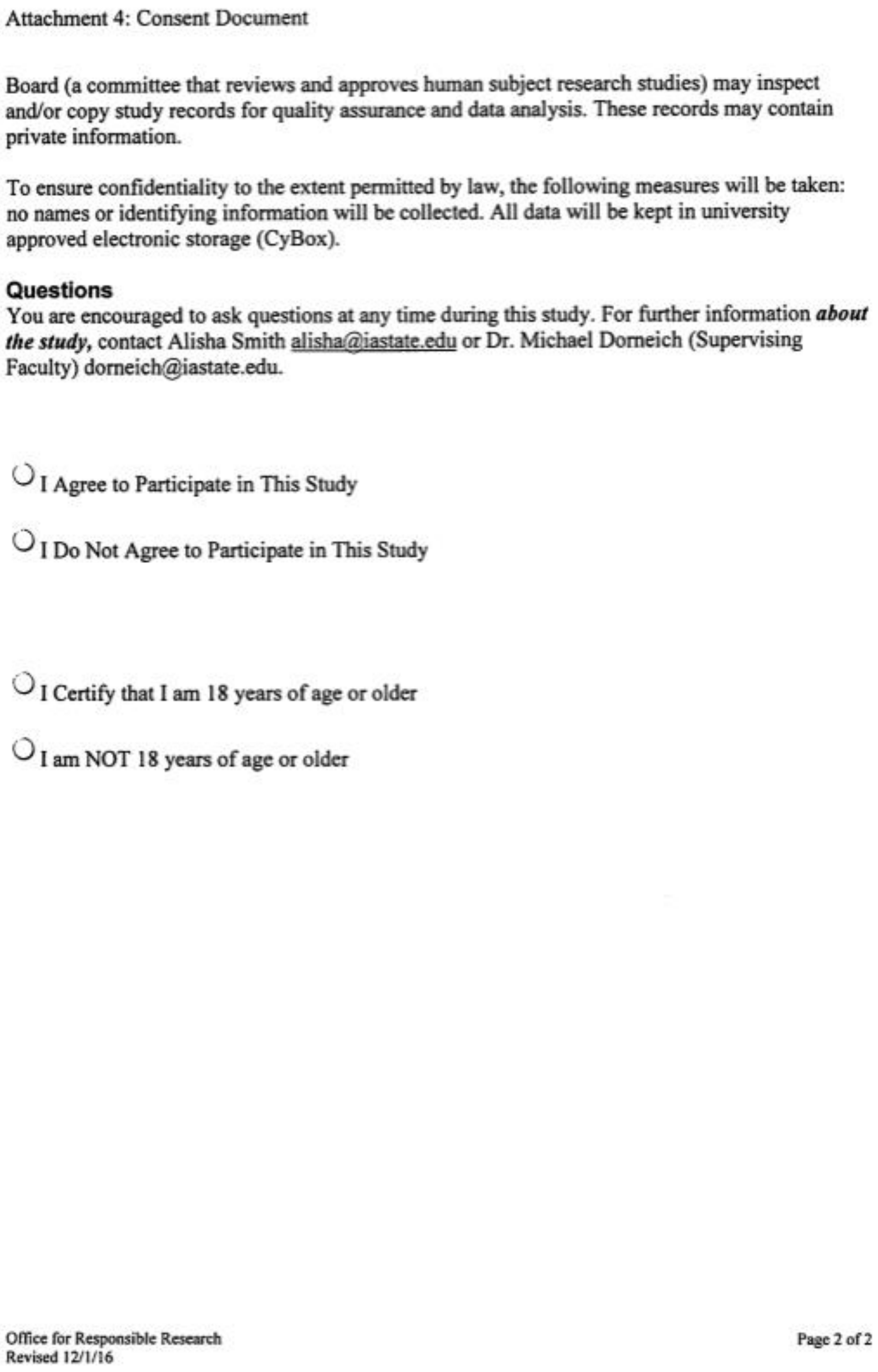
Participant Rights

Participating in this study is completely voluntary. You may choose not to take part in the study or to stop participating at any time, for any reason, without penalty or negative consequences. You can skip any questions that you do not wish to answer. The survey is completely anonymous and no identifying information will be collected.

If you have any questions *about the rights of research subjects or research-related injury*, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.

Confidentiality

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies, auditing departments of Iowa State University, and the Institutional Review



Attachment 4: Consent Document

Board (a committee that reviews and approves human subject research studies) may inspect and/or copy study records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, the following measures will be taken: no names or identifying information will be collected. All data will be kept in university approved electronic storage (CyBox).

Questions

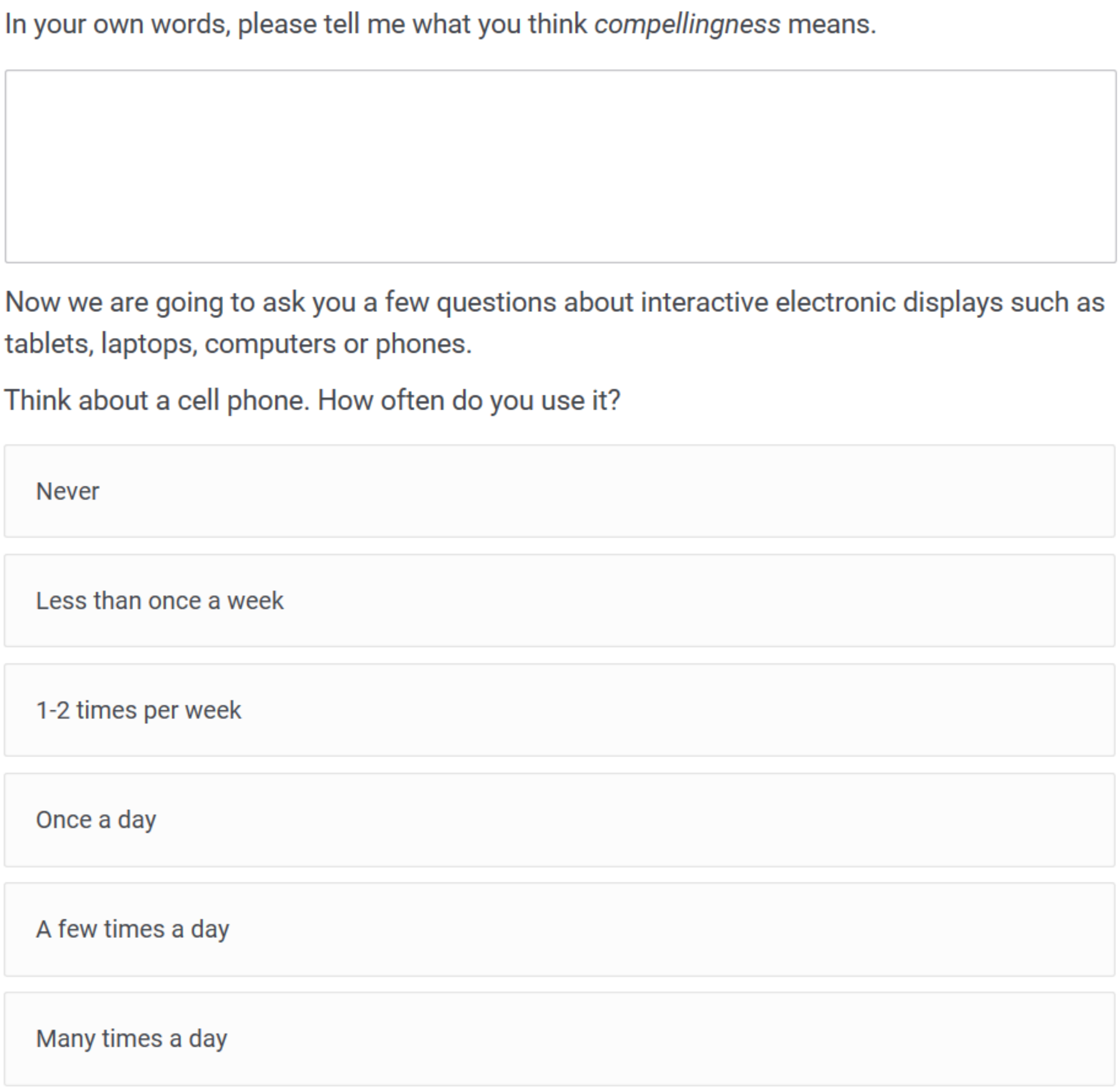
You are encouraged to ask questions at any time during this study. For further information ***about the study,*** contact Alisha Smith alisha@iastate.edu or Dr. Michael Dorneich (Supervising Faculty) dorneich@iastate.edu.

○ I Agree to Participate in This Study

○ I Do Not Agree to Participate in This Study

○ I Certify that I am 18 years of age or older

○ I am NOT 18 years of age or older



In your own words, please tell me what you think *compellingness* means.

Now we are going to ask you a few questions about interactive electronic displays such as tablets, laptops, computers or phones.

Think about a cell phone. How often do you use it?

Never

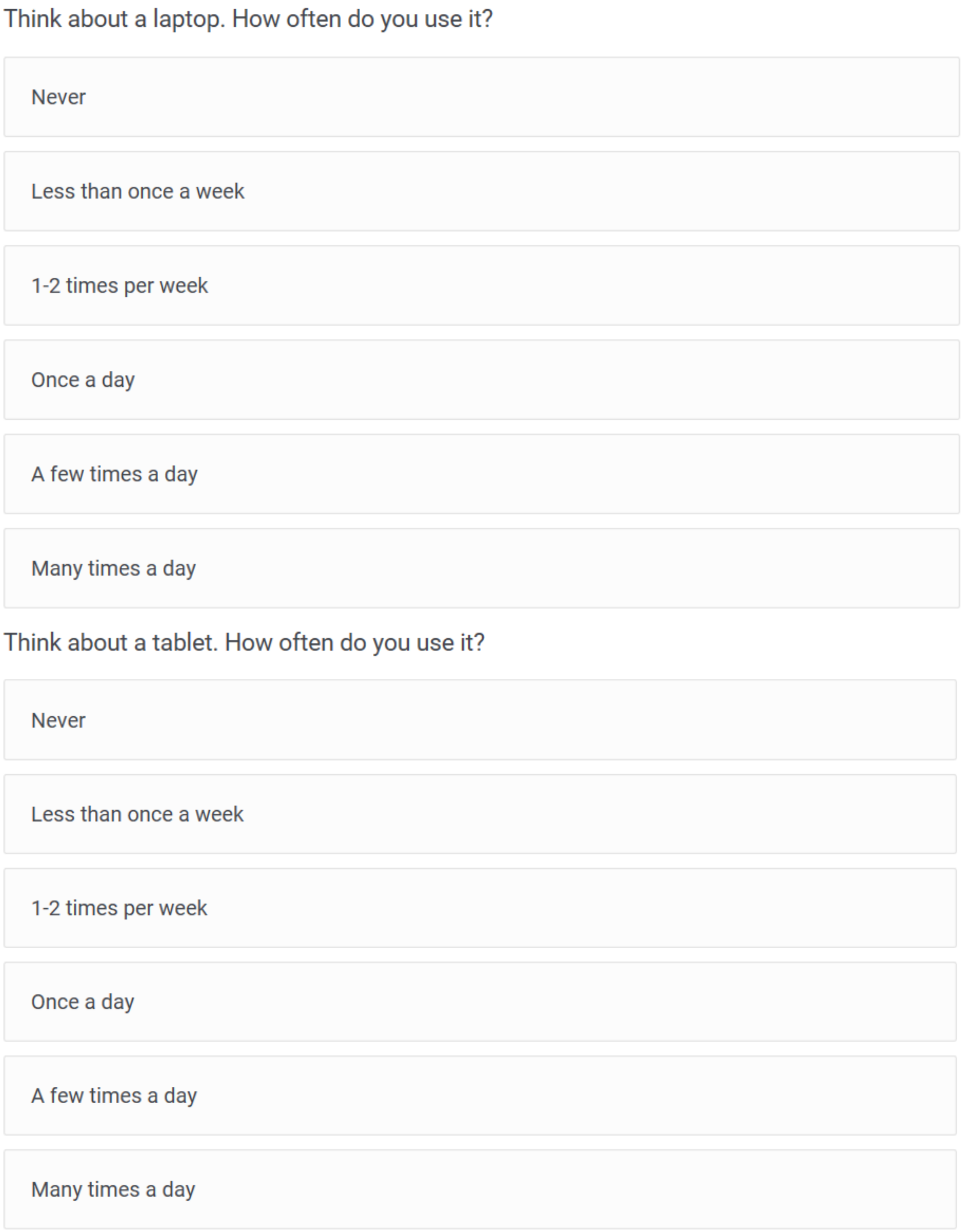
Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day



Think about a laptop. How often do you use it?

Never

Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day

Think about a tablet. How often do you use it?

Never

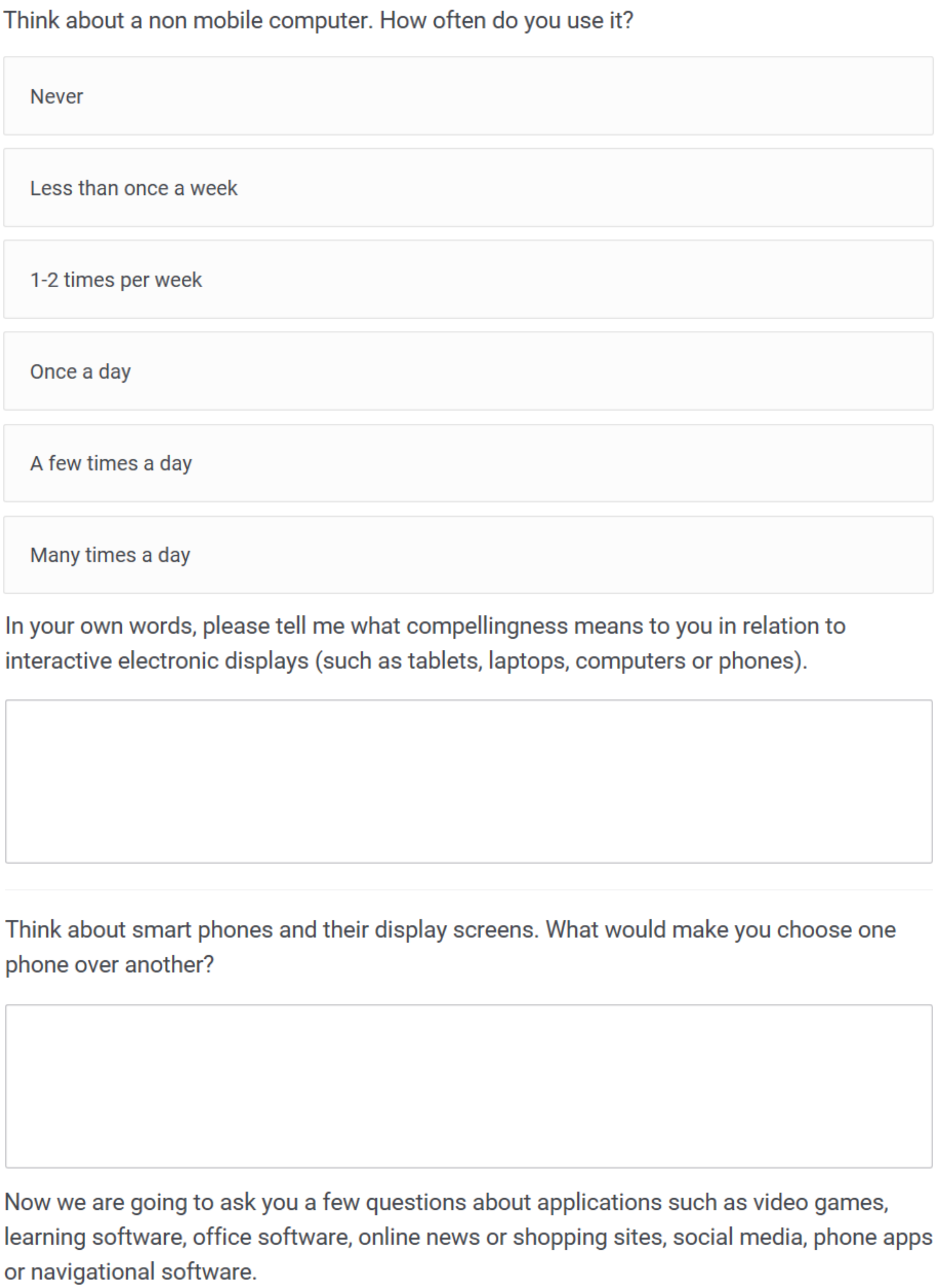
Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day



Think about a non mobile computer. How often do you use it?

Never

Less than once a week

1-2 times per week

Once a day

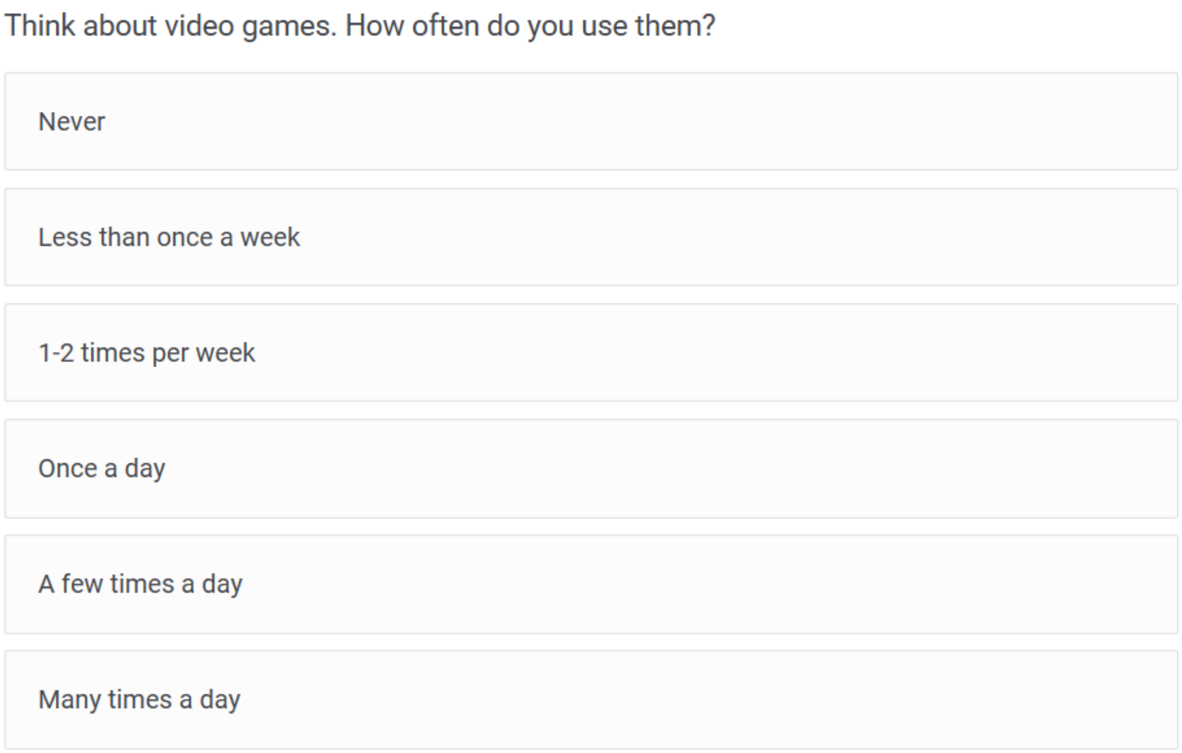
A few times a day

Many times a day

In your own words, please tell me what compellingness means to you in relation to interactive electronic displays (such as tablets, laptops, computers or phones).

Think about smart phones and their display screens. What would make you choose one phone over another?

Now we are going to ask you a few questions about applications such as video games, learning software, office software, online news or shopping sites, social media, phone apps or navigational software.



Think about video games. How often do you use them?

Never

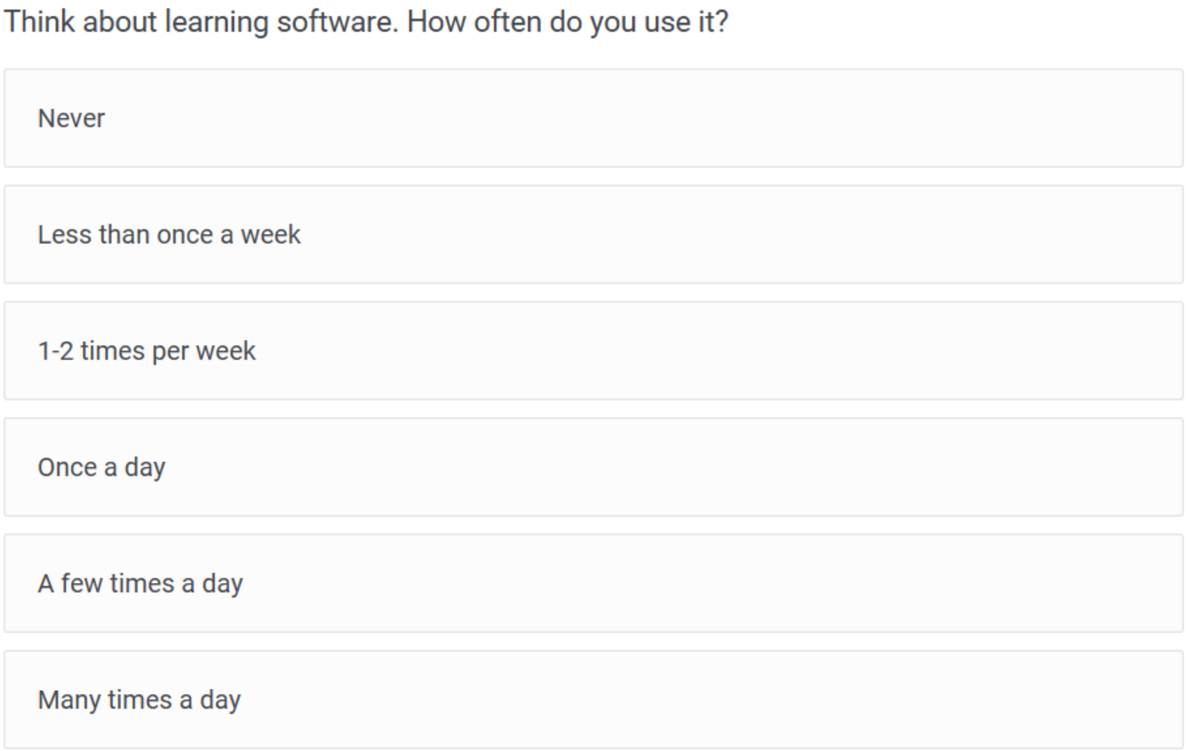
Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day



Think about learning software. How often do you use it?

Never

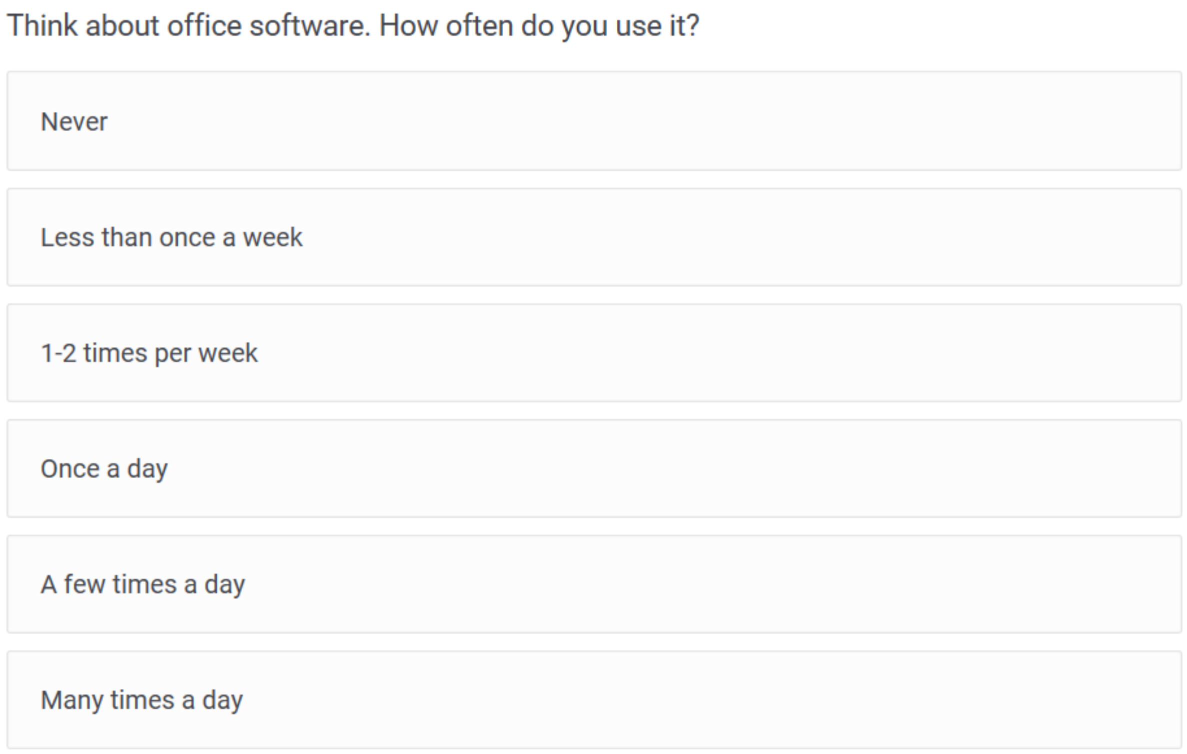
Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day



Think about office software. How often do you use it?

Never

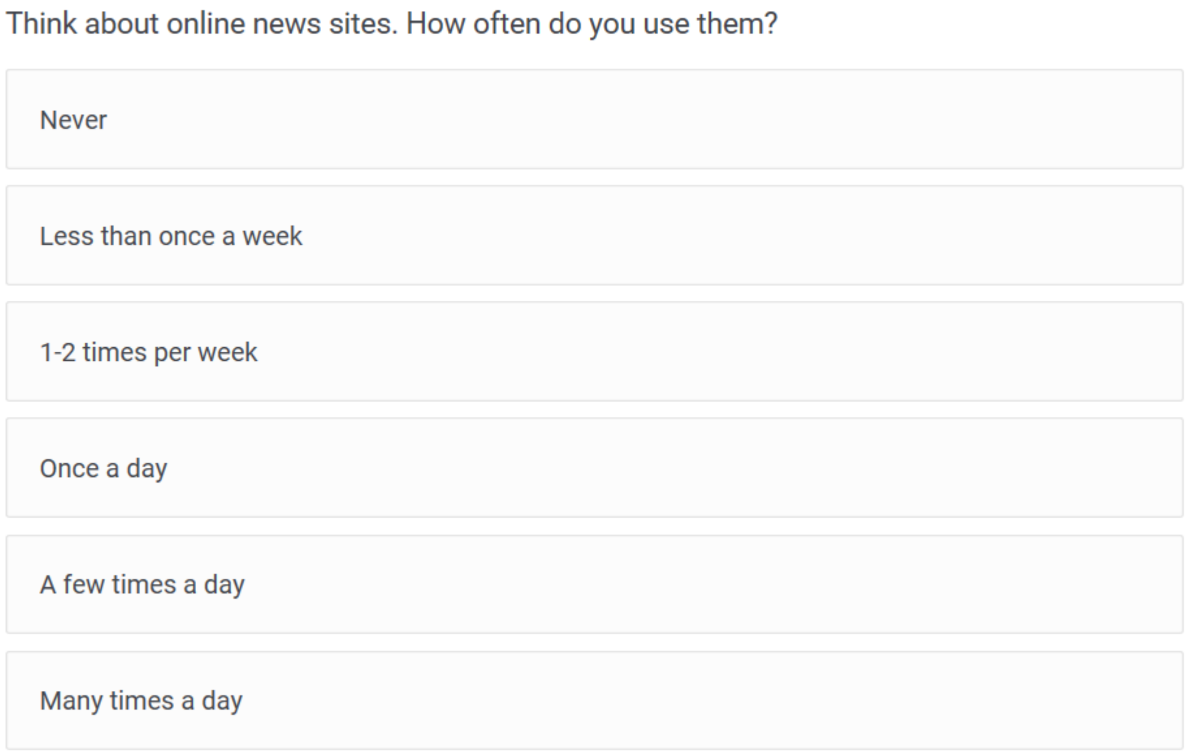
Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day



Think about online news sites. How often do you use them?

Never

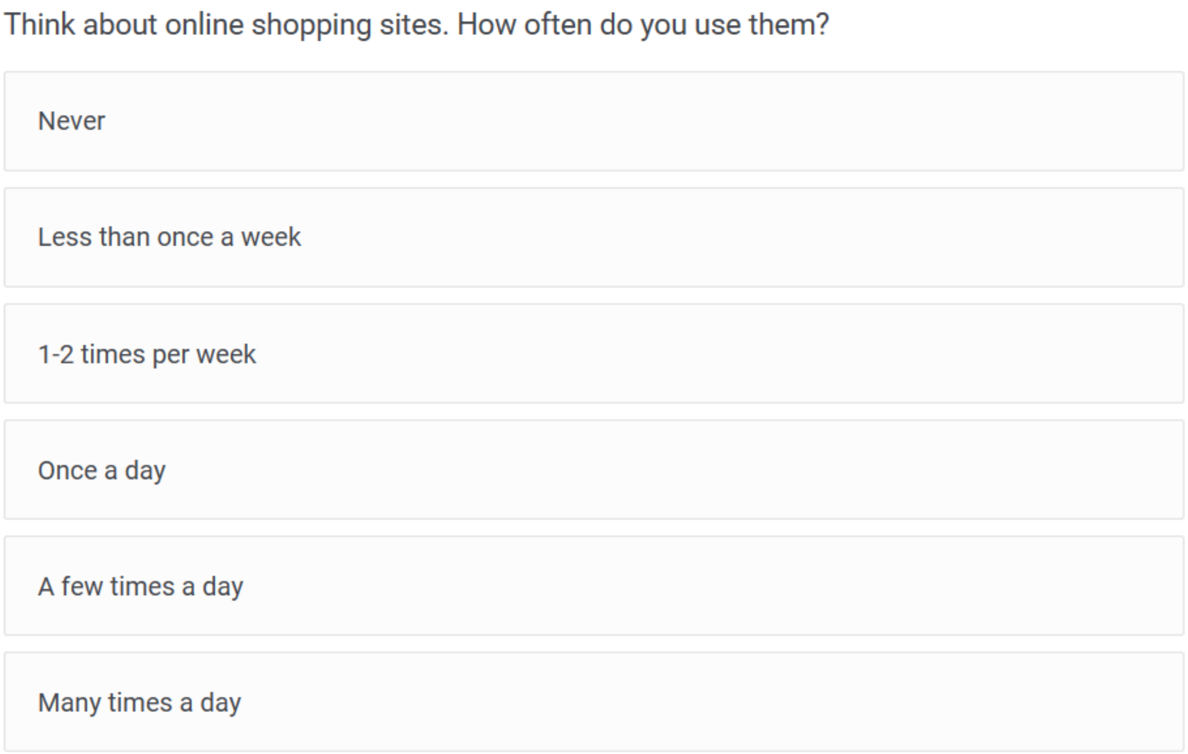
Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day



Think about online shopping sites. How often do you use them?

Never

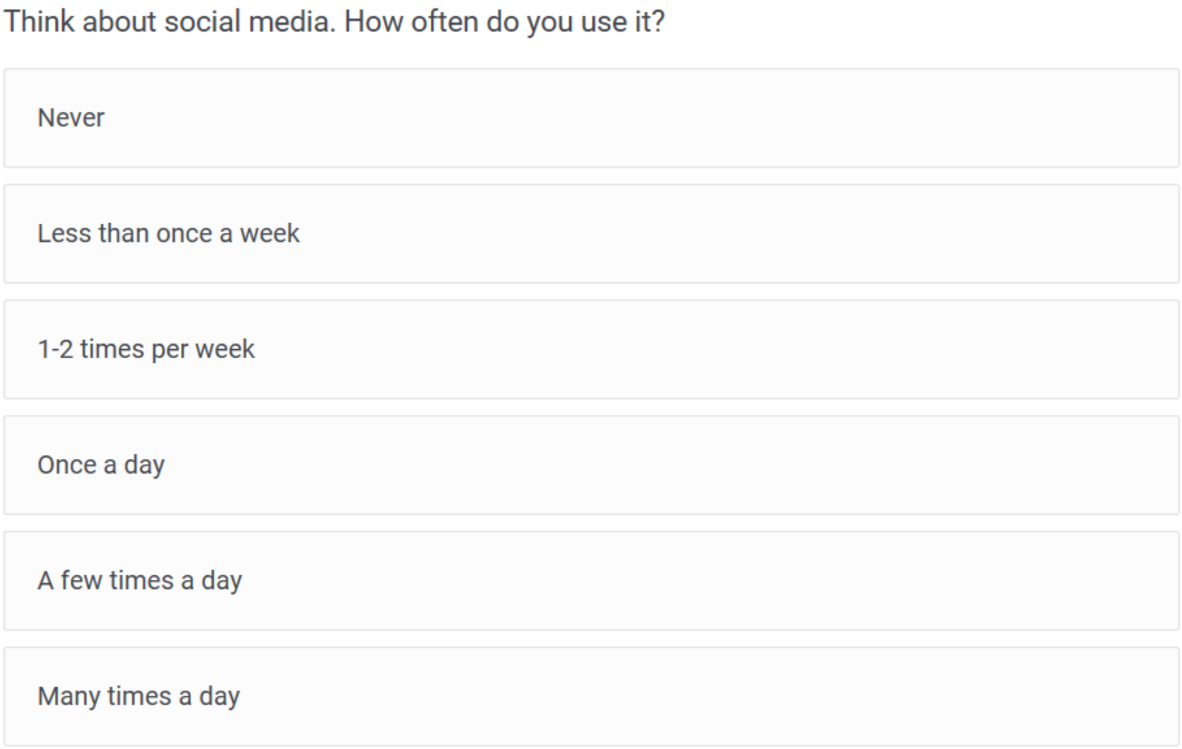
Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day



Think about social media. How often do you use it?

Never

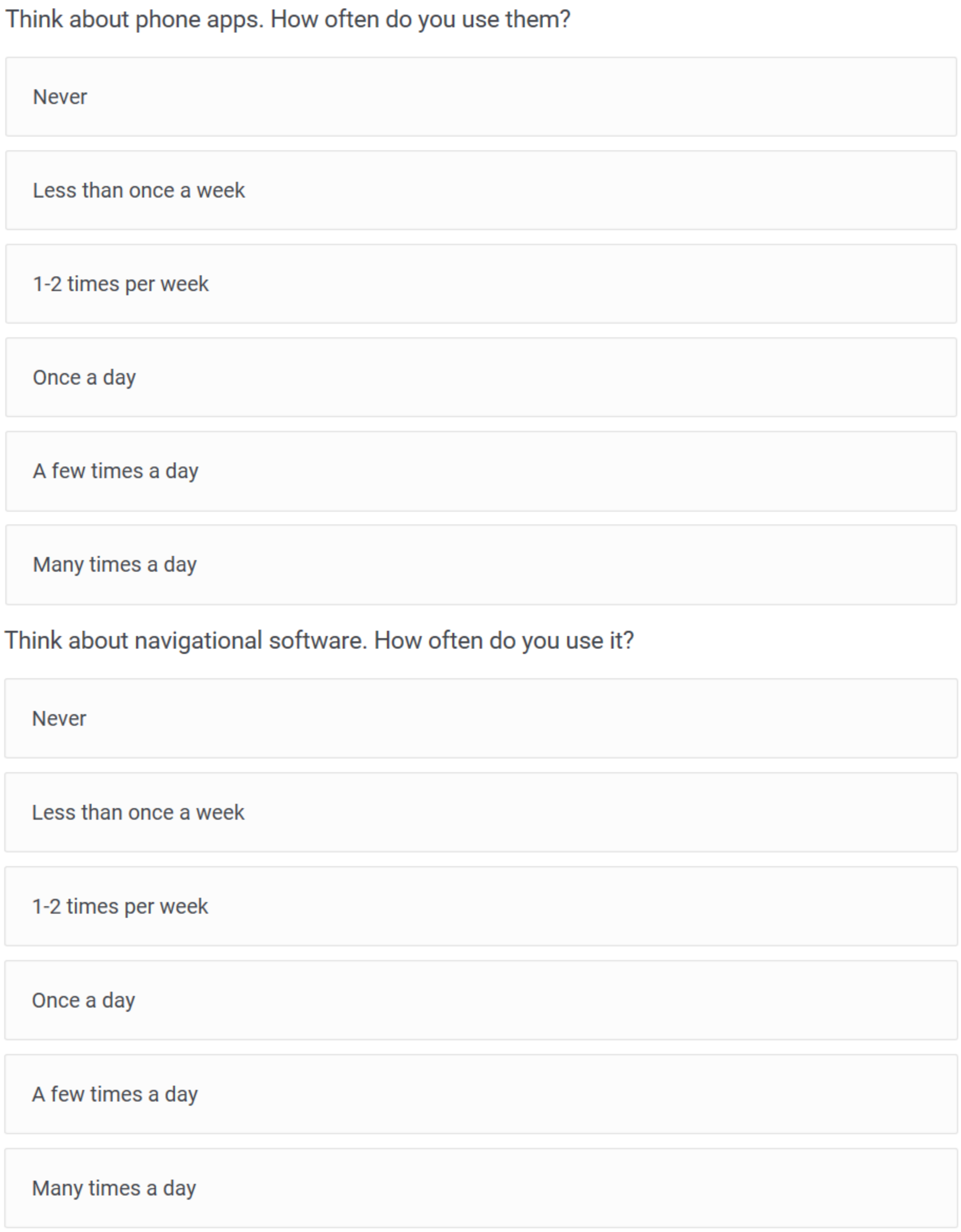
Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day



Think about phone apps. How often do you use them?

Never

Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day

Think about navigational software. How often do you use it?

Never

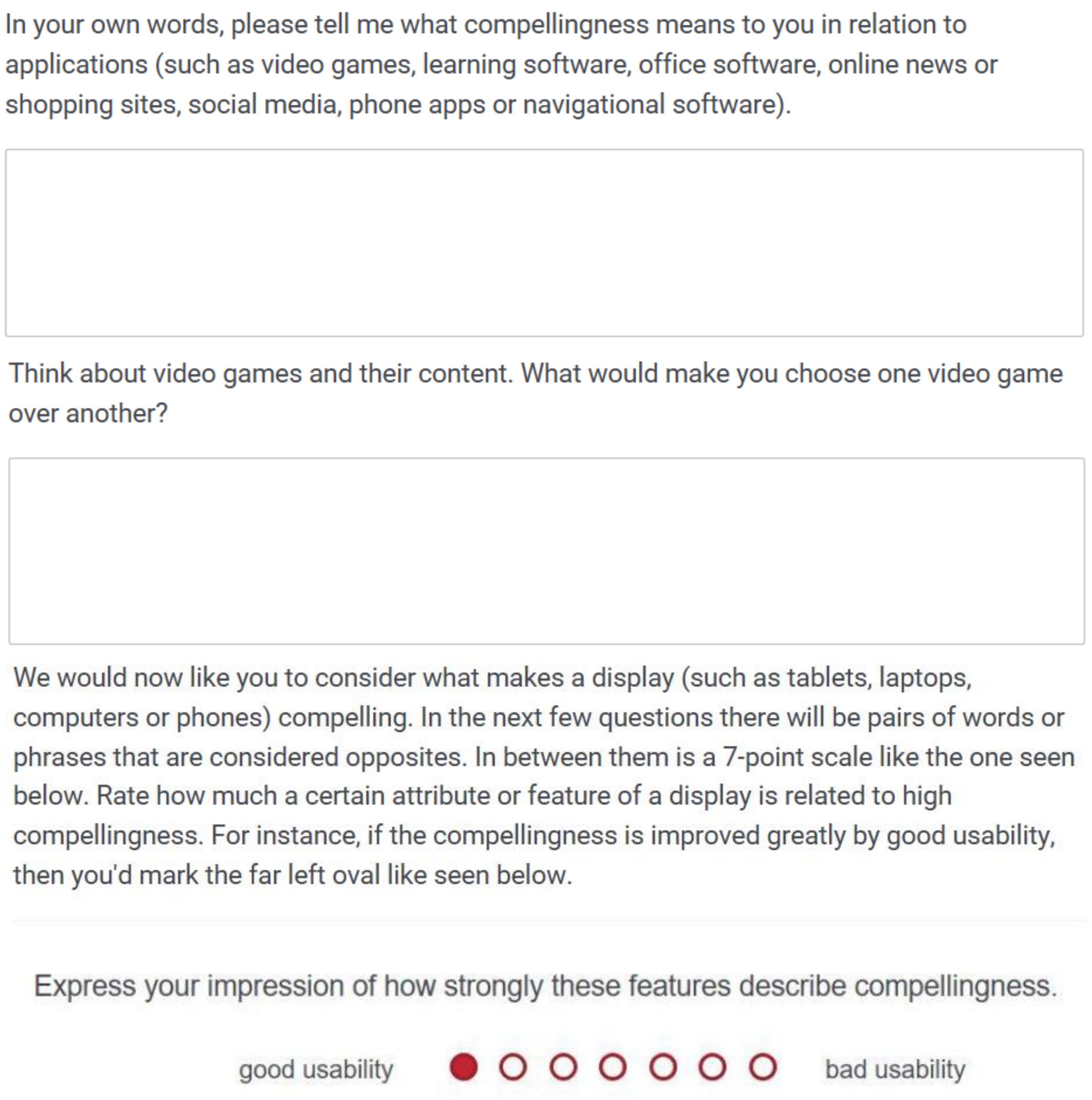
Less than once a week

1-2 times per week

Once a day

A few times a day

Many times a day



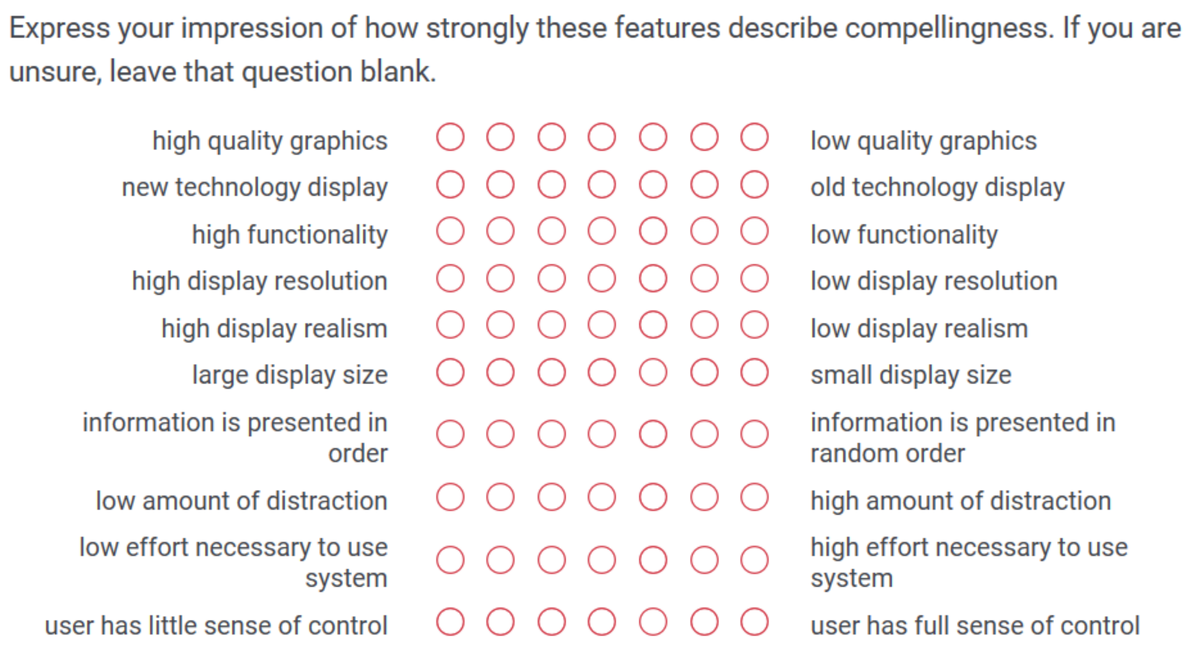
In your own words, please tell me what compellingness means to you in relation to applications (such as video games, learning software, office software, online news or shopping sites, social media, phone apps or navigational software).

Think about video games and their content. What would make you choose one video game over another?

We would now like you to consider what makes a display (such as tablets, laptops, computers or phones) compelling. In the next few questions there will be pairs of words or phrases that are considered opposites. In between them is a 7-point scale like the one seen below. Rate how much a certain attribute or feature of a display is related to high compellingness. For instance, if the compellingness is improved greatly by good usability, then you'd mark the far left oval like seen below.

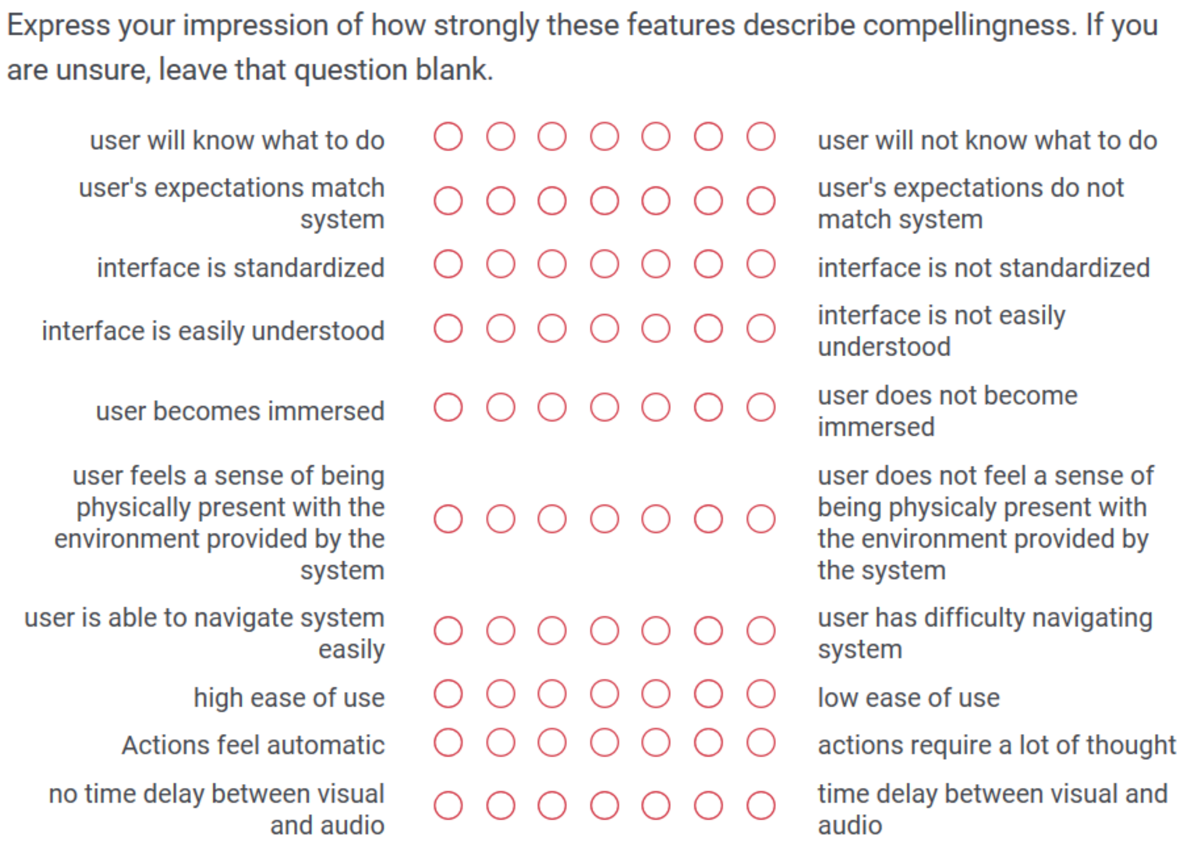
Express your impression of how strongly these features describe compellingness.

good usability ● ○ ○ ○ ○ ○ ○ bad usability



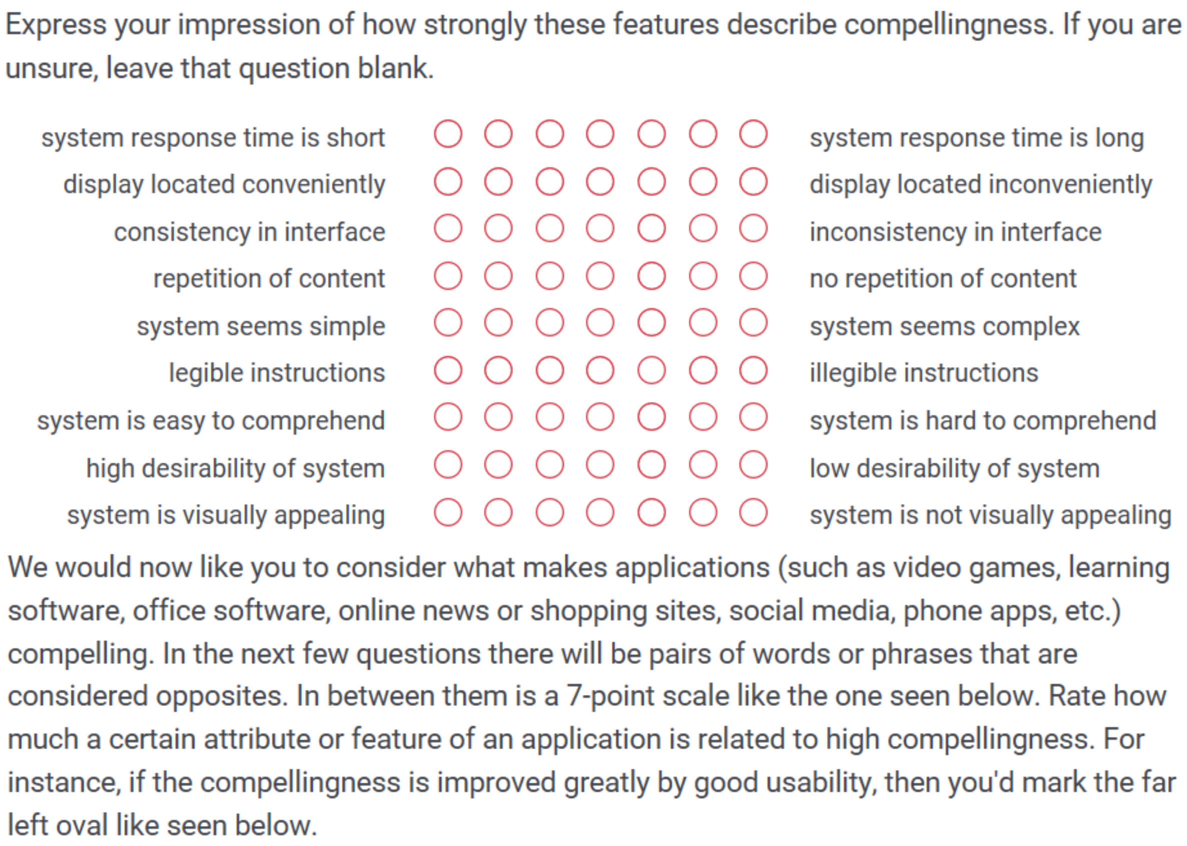
Express your impression of how strongly these features describe compellingness. If you are unsure, leave that question blank.

high quality graphics	○	○	○	○	○	○	○	low quality graphics
new technology display	○	○	○	○	○	○	○	old technology display
high functionality	○	○	○	○	○	○	○	low functionality
high display resolution	○	○	○	○	○	○	○	low display resolution
high display realism	○	○	○	○	○	○	○	low display realism
large display size	○	○	○	○	○	○	○	small display size
information is presented in order	○	○	○	○	○	○	○	information is presented in random order
low amount of distraction	○	○	○	○	○	○	○	high amount of distraction
low effort necessary to use system	○	○	○	○	○	○	○	high effort necessary to use system
user has little sense of control	○	○	○	○	○	○	○	user has full sense of control



Express your impression of how strongly these features describe compellingness. If you are unsure, leave that question blank.

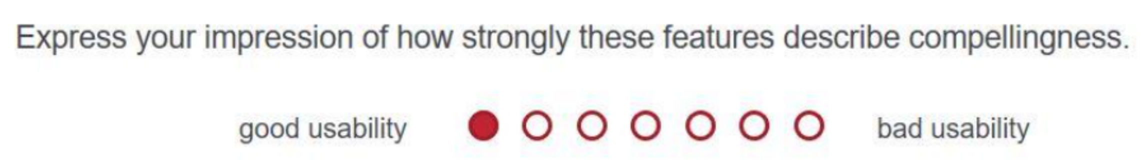
user will know what to do	○	○	○	○	○	○	○	user will not know what to do
user's expectations match system	○	○	○	○	○	○	○	user's expectations do not match system
interface is standardized	○	○	○	○	○	○	○	interface is not standardized
interface is easily understood	○	○	○	○	○	○	○	interface is not easily understood
user becomes immersed	○	○	○	○	○	○	○	user does not become immersed
user feels a sense of being physically present with the environment provided by the system	○	○	○	○	○	○	○	user does not feel a sense of being physicaly present with the environment provided by the system
user is able to navigate system easily	○	○	○	○	○	○	○	user has difficulty navigating system
high ease of use	○	○	○	○	○	○	○	low ease of use
Actions feel automatic	○	○	○	○	○	○	○	actions require a lot of thought
no time delay between visual and audio	○	○	○	○	○	○	○	time delay between visual and audio



Express your impression of how strongly these features describe compellingness. If you are unsure, leave that question blank.

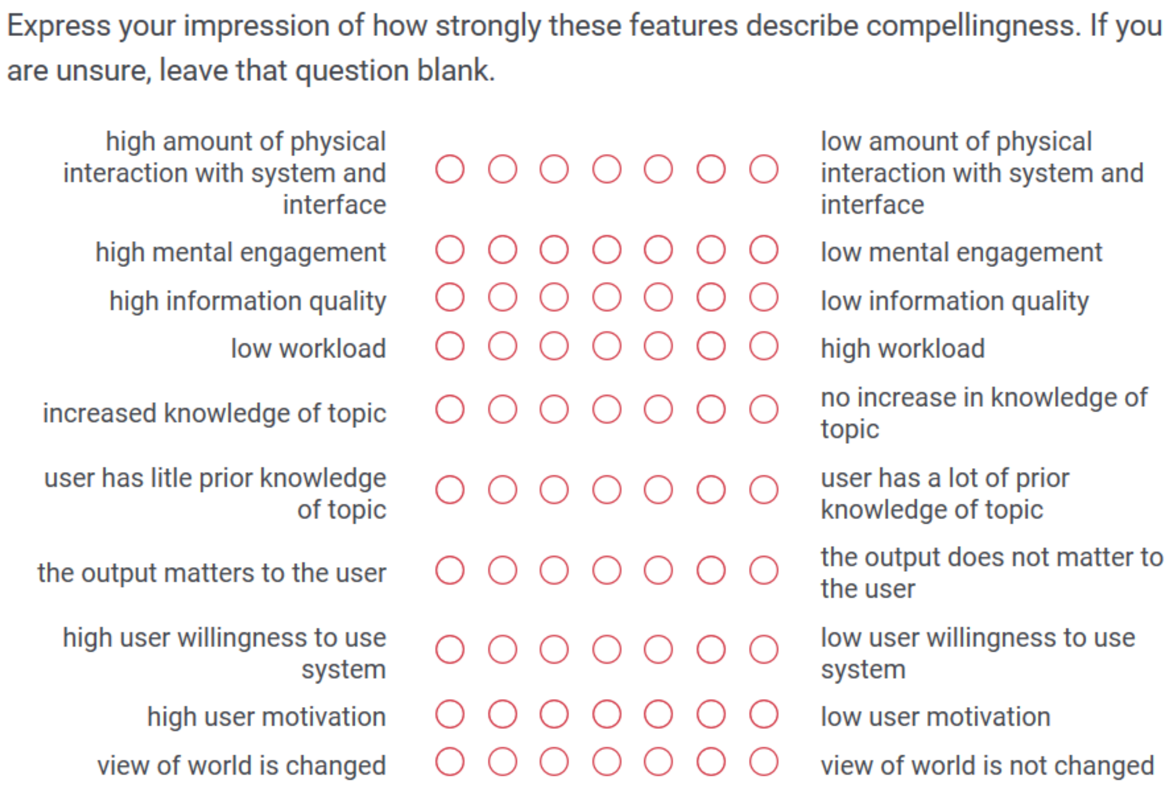
system response time is short	○	○	○	○	○	○	○	system response time is long
display located conveniently	○	○	○	○	○	○	○	display located inconveniently
consistency in interface	○	○	○	○	○	○	○	inconsistency in interface
repetition of content	○	○	○	○	○	○	○	no repetition of content
system seems simple	○	○	○	○	○	○	○	system seems complex
legible instructions	○	○	○	○	○	○	○	illegible instructions
system is easy to comprehend	○	○	○	○	○	○	○	system is hard to comprehend
high desirability of system	○	○	○	○	○	○	○	low desirability of system
system is visually appealing	○	○	○	○	○	○	○	system is not visually appealing

We would now like you to consider what makes applications (such as video games, learning software, office software, online news or shopping sites, social media, phone apps, etc.) compelling. In the next few questions there will be pairs of words or phrases that are considered opposites. In between them is a 7-point scale like the one seen below. Rate how much a certain attribute or feature of an application is related to high compellingness. For instance, if the compellingness is improved greatly by good usability, then you'd mark the far left oval like seen below.



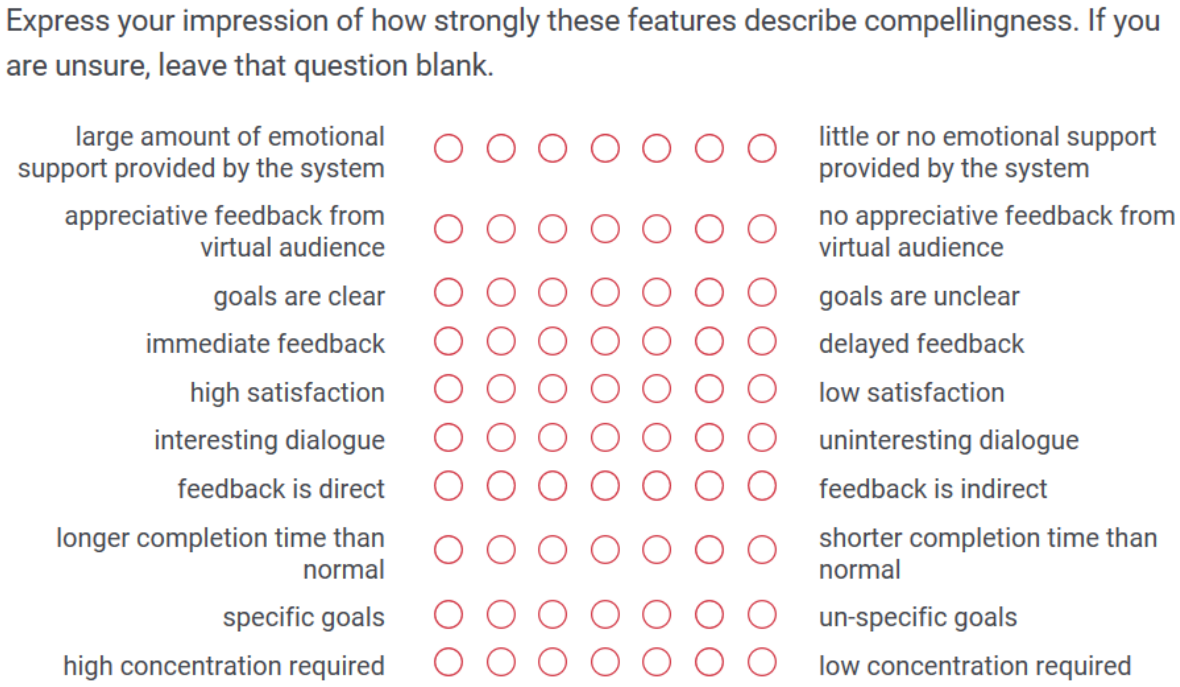
Express your impression of how strongly these features describe compellingness.

good usability	●	○	○	○	○	○	○	bad usability



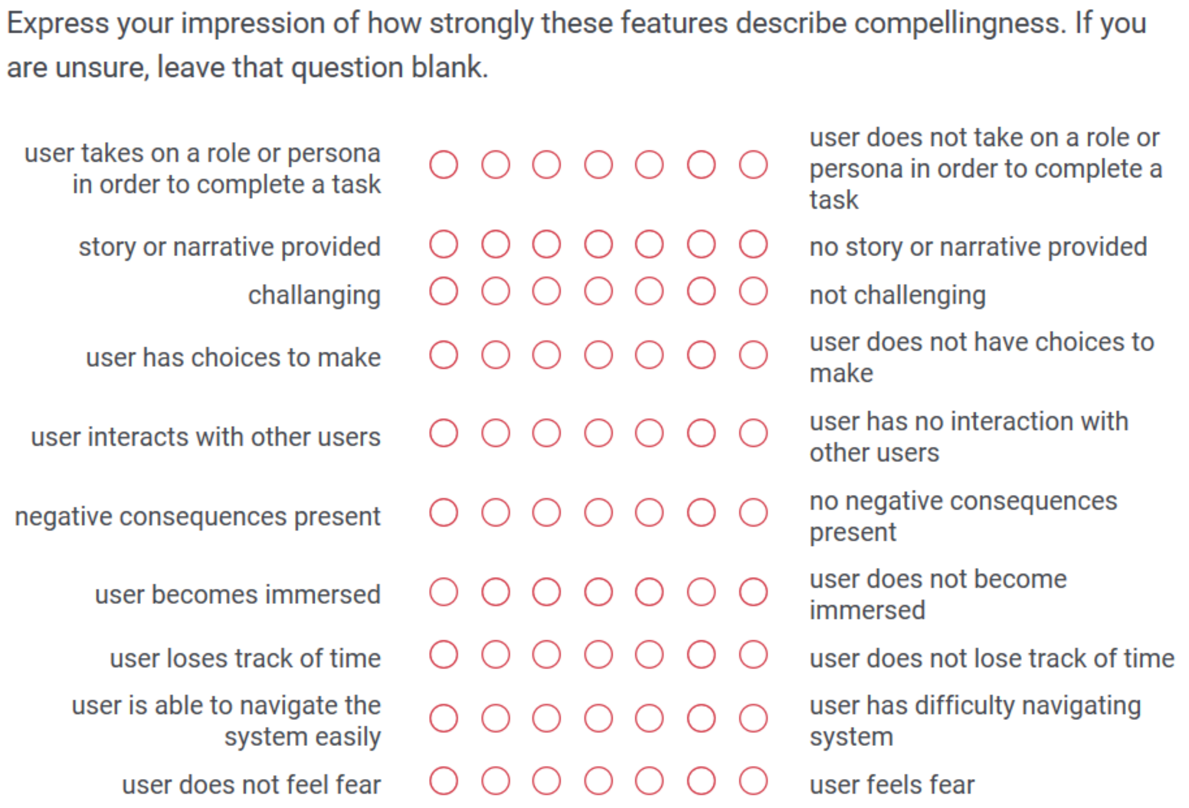
Express your impression of how strongly these features describe compellingness. If you are unsure, leave that question blank.

high amount of physical interaction with system and interface	○	○	○	○	○	○	○	low amount of physical interaction with system and interface
high mental engagement	○	○	○	○	○	○	○	low mental engagement
high information quality	○	○	○	○	○	○	○	low information quality
low workload	○	○	○	○	○	○	○	high workload
increased knowledge of topic	○	○	○	○	○	○	○	no increase in knowledge of topic
user has litle prior knowledge of topic	○	○	○	○	○	○	○	user has a lot of prior knowledge of topic
the output matters to the user	○	○	○	○	○	○	○	the output does not matter to the user
high user willingness to use system	○	○	○	○	○	○	○	low user willingness to use system
high user motivation	○	○	○	○	○	○	○	low user motivation
view of world is changed	○	○	○	○	○	○	○	view of world is not changed



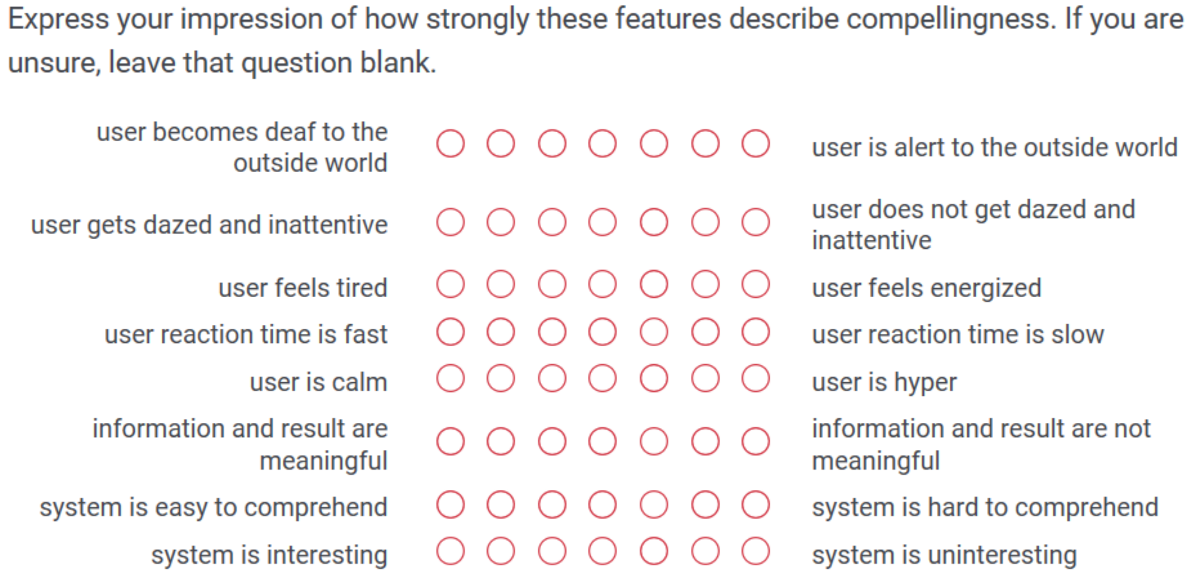
Express your impression of how strongly these features describe compellingness. If you are unsure, leave that question blank.

large amount of emotional support provided by the system	○	○	○	○	○	○	○	little or no emotional support provided by the system
appreciative feedback from virtual audience	○	○	○	○	○	○	○	no appreciative feedback from virtual audience
goals are clear	○	○	○	○	○	○	○	goals are unclear
immediate feedback	○	○	○	○	○	○	○	delayed feedback
high satisfaction	○	○	○	○	○	○	○	low satisfaction
interesting dialogue	○	○	○	○	○	○	○	uninteresting dialogue
feedback is direct	○	○	○	○	○	○	○	feedback is indirect
longer completion time than normal	○	○	○	○	○	○	○	shorter completion time than normal
specific goals	○	○	○	○	○	○	○	un-specific goals
high concentration required	○	○	○	○	○	○	○	low concentration required



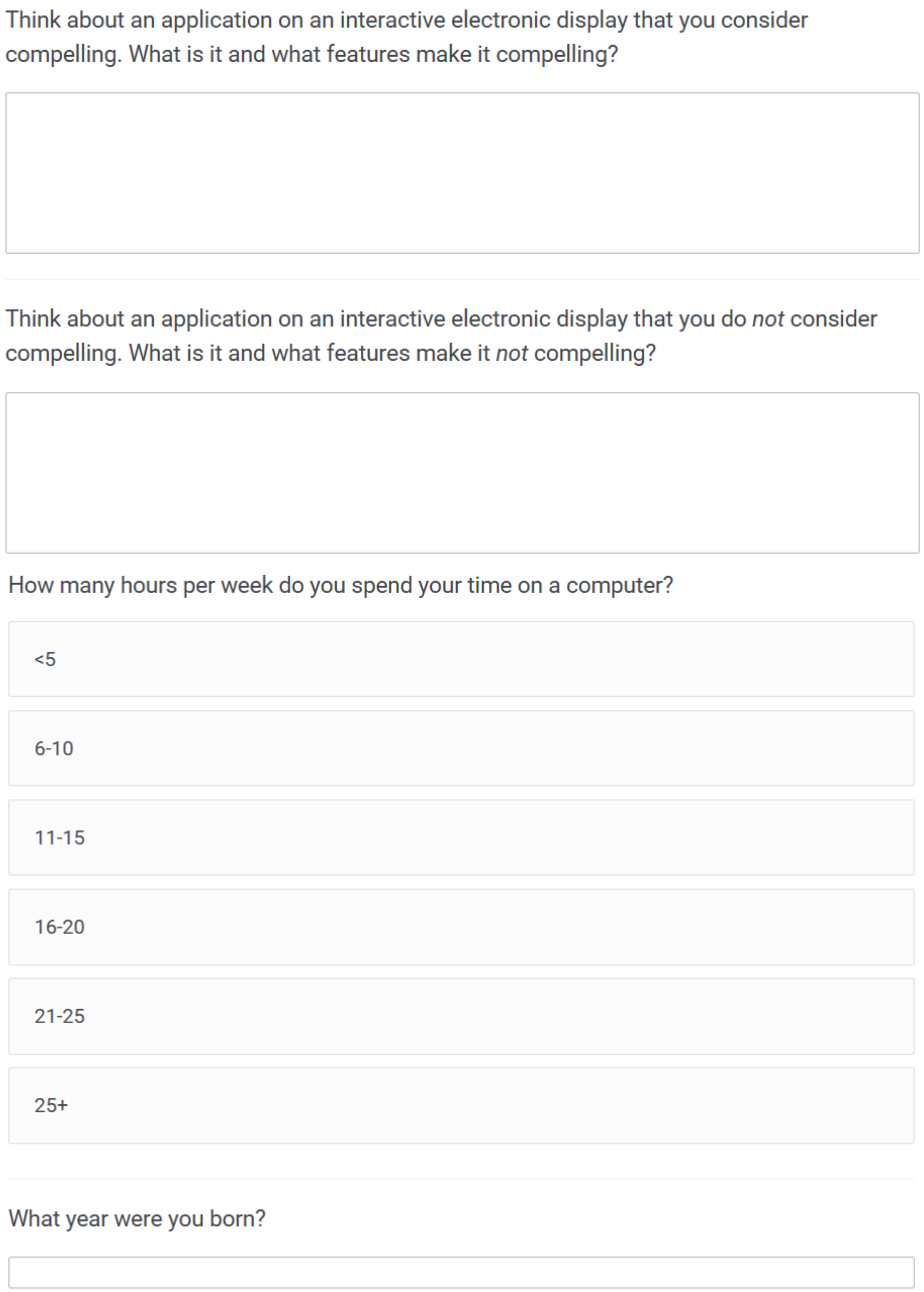
Express your impression of how strongly these features describe compellingness. If you are unsure, leave that question blank.

user takes on a role or persona in order to complete a task	○	○	○	○	○	○	○	user does not take on a role or persona in order to complete a task
story or narrative provided	○	○	○	○	○	○	○	no story or narrative provided
challanging	○	○	○	○	○	○	○	not challenging
user has choices to make	○	○	○	○	○	○	○	user does not have choices to make
user interacts with other users	○	○	○	○	○	○	○	user has no interaction with other users
negative consequences present	○	○	○	○	○	○	○	no negative consequences present
user becomes immersed	○	○	○	○	○	○	○	user does not become immersed
user loses track of time	○	○	○	○	○	○	○	user does not lose track of time
user is able to navigate the system easily	○	○	○	○	○	○	○	user has difficulty navigating system
user does not feel fear	○	○	○	○	○	○	○	user feels fear



Express your impression of how strongly these features describe compellingness. If you are unsure, leave that question blank.

user becomes deaf to the outside world	○	○	○	○	○	○	○	user is alert to the outside world
user gets dazed and inattentive	○	○	○	○	○	○	○	user does not get dazed and inattentive
user feels tired	○	○	○	○	○	○	○	user feels energized
user reaction time is fast	○	○	○	○	○	○	○	user reaction time is slow
user is calm	○	○	○	○	○	○	○	user is hyper
information and result are meaningful	○	○	○	○	○	○	○	information and result are not meaningful
system is easy to comprehend	○	○	○	○	○	○	○	system is hard to comprehend
system is interesting	○	○	○	○	○	○	○	system is uninteresting



Think about an application on an interactive electronic display that you consider compelling. What is it and what features make it compelling?

Think about an application on an interactive electronic display that you do *not* consider compelling. What is it and what features make it *not* compelling?

How many hours per week do you spend your time on a computer?

<5

6-10

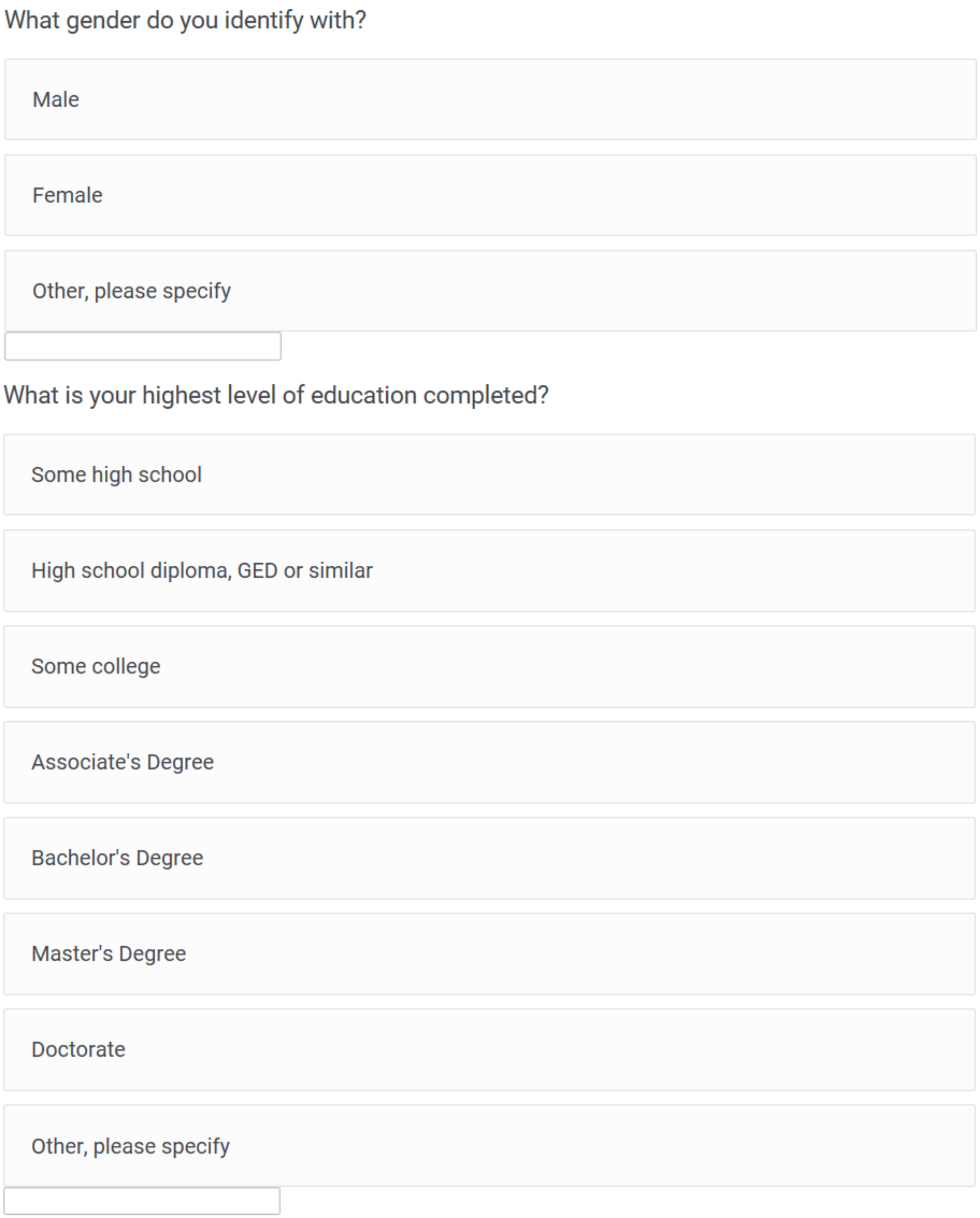
11-15

16-20

21-25

25+

What year were you born?

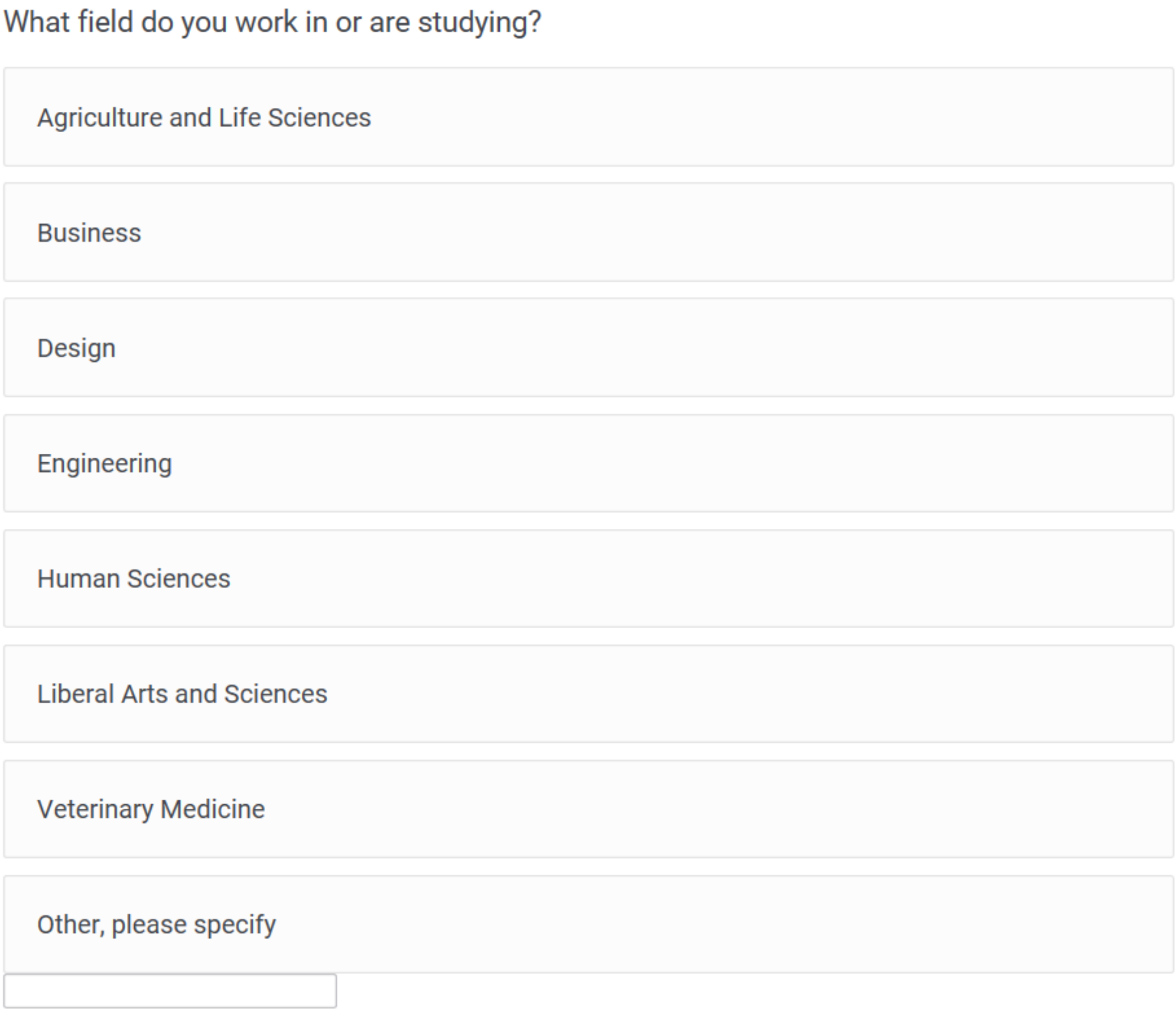


What gender do you identify with?

- Male
- Female
- Other, please specify

What is your highest level of education completed?

- Some high school
- High school diploma, GED or similar
- Some college
- Associate's Degree
- Bachelor's Degree
- Master's Degree
- Doctorate
- Other, please specify



What field do you work in or are studying?

- Agriculture and Life Sciences
- Business
- Design
- Engineering
- Human Sciences
- Liberal Arts and Sciences
- Veterinary Medicine
- Other, please specify

APPENDIX B

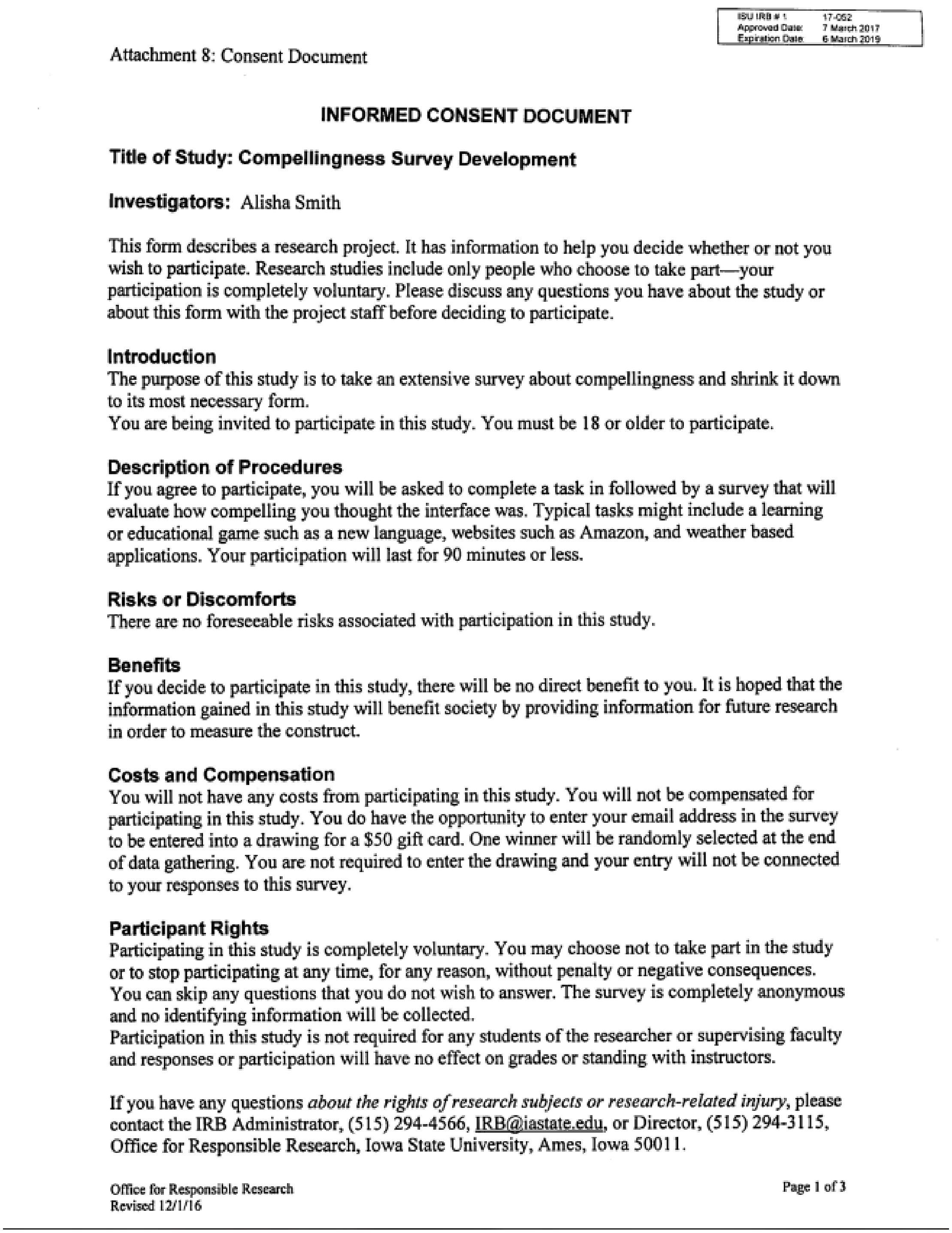
STUDY 2 PARTICIPANT GUIDE

Briefing and Introduction

Thank you for coming to participate in my study today. Before we get started, please read over and sign this informed consent document. It explains to you that you will be completing a map based task followed by a survey. We will de-identify all of your data and you can stop your participation at any time.

If you have any questions, please ask. All the data will be collected in this booklet. Please do not look ahead and only at the page you are given.

Do you have any questions at this time?



Attachment 8: Consent Document

INFORMED CONSENT DOCUMENT

Title of Study: Compellingness Survey Development

Investigators: Alisha Smith

This form describes a research project. It has information to help you decide whether or not you wish to participate. Research studies include only people who choose to take part—your participation is completely voluntary. Please discuss any questions you have about the study or about this form with the project staff before deciding to participate.

Introduction

The purpose of this study is to take an extensive survey about compellingness and shrink it down to its most necessary form.

You are being invited to participate in this study. You must be 18 or older to participate.

Description of Procedures

If you agree to participate, you will be asked to complete a task in followed by a survey that will evaluate how compelling you thought the interface was. Typical tasks might include a learning or educational game such as a new language, websites such as Amazon, and weather based applications. Your participation will last for 90 minutes or less.

Risks or Discomforts

There are no foreseeable risks associated with participation in this study.

Benefits

If you decide to participate in this study, there will be no direct benefit to you. It is hoped that the information gained in this study will benefit society by providing information for future research in order to measure the construct.

Costs and Compensation

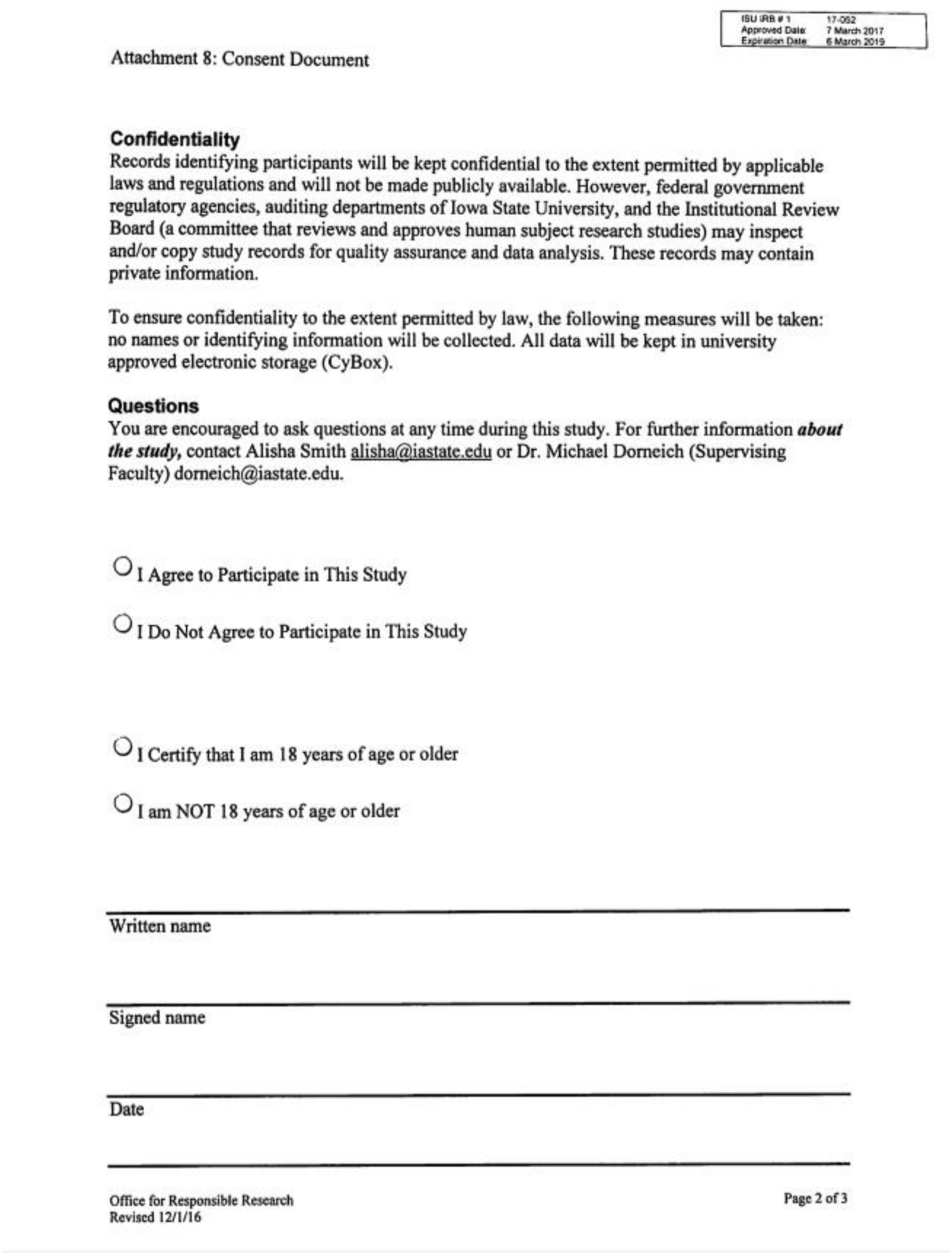
You will not have any costs from participating in this study. You will not be compensated for participating in this study. You do have the opportunity to enter your email address in the survey to be entered into a drawing for a $50 gift card. One winner will be randomly selected at the end of data gathering. You are not required to enter the drawing and your entry will not be connected to your responses to this survey.

Participant Rights

Participating in this study is completely voluntary. You may choose not to take part in the study or to stop participating at any time, for any reason, without penalty or negative consequences. You can skip any questions that you do not wish to answer. The survey is completely anonymous and no identifying information will be collected.

Participation in this study is not required for any students of the researcher or supervising faculty and responses or participation will have no effect on grades or standing with instructors.

If you have any questions *about the rights of research subjects or research-related injury*, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.



ISU IRB # 1 17-062
Approved Date 7 March 2017
Expiration Date 6 March 2019

Attachment 8: Consent Document

Confidentiality

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies, auditing departments of Iowa State University, and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy study records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, the following measures will be taken: no names or identifying information will be collected. All data will be kept in university approved electronic storage (CyBox).

Questions

You are encouraged to ask questions at any time during this study. For further information ***about the study,*** contact Alisha Smith alisha@iastate.edu or Dr. Michael Dorneich (Supervising Faculty) dorneich@iastate.edu.

○ I Agree to Participate in This Study

○ I Do Not Agree to Participate in This Study

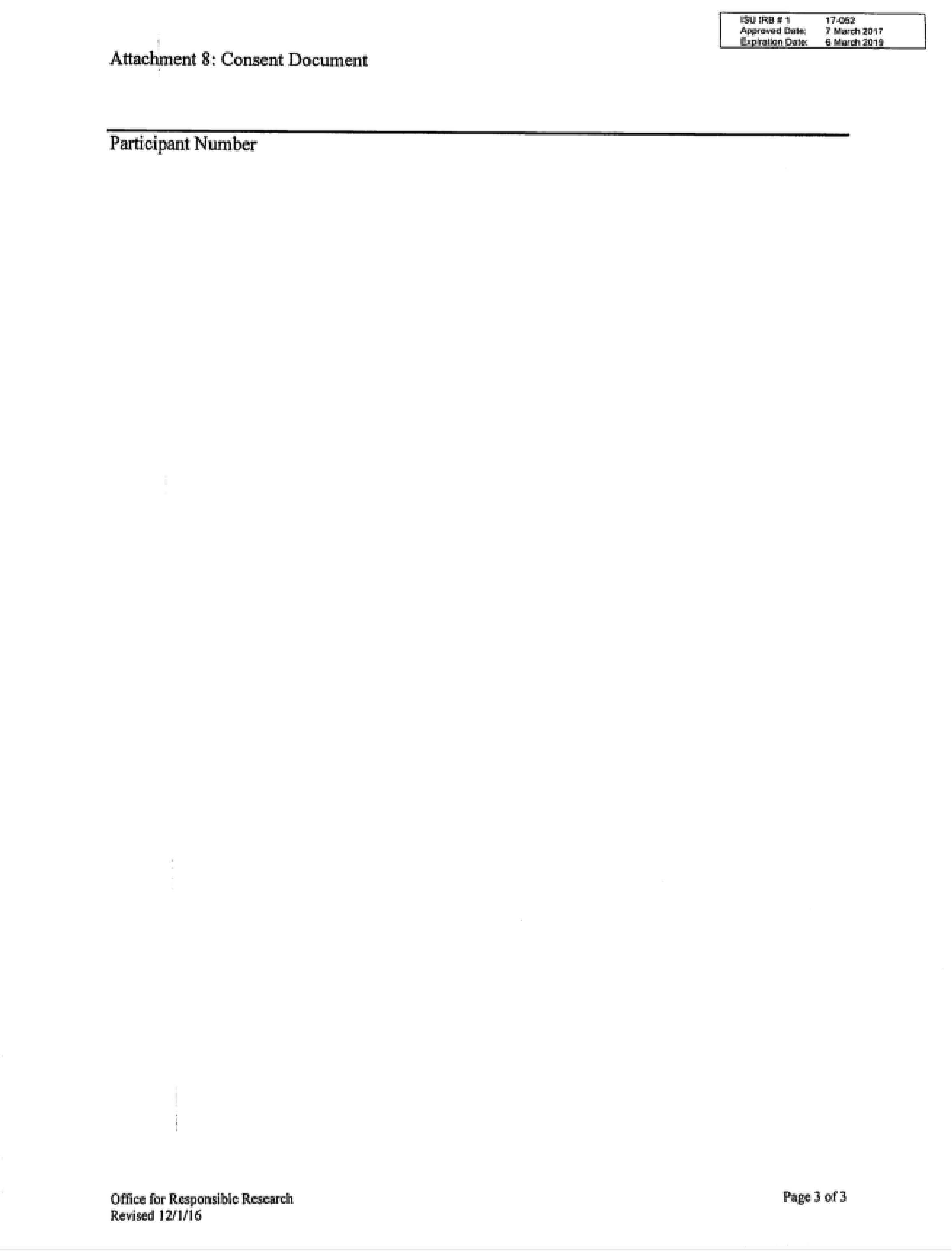
○ I Certify that I am 18 years of age or older

○ I am NOT 18 years of age or older

Written name

Signed name

Date



ISU IRB # 1	17-052
Approved Date:	7 March 2017
Expiration Date:	6 March 2019

Attachment 8: Consent Document

Participant Number

Training

The tasks you will be doing will be done in a Google Maps program called MyMaps. In this program you can not only search for locations, get navigational instructions, and indicate locations, but you can also draw on the map. You will be using this drawing feature to indicate what route you would choose to take for the given scenario. We are going to do some short training here for you to learn how to use this program.

We will start by opening the MyMap called “Training”. To open this map, simply click on the map in the menu. Everything will automatically save so if you ever accidentally back out of the map to this page, you can just click on the map again to get to your previous work.

The left side navigational menu panel is called the Legend. Please select the button labeled “legend” to open that menu now. Selecting this button will open and close the side menu.

In this menu you will now see a layer entitled “Layer 1-Locations”. Under this layer, I have already created one location for you entitled “Black Engineering”. This is the building I take most of my classes in and do much of my research in at Iowa State. I am now going to have you add a location to this layer. Please find the search bar at the top left of the map view. In it, start typing “Hilton Coliseum”. As you type, automatic suggestions should be appearing in a list below where you are typing. Select the one that says “Hilton Coliseum, Ames, IA, United States”. The map should now have zoomed in on that location and popped up a box that says Hilton Coliseum on the top. On the bottom of that box there is an option to add that location to the map. Click on the plus sign or words to add it. You should now see Hilton Coliseum in your Layer 1- Location under Black Engineering in your Legend to the left.

Try adding a third location, “Hickory Park” by yourself.

Great, now let’s try searching near here. To begin, start typing “hotels” into the search bar. You will notice that it will give you exact hotel name options to select but if you want to see all options appear on the map at the same time, there is a choice at the bottom of the dropdown list that says “search places near current view”. Select that option and all hotels in your current map will appear. We are not going to select a hotel at this time but this is an important search feature to know for the later tasks.

Next I will teach you how to get navigational directions on a layer. To do this we will add another layer to keep organized. Think of a layer as a grouped section of additions to a map such as location dots or navigational routes. Each layer can be shown or hidden in order to make the map easier to read.

To create a driving layer, there are a few button options underneath the search bar we used previously. Select the one that looks like an arrow choosing one of two paths shaped like a Y. This should create a layer in your legend that is untitled and says “driving” below the title in blue lettering. There are also two input boxes denoting the starting location and final destination. Please click inside the first box.

Notice that the layer you are working in has a blue bar to the left of it denoting which layer you are in. To switch between layers you simply click inside that layer box and the left bar will turn blue.

If you begin to type “Black Engineering” you will see the first option that appears is your location from Layer 1. Select that option. In the second box, start typing “Hilton Coliseum” and select the first option from layer 1. After the page automatically refreshes, a blue line will appear on the map denoting the best route, and the words “Add Destination” will appear in the Directions layer (which has now renamed itself to Directions from Black Engineering to Hilton Coliseum”). Click the words “Add Destination” now and add the destination of Hickory Park from Layer 1.

You will notice that next to the name of the layers there is a small check box. Try unchecking the one next to the directions. See how the blue lines disappeared? Now click the check box again to make them reappear.

Now we are going to make our own route just by drawing lines. This may take a bit of practice so take your time experimenting with this portion. We’ll start by learning how to make a line in the first place. Under the search bar, select the icon that looks like three dots connected by lines. Under it, select the option “add line or shape”. You are now ready to start drawing your line. To begin, click anywhere on the map. Click again elsewhere and a line will be drawn between these two points. Click a few more times to make your line longer and zig-zaggy. When you are finished making your line, double click to finish. You will then see a box entitled “Line 1” with options in the bottom left to change the color of the line, edit the line, upload an image for the line, and delete the line. Go ahead and select the edit feature that looks like a pencil. Take some time clicking on the points of the line and moving them around to familiarize yourself with how you can change its shape.

Please note that when you are in the line drawing mode, you cannot zoom in or out or pan in any direction. This may force you to zoom in and draw smaller sections of lines at a time so that you can add more detail to them. To get out of the line drawing mode in order to zoom you may select the hand icon under the search bar.

Once you feel comfortable drawing lines, I will now ask you to try to make some lines that trace out the path that the directions in the second layer give you between each of the locations we made in Layer 1. This does not have to be one continuous line but can be many short line segments if you would so desire. I just would like to see something similar to the blue navigational lines if I were to hide them.

Please let me know if you have any questions as you are attempting this and also let me know when you feel you are finished with the task.

Finally, the routes you will be making in today's tasks will require you to make as few left turns as possible. From the lines that you have already drawn, or from completely new lines, try to take this route with as few left turns as possible. It may be helpful to hide the navigation layer at this point.

NASA TLX

I will now have you complete a quick study about how much workload the training was. This study consists of six questions that gauge how much work the tutorial was. Please note that the performance scale goes in the opposite direction of the other 5 factors.

- □ Have participant take qualtrics survey "NASA TLX"

Start Time: _____________

End time: ___________

Overview

For this experiment we are going to start by conducting a route planning task. In the recruitment materials and in the informed consent you may have read about the three $50 gift cards. The number of entries you get for this gift card will depend on your performance on this task compared to the other participants. If you are in the top 10% of participants you will receive 10 entries into the gift card drawing for this task. If you are in the 80-90th percentile you will get 9 entries and so on and so forth. The bottom 10% of participants will only get 1 entry into the gift card drawing.

Any questions?

- □ Open MyMap file "Participant #, Trial 1"

I will now read to you the first scenario that you will be deciding your route based on. You will have this scenario in front of you when planning your route.

Scenario 1: Nevada dinner

You and a friend are heading out to dinner for the night. You are at your house and must pick them up from theirs before getting to the restaurant. You are a little short on gas so you want to be sure to get some before you pick up your friend. You also hear that there is an accident along your route that you must avoid. You are all starving so you want to get to the restaurant as fast as possible and so to cut down on time you want to take as few left turns as possible.

Using the home, friend's house, accident, and restaurant locations on your map, navigate the best route for this scenario. You may choose what gas station you would like to stop at and which roads you would like to take. Remember to avoid the accident marked on the map and to take as few left turns as possible.

To denote which path you are going to take you will draw lines on the map in a "Final Route" layer like you were taught in the tutorial. You are welcome to add any destinations you would like to the other layers and create additional layers if it will help you with the task. Your final route that you draw will be scored against the other participant to determine your number of entries into the gift card drawing.

You will be scored on the length of your route, your ability to avoid the accident, whether you picked up gas before your friend, and how few left turns you took.

Scenario A: no navigation, map format

For this task I will ask that you keep the map view on at all times. Additionally, you cannot use the route planning navigational tool that you were taught in the tutorial, you must select the route on your own without route guidance. You are welcome to type in “gas”, “gas station”, or other keywords to help to identify locations but cannot ask Google Maps to help you choose a route from one point to another. Remember to please use the line drawing tools to draw your route.

First or Second task (circle one)

Start Time: _____________

End time: ___________

Compellingness Questionnaire

Now we will ask that you fill out an online questionnaire while reflecting on the task you just completed. Try to answer these questions about the way you felt while performing the task, not the way you feel now.

- □ Have participant take qualtrics survey “Study 2”

Start Time _______________

End Time _____________

Briefing Cont.

I will now read to you the second scenario that you will be deciding your route based on. You will have this scenario in front of you when planning your route. For this task, you have the opportunity to get 1 to 10 more entries into the gift card drawing. Again, the number of entries you get for this gift card will depend on your performance on this task compared to the other participants.

Any questions?

- □ Open MyMap file “Participant #, Trial 2”

Scenario 2- Tennessee Movie Theater

You and a friend are heading out to a movie for the night. You are at your house and must pick them up from theirs before arriving at the theater. You are a little short on gas so you want to be sure to get some before you pick up your friend. You also hear that there is an accident along your route that you must avoid. You are running a bit late so you want to get to the movie theater as fast as possible and so to cut down on time you want to take as few left turns as possible.

Using the home, friend's house, accident, and movie theater locations on your map, navigate the best route for this scenario. You may choose what gas station you would like to stop at and which roads you would like to take. Remember to avoid the accident marked on the map and to take as few left turns as possible.

To denote which path you are going to take you will draw lines on the map in a "Final Route" layer like you were taught in the tutorial. You are welcome to add any destinations you would like to the other layers and create additional layers if it will help you with the task. Your final route that you draw will be scored against the other participant to determine your number of entries into the gift card drawing.

You will be scored on the length of your route, your ability to avoid the accident, whether you picked up gas before your friend, and how few left turns you took.

Scenario B: navigation, satellite format

For this task I will ask that you keep the satellite view on at all times. Additionally, you are required to use the route planning tools available to you through the application including route guidance, keyword search and zoom features. You are welcome to type in "gas", "gas station", or other keywords to help to identify locations. Remember to please use the line drawing tools to draw your route.

First or Second task (circle one)

Start Time: _____________

End time: ___________

Compellingness Questionnaire

Now we will ask that you fill out the same online questionnaire as you did previously while reflecting on the task you just completed. Try to answer these questions about the way you felt while performing the task, not the way you feel now.

- □ Have participant take qualtrics survey “Study 2”

Start Time _______________

End Time _____________

Post-Experiment Questionnaire

Now we will ask that you fill out a final brief questionnaire that includes a few demographic questions for our records. This is the last thing I will need from you today. If you would like to receive the gift card entries you earned today, please enter your email in the last question of this survey.

- □ Have participant take qualtrics survey “Study 2 Post Survey”

Start Time _______________

End Time _____________

Debriefing

Thank you for participating in my study today, I greatly appreciate it. This research will help develop a measurement tool to better understand the level of compellingness that an interface or device design has. This research helps me to complete my Master’s in Science and I again appreciate your contribution. Please refrain from mentioning any details of this study to anyone else so as not to compromise any future participants.