The Effect of Gamification on Comprehension of Interactive Visualization

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Contents

Abstract

Interactive visualization conveys information about data by combining visuals, illustrations, text and images together and by allowing users to interact directly with the displays themselves. Several studies indicate that interactive visualization is beneficial to user engagement. Another recent study trend, gamification, as the use of game design elements in non-game contexts has already been applied in many different domains. Designers and users are fond of gamification because it brings fun. Moreover, several studies indicate that gamification could also enhance user engagement. However, so far there are few studies combing both interactive visualization study and gamification study. The present study combined these two aspects with a between subject design to explore what is the effect of gamification on user engagement, comprehension and exploration of interactive visualization. An on-line experiment was manipulated with two conditions. The result shows that gamification enhances user engagement and comprehension of interactive visualization. However, in this study, the result shows that gamification did not enhance exploration of interactive visualization. Due to limitation of time and sample size, future studies should be implemented with more diverse and larger sample. Different game mechanics, dataset and more complicated and attractive visual representations could be used for designing more different conditions.

Keywords: gamification, interactive visualization, game mechanics, user engagement, comprehension, exploration

The Effect of Gamification on Comprehension of Interactive Visualization

Introduction

Nowadays, information visualization is used as a strategy for users to understand data and gain insights. Many studies and handbooks are focusing on exploring the aim, activity and effect of information visualization. According to Spence (2007), the activity of information visualization can be summarized as the process in which various data is transformed into pictures and interpreted by human beings through useful discovery. The main goal of information visualization is to let humans comprehend through exploration.

Due to the development of technology, the attention of researchers and designers for information visualization is transferred from static information visualization to interactive visualization. Different from static information visualizations, interactive information visualizations such as interactive infographics give users a degree of control over the information and data displayed (Krum, 2013). Both academia and industry are focusing on interactive visualization. Studies have shown that interactive information visualizations are helpful to enhance user engagement (Krum, 2013; Lazard et al. 2015; Locoro et al. 2017). Additionally, interactive visualizations are used more often in society such as social media development report and designers become fond of making on-line interactive information visualization with the rapid development of Internet technology.

The technology advances not only fertilized the study of information visualization but also stimulated a new approach related to human computer interaction study- gamification. Deterding et al. (2011) propose the definition for gamification as the use of game design elements in non-game contexts. One of the reasons why many researchers and designers are interested in gamification is because it brings fun, enjoyment and motivation in the users' experience (Kankanhalli et al., 2012; Rigby, 2015). Moreover, many studies have implied

that gamification could enhance user engagement (Deterding et al., 2011; Kankanhalli et al., 2012; Linehan et al., 2015; Rigby, 2015). In brief, gamification is the use of game elements in non-game contexts which potentially improves user's engagement.

To gamify a non-game context, it is necessary to apply game mechanics as the building blocks into the non-game context. In other words, game mechanics are the essential components of gamification. Throughout the years there have been various conceptual frameworks developed for the definition and categorization of game mechanics. For instance, Weisfeld (2000) defines game mechanics as the action invoked by an agent to interact with the game world. As for categorization, Werbach (2015) divides the categories of game mechanics as challenges, chance, competition, cooperation, feedback, resource acquisition, rewards, transactions, turns, and win states. In this study, the quest game mechanic will be investigated. Quest is a widely used game mechanic. According to Werbach (2015), a quest is a concrete example of a challenge which usually has rewards specified at the outset.

It is interesting to further study the combination of adding gamification in interactive visualization because it is found that these two concepts could both relate to user engagement. This may potentially lead to positive effect for user experience. Diakopoulos et al. (2011) find that game-y infographics (infographics gamified based on the non-gamified version) could motivate interactions and cause users to explore the data presented. However, they note that users prefer more explicit messaging in the interactive infographics to know more facts. This suggests that it is wrong to affirm that gamification always has a positive effect, which demands more specific research on gamification from different approach. Until now, only few studies have combined gamification and interactive visualization.

Based on the findings from previous studies, the present study explores the effect of gamification on comprehension of interactive visualization from a systematic theoretical framework to raise the questions to be studied further. Several studies indicate that user

engagement could potentially enhance comprehension since felt-involvement is key component of user engagement (O'Brien et al., 2010; O'Brien et al.,2018) and felt-involvement could enhance comprehension (Celsi et al.,1988; Macias, 2003). As it is both suggested from previous study that gamification could enhance user engagement and user engagement could enhance comprehension, it can be inferred that gamification could also potentially enhance comprehension.

Since gamification could potentially help comprehension and comprehension is the main aim of interactive visualization, it might be that interactive visualization could benefit from gamification. Therefore, the aim of this study is to further investigate whether gamification affects the comprehension of interactive visualization. The research question of this study is: *"What is the effect of gamification on comprehension of interactive visualization?"*

To sum up, the present study aims to combine gamification and interactive visualization with an exploratory study. By researching the effect of gamification on the comprehension of interactive visualization, the present study may contribute to inspiration for scientists and designers for future elaboration applying gamification on interactive visualization.

Theoretical Framework

(Interactive) information visualization

Recently, information visualization has become an increasingly relevant study domain. Information visualization is now used as a strategy for users to understand data and gain insights. According to Spence (2007), information visualization can be summarized as the process in which various data is transformed into pictures and interpreted by human beings. Deriving information from data is the principle task of this process from which users try to comprehend and understand the information. Bederson et al. (2013) note that one of the

major uses of information visualization is data exploration and discovery by seeking information on the display. The other major use of information visualization is the data explanation, which is one of the basic stages of the process of information visualization according to Ware (2012). It can be concluded that information visualization helps users to comprehend data through discovery and exploration by seeking and browsing the information.

Beyond static information visualization, interactive information visualization seems to carry more and more power with user interaction and engagement. To understand interactive information visualization, it is important to first know about interaction. Interactivity is defined by Sundar et al. (2013) as the affordance that allows users to make real-time changes to the content in the medium. Spence (2007) describes the importance of interaction between human and computer as the ability to change one's view of data which could lead to insights. Interaction can also be specified into different categories. In Spence (2007)'s study, interaction is divided into continuous interaction, stepped interaction, passive interaction and composite interaction. These four categories of interaction also include interaction such as navigation and pop-out (which means the information could be visually identified even only with a very brief exposure to users). Navigation and pop-out are commonly used for interactive information visualization. Bederson et al. (2013) emphasize that a good information visualization is not just a static information visualization but an interactive one. Interactive information visualization is ideated based on three feedback loops (Ware, 2012). The lowest level is the data manipulation loop. The intermediate level is the exploration and navigation loop. The highest level is the problem-solving loop. These feedback loops bring users different experience when using the visualization and let designers be more creative with designing the visualization.

With the rapid development of Internet technology, on-line interactive information visualization become more popular among information visualization designers and users. More and more information visualizations are made online, meanwhile, the preference of interactivity can be seen also among on-line information visualizations such as on-line interactive infographics. Krum (2013) mentions that the Internet has developed into a main source for daily news and information. Due to this development, a great number of information visualizations such as infographics are presented and consumed online. Online infographics usually combine text, images, illustrations and graphs. Dur et al. (2014) discuss that, compared to static on-line infographics, interactive on-line infographics accommodate various forms open to user interaction with the information. Users can search and discover the desired information in their own ways with their own goals and go through the depths as they want. Figueiras (2015) emerges eleven categories of interactivity of interactive information visualization in his study which are filtering, selecting, abstract/elaborate, overview and explore, connect/relate, history, extraction of features, reconfigure, encode, participation/collaboration, and gamification. Such categorization of interactivity adds values to inspire both academia and industry for more research topics about interactive information visualization.

To sum up, previous studies have shown that interactive visualizations are helpful for users to comprehend data and gain insights. Interactive visualization conveys data information by combining data visualizations, illustrations, text and images together and by allowing users to directly interact with the displays themselves.

User engagement

Several studies suggest that interactive information visualization can be helpful to enhance user engagement. User engagement can be defined as the emotional, cognitive and behavioral experience of a user with a technological resource that exists at any point in time

and over time (Lalmas et al., 2014). Researchers try to understand user engagement by going through different perspectives to find out the key components of user engagement. O'Brien et al. (2008) reviewed historical studies about the conceptual framework of user engagement. They studied it from perspectives in flow, play and aesthetic theories examining attributes of challenge, aesthetic and sensory appeal, feedback, novelty, interactivity, perceived control and time, awareness, motivation, interest and affect which described engaging experiences with technology. Studying user engagement from different perspectives also contributes to how to measure user engagement for researchers. Researchers not only build measurement scales for user engagement, but also categorize user engagement into different dimensions to benefit specific exploratory studies related to user engagement. When measuring user engagement by using the User Engagement Scale (UES), O'Brien et al. (2010) categorized user engagement into six dimensions. These six dimensions are focused attention, perceived usability, aesthetics, endurability, novelty and felt involvement. This leads to chances for researchers to relate their study results to these different dimensions for potentially interesting conclusions. However, O'Brien et al. (2018) questioned the six dimensions and verified a four-dimension structure of user engagement which are focused attention, perceived usability, aesthetic appeal and reward. The last dimension- reward dimension- consists of endurability, novelty and felt involvement.

When building the conceptual framework of user engagement, O'Brien et al. (2008) proposed a user engagement process model which consists of three stages. These three stages are point of engagement, period of engagement, and disengagement. At the same time, O'Brien et al. (2008) bring out another concept- positive affect, which is the attribute existing in both the period of engagement and disengagement stages in the user engagement process model mentioned above. Positive affect is a positive response referring to emotional investment users make to be immersed and sustain in an environment. According to Watson

et al. (1988), positive affect indicates the extent to which a person feels enthusiastic, active and alert. High level of positive affect reflects high energy, full concentration and pleasurable engagement. O'Brien et al. (2008) also point out that positive affect contributes to maintain users' attention and interest with a positive emotion. It refers to enjoyment and fun during the period of engagement stage while it refers to feelings of success and accomplishment during the disengagement stage of the whole user engagement process model. Thus, positive affect indicates potential study approaches to link user engagement with other concepts.

Regarding interactive visualization and user engagement, there have been several studies suggest that interactive information visualization is helpful in enhancing user engagement. Lazard et al. (2015) discuss that interactive information visualization such as interactive infographics can increase user engagement when comprehending message content. They find that interactive infographics make individuals engage in higher levels of issue-relevant thinking, in which the visual content plays an important role on persuasive message processing. Moreover, Locoro et al. (2017) find that users prefer interactive infographics more than static infographics because they ensure a better task completion and quality evaluation. Furthermore, Krum (2013) point out that users prefer interactive information visualization more because they can get more engaged with the data and information on the display for a much longer period of time. In conclusion, interactive visualization is beneficial to user engagement.

Gamification

Deterding et al. (2011) propose gamification as the use of game design elements in non-game contexts. "Gamefulness" represents playing structured by rules and competitive strife toward goals. With the concept of gamefulness appearing, some researchers also try to compare gamefulness with playfulness. Deterding et al. (2011) compare gamefulness with playfulness and conclude that playfulness relates to paidia activities (more freedom in

activities) but gamefulness relates to ludus activities (more structured by rules and competitive with certain goals). They find that gamification is a systematic complement of playfulness.

Muntean (2011) note that gamification is becoming a new popular concept in recent years and still has a big research and industry potential. After the launch of Foursquare, there has been a rise of gamification industry such as gamification consultants, agencies and software providers (Warz et al., 2015). There are many studies focusing on gamification in various domains such as social media, marketing, governance, culture, psychology, education, economics, and healthcare. In these studies, the focus is mainly on users' motivation, user engagement and ethics. Mora et al. (2017) review recent studies related to gamification frameworks in education, psychology, game theory and design, human-computer interaction, digital information systems and medical science. They propose three major approaches in reviewed studies analyzing gamification as user-centered, game-centered and technology-centered. Lucero et al. (2014) note that over the past years gamification has focused on the use of game-design elements, which includes points, levels, achievements and rewards in non-game contexts to motivate and increase user activity. They mention a typical example- Chore Wars (http://www.chorewars.com/), an application aiming to motivate competition between roommates to finish housework. In this application, users could claim experience points for housework. Furthermore, Hamari et al. (2014) create a framework to examine the effects of gamification based on the definition of gamification and the arguments on motivational affordances. They emphasize that gamification does provide positive effects but these effects are dependent on the context being gamified and the qualities of the users. They note that gamification mostly provides positive effects in education or learning contexts. On the other hand, gamification could provide negative

effects due to increased competition, task evaluation difficulties and design features. These aspects should be taken into account when applying gamification.

Similar to interactive visualization, the effect of gamification also relates to user engagement. The impact and outcome of gamification on user engagement has been widely studied. Deterding et al. (2011) emphasize that gamification improves user experience and user engagement. Moreover, Linehan et al. (2015) note that game elements could motivate and maintain user engagement. Rigby (2015) discusses how gamification could enhance user engagement by connecting engagement with motivation. Gamification is optimized for user satisfaction, more lasting behavior change and sustained user engagement with motivational goals. His study also implies that gamification as a reward system gives users more motivation and enjoyment. Kankanhalli et al. (2012) review previous studies relating to definition of gamification and conclude that all gamification forms have the aspect of 'fun' in common. Fun is one of the key components of gamification to evoke user engagement. From studies mentioned above it can been seen that gamification brings users more motivation and fun and it could enhance user engagement.

With the reviews above, it can be concluded that gamification has already been applied in many different domains. Designers and users are fond of gamification because it brings fun. Moreover, there are plenty of studies indicating that gamification could enhance user engagement.

Game mechanics

As mentioned in the introduction, game mechanics are the key element to be applied in non-game contexts to arouse gamification effect. Without game mechanics, the non-game context cannot be gamified. Game mechanics is a wide concept with various definitions and categorizations. Researchers study the definition of game mechanics from various perspectives such as what is the nature, structure or function of game mechanics. As for

nature, Weisfeld (2000) defines game mechanics as the action invoked by an agent to interact with the game world. Fabricatore (2007) describes game mechanics as the needs of players that they want to be challenged, have control and be rewarded consequently in the game. It was mentioned that challenge and reward should relate to three activities: learning the game mechanics, using the mechanics as a tool in ordinary situations and using the mechanics as a tool in extra-ordinary situations. Werbach (2015) defines game mechanics as the basic processes which drive the action forward and create engagement. As for structure, Sicart (2008) discusses in his study that game mechanics are not only formally recognizable by designers; they are also a big part of the players' repertoire. As for function, according to Salen and Zimmerman (2003), the core game mechanic is the necessity to repeat play activities players perform in a game. Jävinen (2008) takes a further step on defining game mechanics by not only distinguishing rules from mechanics but also relating them with player agency. Based on his study, he describes game mechanics as the means to lead the player to certain behavior with plans to certain goals. Although these studies show the definition framework of game mechanics from different perspectives, the view in common is that game mechanics motivate players to have control and interact with the game world.

The categorization difference of game mechanics corresponds to the definition difference. The overlapping categorizations can be seen as challenges, competition and rewards. This corresponds to the definition framework of Fabricatore (2007) and Werbach (2015) that game mechanics motivate players to be challenged and drive the players engaged to compete for the reward. Zichermann et al. (2011) list the categories of game mechanics as points, levels, leaderboards, badges, onboarding, challenges and quests. Werbach (2015) categorizes game mechanics as challenges, chance, competition, cooperation, feedback, resource acquisition, rewards, transactions, turns, and win states. Arnab et al. (2015) list the categories of game mechanics in their study as collaboration, role play, tokens, questions and

answers, resource management, assessment, competition, ownership and etc. Diakopoulos et al. (2011) discuss in their study that the game mechanics include conflict in the game such as scoring, competition, reward mechanisms and winning.

Combining gamification with interactive visualization

The promising findings and limitation of previous studies.

As discussed above, it can be seen that both interactive information visualization and gamification have become a rising study trend in recent years. Both interactive visualizations and gamification are found to be helpful in enhancing user engagement. By combining gamification and interactive visualization, the present study could contribute to inspiration for scientists and designers applying gamification on interactive visualization in the future.

There have been few researchers trying to combine gamification and interactive visualization to figure out how gamification could affect users when using interactive visualization. According to Diakopoulos et al. (2011), guessing and color matching are popular game mechanics. They chose these two game mechanics and designed three different versions of infographics containing the same data, through which they gamified the infographics. The original infographic was one designed without game mechanics. Furthermore, there were two gamified infographics of which one with the guessing mechanic and one with the color matching mechanic. They find that game-y infographics could motivate interactions and cause users to explore. But they also note that users prefer more explicit messaging in the interactive infographics to know more facts. This indicates that it is wrong to affirm that gamification always has a positive effect. A more specific research on gamification is needed. However, so far there have been few studies that combine both gamification and interactive visualization. To fill in this gap, it is also necessary to first explore factors which could connect gamification and interactive visualization. Thus, with

this study, we suggest possible effect of gamification on comprehension of interactive visualization.

Gamification and user engagement with interactive visualization.

In previous studies, it has been shown that gamification could enhance user engagement (Deterding et al., 2011; Kankanhalli et al., 2012; Linehan et al., 2015; Rigby, 2015). Moreover, user engagement is valuable for information visualization. There have been studies showing user engagement is helpful for completing the aim of information visualization (Lazard et al., 2015; Locoro et al. 2017; Krum, 2013). Also, O'Brien et al. (2008) has pointed out that user engagement as engaging experience with interactive technology is desired for every interactive product. In other words, user engagement could be potentially beneficial to the experience of interactive visualization. Based on these findings, the first hypothesis can be built as:

H1: Gamification enhances user engagement with interactive visualization.

Gamification and comprehension of interactive visualization.

Previous studies indicate that user engagement is beneficial to comprehension. As mentioned in the theoretical framework above, according to O'Brien et al. (2018) felt-involvement is one of the key components of the reward dimension of user engagement. Several studies suggest felt-involvement could enhance comprehension. Celsi et al. (1988) define felt-involvement as a motivational state which has an effect on the focus of users' attention and comprehension. They note that felt-involvement could arouse greater cognitive and physical effort during comprehension and engage in more focus and elaboration. Thus, they conclude that felt-involvement could motivate and enhance comprehension. Moreover, Macias (2003) emphasizes that felt-involvement is the core element to enhance comprehension. As felt- involvement could enhance comprehension and it is one of the key components of the reward dimension of user engagement, it can be inferred that user

engagement could also potentially enhance comprehension. Blumenfeld et al. (2006) pointed out that user engagement helps with thinking deeply about the information perceived and construct better understanding which implies that user engagement could enhance comprehension.

With the implication mentioned above, gamification could be connected with comprehension of the interactive visualization via user engagement. The connection between gamification and interactive visualization can be built from the following aspects. Firstly, previous studies create a solid framework to show that gamification could enhance user engagement (Deterding et al., 2011; Kankanhalli et al., 2012; Linehan et al., 2015; Rigby, 2015). Secondly, user engagement is suggested that it could enhance comprehension. Lastly, comprehension is the main aim of information visualization (Spence, 2007). It can be inferred from the given aspects that gamification is beneficial to the comprehension of interactive visualization and there is a potential that gamification could enhance comprehension via user engagement. Moreover, in this connection, user engagement is a mediator variable to connect the potential effect of gamification on comprehension of interactive visualization. With such a connection built, the second hypothesis is:

H2: Gamification enhances user engagement which, in turn, enhances comprehension of interactive visualization.

Gamification and exploration of interactive visualization.

Previous studies indicate that user engagement is also beneficial to exploration. Positive affect as the attribute of the user engagement process model has already been mentioned in the theoretical framework above. Lalmas et al. (2014) emphasize that positive affect could arouse the desire for exploration and discovery. Kashdan et al. (2004) emphasize that positive affect arouses curiosity and desire for exploration. These studies indicate that positive affect motivates exploration. As positive affect is the attribute existing in both the

period of user engagement stage and disengagement stage and positive affect motivates exploration, it can be inferred from here that user engagement could also potentially motivate exploration. As gamification could enhance user engagement and user engagement motivates exploration, the connection can be inferred that gamification could potentially enhance motivation through user engagement. Here, in this connection, user engagement also plays a role as a mediator variable. The third hypothesis is:

H3: Gamification enhances user engagement which, in turn, motivates more exploration of interactive visualization.

The conceptual model showing the hypothesized relationships between variables of this study can be seen in Figure 1.

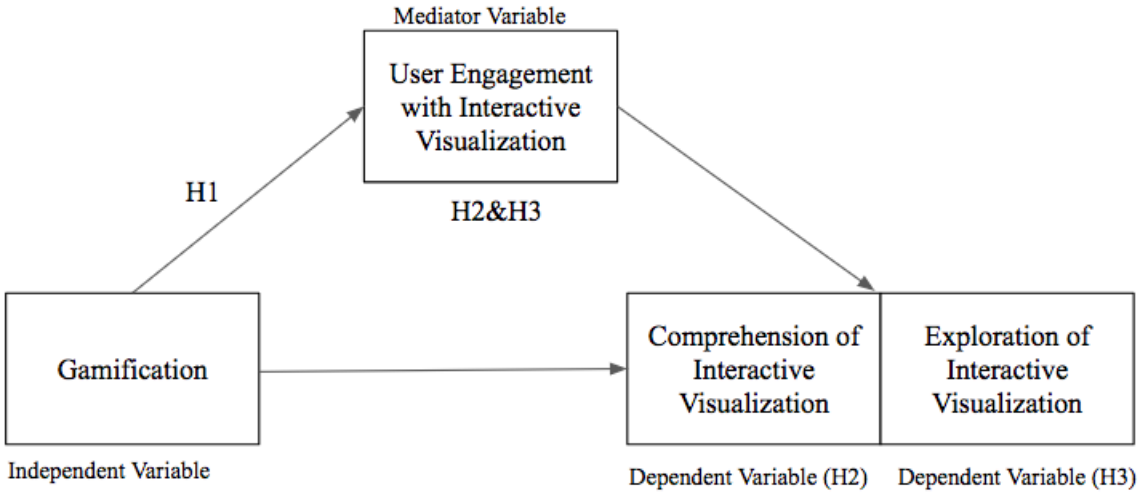

Figure 1: Conceptual model showing hypothesized relationships

Method

Design

A between subject design was used to investigate the effect of gamification on user engagement, comprehension and exploration of the interactive visualization. The independent variable of this study is gamification (gamified condition or non-gamified condition). The

dependent variables are user engagement with interactive visualization, comprehension of interactive visualization and exploration of interactive visualization. An on-line experiment was manipulated with two conditions. The two conditions were two websites with either a non-gamified interactive visualization or a gamified interactive visualization. In comparison with the non-gamified interactive visualization, the gamified one has a quest above the interactive visualization.

Participants

Participants were recruited from the researcher's network and social media with an experiment schedule poll. The participants were randomly assigned to the two conditions. The random sampling was created in Excel using random formula to assign each participant to either the gamified condition or the non-gamified condition. 43 participants participated in this experiment. However, the website user action tracking (see Measures-Exploration) of 2 participants failed. In addition, the tracking record of one other participant could not be replayed probably. Thus, the data of these 3 cases were excluded. In the end, the data of 40 participants were used for this study. Among all the 40 participants, 14 were men and 26 were women. The average age of the participants was 24.85 years old (*SD*=3.65). The average age of women was 25.58 years old (*SD*=4.03) and the average age of men was 23.50 years old (*SD*=2.38). As for the nationality, most of the participants came from China (*N*=26). The others came from the Netherlands (*N*=7), Poland (*N*=1), Paraguay (*N*=1), Turkey (*N*=1), Germany (*N*=1), Switzerland (*N*=1), Korea (*N*=1) and France (*N*=1). The education level of 22 participants was higher than bachelor, while 13 participants were of bachelor level and 5 were of lower than bachelor level.

Materials

Participants needed to explore an interactive visualization on the website of either condition. The idea to conduct the experiment on-line was in order to enhance the external

validity of the study since normally interactive visualizations are experienced online. The website was made in HTML+ JavaScript using Dreamweaver. To select the interactive visualization, five existing interactive visualizations from Tableau Public were considered. Tableau Public is a platform which allows people to create interactive visualizations online and share the visualizations on this platform. Ten people were asked by an interview to choose from these five existing interactive visualizations the most attractive and interesting visualization to explore. The ten people were also asked how many questions related to the visualization was appropriate to be raised. They suggested three questions in total was appropriate. These ten people were excluded from the actual experiment. The final chosen interactive visualization (see Figure 2-1) was about different reactions to food combinations created by David Murphy (https://public.tableau.com/zh-cn/s/gallery/food-combo-reaction-matrix?gallery=votd).

Figure 2-1 Complete interface of the interactive visualization

The interactive visualization was exported from Tableau Public by embedding the JavaScript of the visualization on the websites made for the experiment. For the interactive visualization, there were five different types of reaction to one hundred and ninety types of

food combinations. Each food combination had a certain type of reaction with a different kind of emoji from amazing, good, ok, bad to disgusting. The visualization had a filter for users to select each type of reaction. “Filter” is a common interactivity effect that enables users to quickly see how data representation is affected when the items which they are not interested in are eliminated or deemphasized (Figueiras, 2015). For the non-gamified interactive visualization website, there are three questions related to the interactive visualization above the visualization (see Figure 2-2). Participants needed to explore the interactive visualization and meanwhile answer the three questions above the interactive visualization. The three questions were: How do banana and strawberry taste together, do pocari sweat and paprika taste OK together and how many drinks taste not bad with meats in total. The degree of difficulty gradually increased from Question 1 to Question 3.

Figure 2-2 Interface of the non-gamified condition website

Based on the original non-gamified interactive visualization website, a gamified version with the same visualization was designed by adding a “quest” game mechanic above the visualization with JavaScript. The quest involved the same three questions related to the interactive visualization, a light and an indicator (see Figure 2-3). Werbach (2015) notes that a quest is a concrete example of a challenge which usually has rewards specified at the outset. According to Chen et al. (2009), quest as a game mechanic has a positive effect on enjoyment, which corresponds with the characteristics of gamification.

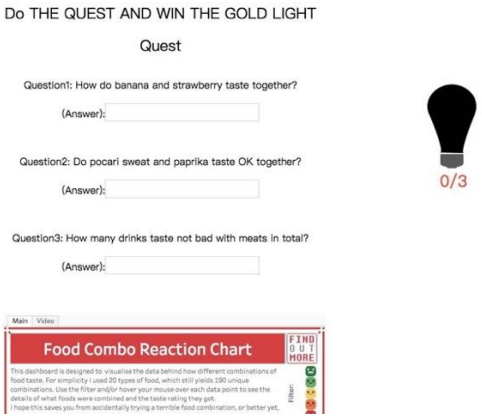

Figure 2-3 Interface of the gamified condition website

For the gamified condition, the participants needed to explore the interactive visualization and meanwhile do the quest above the interactive visualization. The interface of the three questions and the interactive visualization were exactly the same between the gamified condition and the non-gamified condition. The only difference of the two condition websites was that the interface of the gamified condition had the light and the indicator beside the questions, along with a tip above the three questions "DO THE QUEST AND WIN THE GOLD LIGHT" to motivate the participants to win the quest. The quest was to find answers for three questions related to the interactive visualization. The light could change its color once any of the questions was answered correctly. There was also an indicator below the light to show how many questions were answered correctly. The color of the light in the beginning was black. If one question was answered correctly then the light would turn bronze. If two questions were answered correctly then the light would turn silver. If all three questions were answered correctly then the light would turn gold. The indicator changed along with the light. The gold light was the reward for participants who completed the quest successfully.

Procedure

A pilot test was performed to test feasibility of the whole procedure before the experiment started. For the pilot test, five test participants were assigned to the non-gamified

condition and five test participants were assigned to the gamified condition. The ten test participants were also excluded from the actual experiment. Although the instruction was explained well before the test, some participants still forgot about the details of the instruction during the test. Thus, it indicated the importance for the researcher to explain the instruction again when necessary.

The researcher in this study was present to instruct the experiment. Before the experiment started, all participants had access to the consent form (see Appendix B) and the instruction (see Appendix C) for the experiment from Qualtrics. After they signed the consent form and finished reading the instruction, they were given a URL link to the website of their corresponding condition. Then the Qualtrics page turned to the website. Participants started to explore the visualization and answer the questions for the non-gamified condition or complete the quest for the gamified condition. Participants could take as much time as they wanted and if they did not know the answer for any question they could just leave it blank. The interaction with the website of the participants was recorded by Hotjar, a tool used for website user action tracking. Participants could quit anytime they wanted. After finishing the three questions for the non-gamified condition or the quest for the gamified condition, participants needed to click “back” on the browser to go back to the Qualtrics page and then go on to finish a questionnaire. The questionnaire consisted of self-report reflecting participants’ user engagement with the interactive visualization and basic demographic information. After finishing the questionnaire then the whole experiment procedure was done.

Measures

Comprehension.

By reviewing previous studies of measurement for comprehension, it can be seen that many researchers measure comprehension with open comprehension questions or true/false

comprehension statements (Jacoby et al., 1987; Jacoby et al., 2003). Comprehension is measured as the correctness of answers of perceived information (Macias, 2003). Thus, in this study comprehension will be measured as the evaluation of correctness of the answers based on the three questions related to the information of the interactive visualization. The answers of the three questions were scored for both non-gamified group and gamified group. The answer of each question was either correct or wrong. The answer was scored with one point if it was correct and with zero point if it was wrong. The scores of each question were added up as the final score of each participant raging from zero to three. The higher the score was, the better the comprehension was. The scores of each participant were counted by watching Hotjar recordings since Hotjar also automatically recorded what answers each participant filled in the blank on the website. None of the participants in this study got a zero score for comprehension.

Exploration.

According to Scholtz (2006)'s framework, visualization exploration can be measured by metrics such as the number of entities browsed. In Diakopoulos et al. (2011)'s study they measure exploration on infographic by the number of unique parameters visualized and the number of hover activity performed by participants. In the present study, exploration was measured by tracking user actions on the visualization of each participant. Hotjar was used to track participants' exploration of the interactive visualization on the website. By plugging the script of the Hotjar tracking code on both of the websites, Hotjar could automatically record all user actions of each participant. How the users explore the visualization with the mouse by clicking, moving and scrolling, how they filled in the answers and how the light and indicator changed were all recorded by Hotjar for each participant in this experiment. The total number of user actions was shown on Hotjar. However, the total number of user actions of Hotjar included both the actions on the interactive visualization and the actions on the

question part. Due to technical limitation, it could only display the total number of user actions on the whole website, not only, however, on the interactive visualization which was exported from Tableau Public. Assuming that for both condition participants performed relatively similar actions on the question part, the measurement for exploration of the interactive visualization in this study still used the total number of user actions.

Engagement.

Engagement was measured by thirty-one items on the questionnaire according to the user engagement scale long-form (UES_LF) of O'Brien et al. (2018). The user engagement scale of their study is constructed based on self-report items, which has been the most common engagement measurement. O'Brien et al. (2018) verify a four-dimension structure which are focused attention, perceived usability, aesthetic appeal and reward to measure user engagement. The first dimension is focused attention which refers to the feelings absorbed in the interaction and losing track of time (Item 1-7). The second dimension is perceived usability which refers to the negative affect experienced (Item 8-15). The third dimension is aesthetic appeal which refers to the aesthetic appeal and attractiveness of the interface (Item 16-20). The fourth dimension is reward which refers to the endurability, novelty, and felt involvement (Item 21-31). The item statements used in this study were slightly modified based on the research object (interactive visualization). For each item, a five-point scale with “strongly disagree” to “strongly agree” is used. For items of each dimension of user engagement scale, the reliability was assessed using Cronbach’s Alpha. This showed good reliability of each dimension scale. The focused attention dimension included seven items (α=.874). The perceived usability dimension included eight items (α=.692). The aesthetic appeal dimension included five items (α=.897). The reward dimension included eleven items (α=.914). The thirty-one items can be seen in Appendix A. In the end, the overall engagement score of each participant was calculated by adding the average score of each dimension.

Results

The independent variable gamification was coded as condition 1 and condition 2. 1 represented for the non-gamified condition and 2 represented for the gamified condition. For either condition *N*=20 and for both conditions in total *N*=40. To check whether education could be regarded as a control variable for the three dependent variables, for each dependent variable a One -Way ANOVA was performed. The results showed that education did not predict user engagement with the interactive visualization (F (2,37) =.44, p = .65), comprehension of interactive visualization (F (2,37) = 1.14, p = .33), or exploration of interactive visualization (F (2,37) =.74, p =.48). The general descriptive statistics of the experiment results can be seen from Table 1 and Table 2.

Table 1

General Means and Standard Deviation

	M	*SD*
User Engagement	14.58	2.34
Comprehension	2.08	.83
Exploration	30.45	47.06

N=40

Table 2

Means and Standard Deviation of Each Dependent Variable per Condition

	M(SD)	*Non-gamified*	*Gamified*
User Engagement		13.63(2.01)	15.54(2.30)
Comprehension		1.45(.60)	2.70(.47)
Exploration		20.35(11.03)	40.55(64.89)

Notes. N=20 per condition

Hypothesis testing

Hypothesis One.

To check whether gamification could enhance user engagement with the interactive visualization an independent t-test was performed. The data was normally distributed (z-score skewness= 0.13, z-score kurtosis= 0.74). The Levene's test showed that the variances of the two groups were homogeneous (F (1,38) = 0.97, p = 0.33). Numerically, on average, the user engagement scores were higher for participants who were assigned to the gamified condition (M=15.54, SD=2.30) than the non-gamified condition (M=13.63, SD=2.01). This difference was significant ($Mdif$ = -1.90, t (38) = -2.79, p = .008). This represented a medium sized effect (r=0.41). Thus, Hypothesis One is supported that gamification enhances user engagement with interactive visualization.

Hypothesis Two.

To check whether gamification could enhance user engagement with interactive visualization which, in turn, enhances comprehension of interactive visualization, a mediation analysis was performed using PROCESS by Andrew F. Hayes. Since the dependent variable comprehension was a counts variable, the data of comprehension was transformed to normal distribution by using log transformation. In this analysis, the independent variable gamification was entered as a predictor to the dependent variable comprehension and user engagement of the visualization was entered as the mediator. The result can be seen in Figure 3. The results indicated the same with Hypothesis One that gamification was a significant predictor of user engagement (b=1.90, SE=.68, p = .00). There was a significant total effect of gamification on comprehension (b=.68, SE=.10, p =.00), indicating that participants assigned to the gamified condition (M=2.70, SD=.47) have a better comprehension than the non-gamified condition (M=1.45, SD=.60). The direct effect of gamification on comprehension when the mediator user engagement was included was significant (b =.70, SE

= .11, *95% BCa CI*= [.49, .92]). However, the mediator user engagement was not a significant predictor of comprehension (*b*= -.01, *SE*=.02, *p*=.*64*). This already disqualified user engagement as a possible mediator in this analysis. The total indirect effect was not significant (*b* = -.02, *SE* = .06, *95% BCa CI*= [-.15, .08]). The results indicated that gamification predicted comprehension excluding the mediator variable and user engagement was not a significant predictor as a mediator for the dependent variable comprehension.

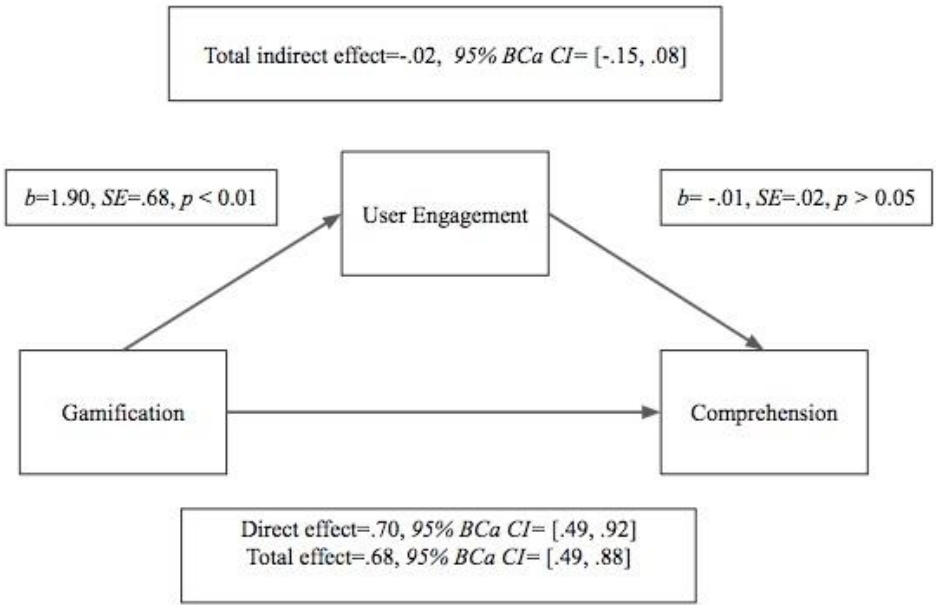

Figure 3 Mediation analysis for Hypothesis Two

Hypothesis Three.

To check whether gamification could enhance the user engagement with interactive visualization which, in turn, enhances exploration of interactive visualization, a mediation analysis was performed using PROCESS by Andrew F. Hayes. Since the dependent variable exploration was a counts variable, the data of exploration was computed to normal distribution by using log transformation. The result of the analysis can be seen in Figure 4. In this analysis, the independent variable gamification was entered as a predictor to the dependent variable exploration and user engagement of the visualization was entered as the mediator. Results indicated the same with the analysis before that gamification was a

significant predictor of user engagement (*b*=1.90, *SE*=.68, *p* = 0.00). There was not a significant total effect of gamification on exploration (*b*=.26, *SE*=.25, *p*=.*30*). The direct effect of gamification on exploration when the mediator user engagement was included was not significant (*b*=.10, *SE*=.27, *95% BCa CI*= [-.45, .64]). Moreover, the mediator user engagement was not a significant predictor of exploration (*b*= .09, *SE*=.06, *p*=.*14*). This already disqualified user engagement as a possible mediator in this analysis. The total indirect effect was not significant (*b* = .17, *SE* =.15, *95% BCa CI*= [-.07, .52]). The results indicated in this analysis that the independent variable gamification could not predict the dependent variable exploration. Moreover, the independent variable gamification could not predict the dependent variable exploration with the mediator variable user engagement included. The mediator was not a significant predictor of the dependent variable.

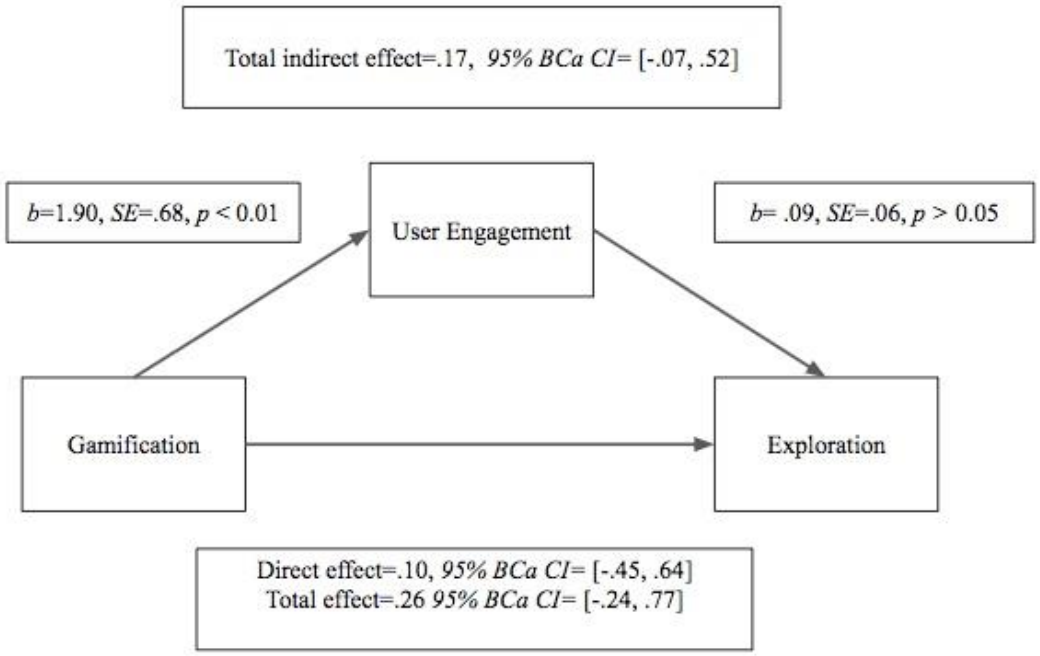

Figure 4 Mediation analysis for Hypothesis Three

Exploratory analysis

According to O'Brien et al. (2018), user engagement consists of four dimensions which are focused attention, perceived usability, aesthetic appeal and reward. In order to

explore whether gamification could predict all the four dimensions, for each dimension an independent t-test was performed separately. An interesting finding was that although the difference between two conditions of the entire user engagement performance was significant, when looking into each dimension, only the difference of the reward dimension between the two conditions was significant (*Mdif* = -.58, *t* (38) = -2.80, *p* = .008), the difference of the other three dimensions were not significant.

Conclusion

This study explored what the effect of gamification on comprehension of interactive visualization is. The hypothesized effect in this study was that gamification could enhance user engagement, comprehension and exploration of interactive visualization. Hypothesis One is supported by the result of the independent t-test. Gamification enhances the user engagement with interactive visualization. For Hypothesis Two, the independent variable gamification could predict the mediator variable user engagement. However, user engagement did not predict the dependent variable comprehension as the mediator variable. The independent variable gamification itself predicted the dependent variable comprehension. In other words, gamification could enhance comprehension of the interactive visualization while the user engagement did not play a role as a mediator. For Hypothesis Three, the independent variable gamification could predict the mediator variable user engagement. However, the independent variable gamification itself could not predict the dependent variable exploration. Moreover, the independent variable gamification could not predict the dependent variable exploration even with the mediator variable user engagement included. User engagement did not play a role as the mediator variable.

Discussion

The aim of this study is to investigate the effect of gamification on comprehension of interactive visualization. By using a between-subjects design, three hypotheses regarding the

effect of gamification on user engagement, comprehension and exploration of interactive visualization were tested. This study has revealed that gamification enhances user engagement with interactive visualization. Gamification also enhances the comprehension of interactive visualization, but this is not because of user engagement. However, gamification could not enhance the exploration of interactive visualization with or without the mediator user engagement.

As mentioned, Hypothesis One is supported that gamification could enhance user engagement with interactive visualization. This corresponds to findings inferred from the conceptual framework by several researchers, namely that gamification could enhance user engagement (Deterding et al., 2011; Kankanhalli et al., 2012; Linehan et al., 2015; Rigby, 2015). In other words, this study proves experimentally, as suggested by the findings from previous studies, that gamification could motivate and enhance user engagement.

Regarding Hypothesis Two, the results show that gamification could enhance comprehension, though not for the reason regarding the mediator effect of user engagement. The mediator user engagement was not a significant predictor of comprehension. From previous studies, this study hypothesized a link between gamification and comprehension via user engagement. However, in this study the result obtained was different. It was found that only gamification itself enhanced comprehension of interactive visualization though not due to the effect of user engagement. Thus, the effect was different from what was inferred from previous studies (O'Brien et al., 2018; Celsi et al., 1988; Macias, 2003; Blumenfeld et al., 2006), as in this study user engagement did not have any effect on the comprehension of interactive visualization. On the other hand, gamification itself did indeed have an impact on the comprehension of interactive visualization. Comprehension scores were better for participants who were assigned to the gamified condition than the non-gamified condition. Informal observation during the experiment suggests that some participants of the gamified

condition showed high motivation after they were made aware that they could win a gold light in the quest as a reward when conducting the experiment. The result of the exploratory analysis also confirms that only the difference of the reward dimension of user engagement was significant, however the difference of the other three dimensions was not significant. In other words, in this study, gamification may have enhanced the motivation of some participants and led to higher comprehension scores. This corresponds to the findings of Werbach (2015) that the quest has a reward characteristic which implies that in this study participants were more motivated by the reward element of the quest game mechanic.

The indications found suggest that motivation may play a mediator role in the effect of gamification on comprehension of interactive visualization. According to Sailer et al. (2013) gamification could address motivational mechanics, from which gamification fosters motivation. According to Rigby (2015), the reward element of gamification is related to motivation. The reward element arouses intrinsic motivation. As for the relationship between motivation and comprehension, previous studies are mainly focused on the reading motivation and reading comprehension. Logan et al. (2011) establish that intrinsic reading motivation enhances reading comprehension, but only for low reading ability participants. Other studies focus on how intrinsic motivation may affect task performance. Fisher (1978) combines personal control over performance and competence with intrinsic motivation. He notes that there is an interaction between personal control over performance and competence. When intrinsic motivation is high, personal control over performance is also high. Moreover, some researchers combine intrinsic motivation with task performance and self-determination. Cerasoli et al. (2014) indicate that mastery goals could mediate in the relationship between intrinsic motivation and task performance. In other words, intrinsic motivation leads to better performance due to the fact that the mastery goals of individuals are intrinsically motivated.

Thus, the performance could be improved. However, whether motivation could enhance comprehension of interactive visualization still needs to be explored.

Hypothesis Three is rejected since in this study gamification could not enhance exploration with or without the mediator user engagement being included. The mediator user engagement itself also could not predict the dependent variable exploration. This is different from what is inferred in the theoretical framework that user engagement could also motivate exploration. The reason why these results were obtained may relate to the mouse device using habit of the participants. In other words, participants naturally explored much or little on the interactive visualization depending on their mouse device using habit. When observing participants conducting the experiment, one of the observations made is that some of the participants continued moving and clicking the mouse regardless of whether they were engaged or not or whether they understood the visualization or not. In other words, for some participants, many mouse actions were conducted on the visualization although they already knew the answers to the questions. In the case of some participants they conducted few mouse actions on the visualization although they still did not know the answers to the questions. In addition, although some participants appeared concentrated with regard to the visualization, their mouse actions were few. From this perspective, it can be inferred that the exploratory actions of some participants were as a result of their mouse device using habit despite being given enough time to explore sufficiently. Some participants, for example, habitually continued clicking and moving their mouse on the website. They were not even aware that they were continually clicking and moving their mouse on the website. This result differs from Diakopoulos et al. (2011)'s study in which they note that game-y infographics could motivate interactions which, in turn, cause users to explore more on the game-y infographics. However, Diakopoulos et al. (2011) also note in their conclusion that different game mechanics, data types and visual representations may affect the interaction with the

visualization differently. This conclusion contributes to explain why in this study gamification could not motivate more exploration of the interactive visualization. This study only used the quest game mechanic. The potential possibility remains that other game mechanics or other datasets, visualizations are more appropriate to enhance user exploration of the interactive visualization.

Limitations and future work

In this study, as a result of time limitations, it was not possible to conduct the experiment with a large number of people. A follow-up study could be carried out with a larger sample size in order to generalize the results of the study to include a larger population. Furthermore, since the participants in this study were mainly from China and the Netherlands, the sample could be manipulated and made more diverse with a larger sample size. Thus, a more ideal study could be implemented with a more diverse and larger sample.

Due to the technical limitations of Hotjar, it could only display the total number of user actions, not only, however, on the interactive visualization which was exported from Tableau Public. Although in this study it was assumed that for both conditions participants performed relatively similar actions on the question section, the measurement for exploration for this study still utilized the total number of user actions. This may still have more or less of an effect on the validity of this study. This issue was already reported to the Hotjar company and it is said that this technical limitation will be solved in the future. As mentioned, in this study some participants' exploration of the interactive visualization could be affected by their mouse device using habit. For future study, it might be an improvement to measure exploration via both the number of user actions and the number of entities users have explored on the interactive visualization.

As mentioned above, that motivation could be a potential mediator of the relationship between gamification and comprehension of interactive visualization, whether gamification

could enhance motivation, and whether motivation could enhance the comprehension of interactive visualization could be explored more specifically in future exploratory research. A potential hypothesis could be built, as gamification could enhance motivation which, in turn, enhances the comprehension of interactive visualization.

Previous studies in the theoretical framework indicate that felt-involvement helps to build Hypothesis Two and positive affect helps to build Hypothesis Three. Although this study is not concentrated on felt-involvement or positive affect, it will be interesting to figure out what game mechanics could trigger either felt-involvement or positive affect. In this way, follow-up studies can further explore how gamification could better enhance comprehension or exploration of interactive visualization via user engagement. Moreover, as Diakopoulos et al. (2011) point out that different game mechanics, dataset, and visual representations may lead to different interaction with the visualization. Only quest was used, for example, as the game mechanic in this study. Thus, future research could add more different game mechanics with different dataset and more complicated and attractive visual representations to further investigate the effect of gamification on user engagement, comprehension and exploration of interactive visualization. It will also be interesting to examine the kind of specific game mechanics that could increase the impact of gamification on user engagement, comprehension and exploration of interactive visualization when added together with other game mechanics. In contrast, it will also be fun to study what kind of specific game mechanics could decrease the effect of gamification on user engagement, comprehension and exploration of interactive visualization when added together with other game mechanics.

Implications

Based on the findings from this study, some practical implications can be concluded for interactive visualization designers as potential inspiration. To encourage users to be more engaged in interactive visualization, more game mechanics such as points, levels, badges or

challenges could be applied in the design of interactive visualization to enhance user interaction. Moreover, the results of this study suggest that it was the reward dimension of user engagement which displayed significant differences between the two conditions. Based on this evidence, designers could try different game mechanics which contain reward element to further improve user engagement with interactive visualization. In this study gamification did not enhance the exploration of interactive visualization, indicating the potential possibility that other game mechanics could be more appropriate to enhance user exploration. Based on this, designers could try different game mechanics to see whether these mechanics could assist in enhancing the user exploration of interactive visualization.

In conclusion, this study attempts to examine whether gamification could enhance user engagement, comprehension and exploration of interactive visualization via an on-line experiment manipulated with two conditions. The result of this study can inspire interactive visualization designers and may lead to further rigorous investigation in this field.

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Appendix

Appendix A

1. I lost myself in this experience.
2. I was so involved in this experience that I lost track of time.
3. I blocked out things around me when I was using this interactive visualization.
4. When I was using this interactive visualization, I lost track of the world around me.
5. The time I spent using this interactive visualization just slipped away.
6. I was absorbed in this experience.
7. During this experience I let myself go.
8. I felt frustrated while using this interactive visualization. *
9. I found this interactive visualization confusing to use. *
10. I felt annoyed while using this interactive visualization. *
11. I felt discouraged while using this interactive visualization. *
12. Using this interactive visualization was taxing. *
13. This experience was demanding. *
14. I felt in control while using this interactive visualization.
15. I could not do some of the things I needed to do while using this interactive visualization. *
16. This interactive visualization was attractive.
17. This interactive visualization was aesthetically appealing.
18. I like the graphics and images of this interactive visualization.
19. This interactive visualization appealed to my visual senses.
20. The screen layout of this interactive visualization was visually pleasing.
21. Using this interactive visualization was worthwhile.
22. I consider my experience a success.

23. This experience did not work out the way I planned. *

24. My experience was rewarding.

25. I would recommend this interactive visualization to my family and friends.

26. I continued to use this interactive visualization out of curiosity.

27. The content of this interactive visualization incited my curiosity.

28. I was really drawn into this experience.

29. I felt involved in this experience.

30. This experience was fun.

31. I felt interested using this interactive visualization.

To score each dimension of the items, sum Item One to Seven and then divide by seven. Sum Item Eight to Fifteen and divide by eight. Sum Item Sixteen to Twenty and divide by five. Sum Item Twenty-one to Thirty-one and divide by eleven. Items with an asterisk (Item 8-13, 15, 23) were reverse-coded.

Appendix B

Consent Form

Purpose of research

Thank you for your participation. This experiment and survey are for the research of my graduation thesis as a student from New Media Design master program, Tilburg University. The research is focused on the effect of gamification (the use of game design elements in non-game contexts) on comprehension of interactive visualization.

Specific procedure to be used

An experiment and a survey are organized for this research project.

Duration of participation

You can take as much time as you want for the experiment and the survey will take approximately 5-8 minutes.

Anonymity and confidentiality

Strict confidentiality of the data will be upheld. Your responses will not be associated with any identifying information. Your name will not be attached to your responses at any point. Your anonymous data will be kept for this project only, no other individuals except the researcher will have access to the data.

Voluntary nature of participation

You do not have to participate in this research project. If you agree to participate you can withdraw your participation at any time without penalty. Any questions you may find too personal, you are not required to answer.

Contact information

If you have any questions about this research project, you can contact me via email: Naijing Jiang

Appendix C

Instruction (for non-gamified condition)

In this research, you need to finish an experiment and a survey. You will be shown a website for the experiment and a questionnaire for the survey. Read this instruction first. Then you can start to explore the website.

Please keep your browser window maximized (full screen). The website contains a visualization and three questions. You need to find the correct answers for the questions from the visualization. You can answer the questions in the orders as you want.

The visualization is about the reaction to different food combination. You can leave it blank if you don't know the answer of any of the three questions and you can quit anytime as you want. After exploring the website and finish answering the questions, please do not close the page. Press 'back' button on the browser and come back to the page with the website link. Then press the 'next' button (the arrow on the lower right corner) to go to the questionnaire and finish it.

Thanks again for your patience and participation.

Instruction (for gamified condition)

In this research, you need to finish an experiment and a survey. You will be shown a website for the experiment and a questionnaire for the survey. Read this instruction first. Then you can start to explore the website.

Please keep your browser window maximized (full screen). The website contains a visualization for you to explore. There's a quest above the visualization for you to participate. To complete the quest, you need to find the correct answers for three questions from the visualization. For Question 1 and 2 please answer with alphabets and for Question 3 please answer with Arabic numbers. You can answer the questions in the orders as you want.

The visualization is about the reaction to different food combination. As for the quest, try to notice what will happen after filling in the answers.

You can leave it blank if you don't know the answer of any of the three questions and you can quit anytime you want. After exploring the website and finish answering the questions, please do not close the page. Press 'back' button on the browser and come back to the page with the website link. Then press the 'next' button (the arrow on the lower right corner) to go to the questionnaire and finish it.

Thanks again for your patience and participation.