Stock Lamp: An Engagement-Versatile Visualization Design

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ABSTRACT
Design methodologies for information visualizations are typically based on the assumption that the users will be fully engaged in the visual exploration of the displayed information. However, recent research suggests that there is an increasing diversity in *how* users engage with modern visualizations, and that the traditional design theories do not always satisfy the varied users needs. In this paper, we present a new design concept, engagement-versatile design, for visualizations that target users with a variety of engagement styles. Without losing generality, we demonstrate the feasibility of this concept through the designing of a system called Stock Lamp, an engagement-versatile visualization that helps users keep track of the stock market in real-time. This design process includes identifying different modes of engagement, deriving design implications from each engagement-mode, and applying them to the visualization's design. Our user study shows that Stock Lamp is able to consistently relay market information even when the users are multi-tasking. We believe this study establishes a new concept that promotes a systematic design approach that leverages both theoretical and empirical design methodologies for future visualization development.

Author Keywords
Design concept; visualization usability; user engagement;

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Information visualization has grown into a ubiquitous technology with various application scenarios. Recent visualizations are no longer limited to the traditional settings that used to focus on single users, advanced data analytics, and desktop monitors. These diverse application scenarios have inspired many studies on new design guidelines for visualizations that exceed the traditional use case scenarios. For example, visualization systems that allow multiple users to conduct collaborative data analyses require various new design guidelines regarding how the collaboration is supported by the system [18, 19]. Visualizations that target public users also often require additional design considerations in order to aid average computer user's limited domain knowledge and to help individual users achieve their personal goals [29, 32]. There are also unique design guidelines for visualizations that are intended for unconventional display settings from mobile displays [11] to wall-sized displays [6]. These studies have provided developers extensive guidance on what elements to consider when designing non-traditional visualizations.

Correspondingly, designing visualizations for real-world applications requires further design consideration with respect to *how* users interact with visualizations in real-world settings. One of the key elements to consider is the varied engagement styles the users exhibit towards visualizations. Visualizations in real-world settings do not always receive the user's full attention or active interaction. Therefore, these visualization system cannot base its design under the assumption that its users will be fully engaged in the visual analytics/exploration of the displayed information (e.g., [8, 26]).

In this paper, we present a new design concept, engagement-versatile design, for visualizations that serve users with a variety of engagement styles. First, we present a simple taxonomy of user engagement styles based on our observation on how users interact with desktop visualizations and discuss how the unique characteristics of each engagement style influences the visualization design. We then apply this new design concept to the construction of a system called Stock Lamp, a visualization system that helps part-time investors to keep track of the stock market in real-time. The results of our user study show that Stock Lamp can effectively relay information to users in different modes of engagement. We believe this study establishes a new systematic approach for deriving visualization designs from a range of engagement styles and will provide future developers with a new perspective for understanding visualization usability in real-world settings.

RELATED WORK
Basing the visualization design on the characteristics of *how* users engage with the system is not a new concept. Ambient display is a type of information visualization specifically designed to reside in the user's peripheral vision. In order to relay information to users who are not actively engaging with the system, ambient displays often require a different set of design considerations from traditional visualizations [28]. There has been extensive research on ambient display designs and their potential effects on users [20, 30]. Based on the absence of user's focused attention and active interaction, ambient displays, in general, need to be unobtrusive to user's daily activities, able to effectively notify users when urgent events arise, and aesthetically pleasing to users. These studies identify ambient displays as a unique type of information visualization which is intended for a particular setting where the users exhibit low-level of engagement towards the system.

Moreover, recent research suggests that there are different phases in how users engage with visualizations, and that visualizations in real-world settings tend to take different roles from ambient displays to interactive visualization systems depending on the user's level of engagement. Brignull and Rogers [10] made an observation that there are three stages of user activity between users and interactive public displays. Based on these different user activity stages, they discussed the design considerations to encourage users to interact with the displays. Vogel and Balakrishnan [33] pointed out that visualizations' application contexts change based on different phases of user interaction and presented a prototype system that allows users to smoothly transition between different interaction phases by taking the characteristics of each interaction phase into the design considerations. Both of these studies recognized the existence of a multi-modal engagement style and discussed the importance of taking each mode of engagement into the visualization's design consideration.

We extend these studies by establishing a clear concept of a design approach for visualizations whose users exhibit a wide range of different engagement styles. Since different visualization systems target different users in different environments and have different goals, how users engage with these different visualizations also vary case by case. Therefore, we do not expect that the different modes of engagement discussed in this paper will directly apply to all visualization systems. Instead, we believe that our design process of extracting distinct modes of engagement through observation and deriving design implications from the characteristics of each engagement style will provide future developers a systematic approach to design visualizations for their intended settings and for understanding visualization usability from perspectives of different user engagement styles.

ENGAGEMENT-VERSATILE DESIGN

Engagement-versatile design is a new design concept for visualization systems that target audiences who exhibit different styles of engagement towards the visualization. Current visualization systems are typically designed under the assumption that the users are fully engaged in the visual exploration of the data. However, recent studies (e.g., [26, 33]) have shown that this assumption does not always align with how users actually interact with visualization systems in the real-world. One of the challenging issues of designing these types of visualizations that exceed the typical assumption is that there is no concrete design guidelines for them since how users engage with these visualizations differ case by case depending on their target audiences, deployed environments, and intended goals among other attributes. The engagement-versatile design concept promotes the development of visualization systems that can effectively relay information to users in various situations by focusing on matching the visualization's utility to each distinct mode of user engagement.

Engagement Modes

Engagement modes refer to the distinct styles in how users engage with the visualization. Identifying different engagement modes from how users interact with the visualization in its intended application context helps developers understand what type of utility is expected by the users. Therefore, by deriving a variation of design implications from each distinct engagement mode and incorporating them into the visualization's design helps the visualization to achieve the versatility necessary to maximize its utility in different situations.

In this study, we consider two attributes, *attention* and *participation*, based on our observation of how users interact with desktop visualizations, to determine the user's engagement mode. Each of these attributes encompasses two statuses. (1) The attention attribute indicates the status of a user's attention towards the visualization, and it is assigned a status of either *peripheral* or *focus*. Peripheral attention suggests that the visualization resides in the user's peripheral vision and is not given full attention. Focus attention suggests that the visualization is observed by the user, and it is given full attention. (2) The participation attribute indicates the status of a user's participation in the visual data exploration, and it is assigned a status of either *passive* or *active*. Passive participation suggests that the user is simply gazing at the visualization and not interacting with its user interfaces to actively explore the data. Active participation suggests that the user is utilizing the user interfaces to actively explore the data.

Based on these attention and participation statuses, we derive three distinct engagement modes relevant to the visualization.

- Periphery-Passive mode
- Focus-Passive mode
- Focus-Active mode

Periphery-Active mode is not included because it is a mode that is not feasible; actively interacting with systems that are in the periphery is not commonly practiced. Each of the three engagement modes we consider defines a unique interaction style and the expected role of the visualization. These modes allow us to accommodate users in different work settings with different degrees of interest.

Periphery-Passive Mode

Periphery-Passive mode describes a situation where the visualization is neither in the user's direct line of sight nor given much attention (it is in the user's periphery). In addition, the users are also not actively interacting with the visualization (passive interaction). In this situation, the users are not particularly interested in gaining specific information. Instead, the users prefer to quickly check data updates by glancing at the visualization without breaking concentration towards their main tasks. Therefore, the visualization in Periphery-Passive mode takes a role similar to an ambient display [28].

Focus-Passive Mode

Focus-Passive mode describes a situation where the visualization is in the user's direct line of sight and is given full attention (focus). However, the users are not interacting with the visualization to explore the data and are only gazing at the visualization (passive interaction). In this situation, the users are interested in gaining information from the visualization, but they have no particular objective or information on which they want to focus. Hence, the users are only interested in receiving information and are not particularly motivated in retrieving specific information. Therefore, the visualization in Focus-Passive mode takes a role similar to a static or an animated visualization system.

Focus-Active Mode

Focus-Active mode describes a situation where the visualization is in the user's direct line of sight and given full attention (focus), and where the user is interacting with the visualization to explore and investigate the data (active interaction). In this situation, the users are not only interested in gaining information from the visualization, but are also motivated to retrieve information based on specific interests. Therefore, the visualization in Focus-Active mode takes the role of a typical interactive visualization system, which facilitates extensive exploration and in-depth data analysis.

Design Approach

The three situations described above reflect the everyday circumstances under which most users interact with visualization systems. Therefore, leaving out any one of these engagement modes from the design consideration confines the types of users that the visualization can support and consequently limits the practical value of the visualization [15].

Engagement-versatile design allows visualizations to encompass all types of users by incorporating the design guidelines suggested by different visualization categories and associating these guidelines to the respective engagement mode into the construction of the visualization.

Our design approach for constructing an engagement-versatile visualization is as follows. For each visual component of the visualization, we identify the engagement modes to support. Then, we make our design decisions for each of these visual components based on the design guidelines appropriate to the engagement modes. By employing the engagement-versatile design concept, the visualization will be able to not only serve a wider range of users but also provide valuable information to the users in different situations.

STOCK LAMP

To demonstrate the feasibility of engagement-versatile design, we created Stock Lamp. Stock Lamp is a real-time visualization system of stock market data and online news feeds that targets the part-time investor demographic. This visualization system incorporates the unique feature of engagement-versatile design to help part-time investors in different situations keep track of market information, ongoing news, and social comments regarding a set of stocks.

We chose stock data for this case study for two reasons. First, stock information is neutral against personal preference. Most investors have a clear goal, which is to maximize capital gain. This consistency in user objective allows us to ask questions with well-defined answers for our user study. Second, there already exists a large population of part-time investors ranging from college students, office workers, to house wives who have limited time to engage with their investing activities. These potential users allowed us to gather valuable feedback throughout the development of Stock Lamp and also suggests the system's prospective real-world application.

Data Processing

The data used in Stock Lamp was collected from two online sources: Google Finance [1] and Twitter [3]. Google Finance provides market information, including price, transaction volume, related companies, and relevant news about the stocks. Twitter provides social comments relevant to the stock companies. In order to maintain this study's focus on its visual presentation method, we did not apply further data processing to derive additional information about the collected data.

Visual Components

Stock Lamp is equipped with two views, *lamp-view* (see Figure 1) and *info-view* (see Figure 3), and it displays either one of them based on the user's interest or engagement mode. Lamp-view displays market information and social attention on each stock through a figurative visual representation of the data. In lamp-view, users can view abstract information about stocks (e.g., whether the stock price is rising or dropping, and whether the companies are mentioned much on Twitter). However, the users in lamp-view cannot see detailed information (e.g., how much growth in price, what type of tweets are currently trending) about the individual stocks. Info-view complements lamp-view by providing users with detailed information in a descriptive fashion using texts and charts.

Lamp-View

Lamp-view employs a design model refered to as organic visualizations that is often considered to be aesthetically pleasing and to attract people's curiosity [25, 27]. In addition to employing organic visualization design, we also pay extra attention to the speeds of moving entities and color transitions in the lamp-view to ensure that the visualization maintains its unobtrusiveness as new data arrives. These design decisions were made to incorporate design guidelines for ambient displays and therefore support users in Periphery-Passive mode.

The inspiration of lamp-view is derived from lava lamps, a popular decorative ornament from the 1960s [2]. We chose lava lamps as a source of inspiration based on its decorative characteristics. Lava lamps have been a popular item for decorating various indoor environments. The liquid wax in lava lamps form various shapes and are constantly moving around, yet lava lamps are not considered distracting. Instead, they are often characterized as relaxing and fun to watch. Therefore, by virtually emulating a lava lamp, we believed that we could attain some of the product's core values: aesthetically pleasing, entertaining, soothing etc. These values are important in order to attract the attention of the uses in Periphery-Passive mode without being conceived as disturbing.

Figure 1 shows a screenshot of lamp-view. In lamp-view, Stock Lamp visualizes a set of stocks as jelly-like blobs[1] whose size, position, color, and brightness conveys information about their respective stocks. The lamp-view also includes a retractable side-panel that displays more detailed information about a featured stock to provide users with further information on stocks of their interest.

Figure 2 illustrates lamp-view's visual encodings. The size of the blob indicates the size of the stock's transaction volume over the last 20 seconds compared to its average volume. The vertical positions of the blobs depict the distribution of the price growth rate among the visualized stocks. The color of the blob indicates the price growth rate of the stock following the conventional practice for stock price indicators. The

[1] Each blob is generated by 20 metaballs [7] that randomly move within a certain radius from the core position of the topic.

brightness of the blob indicates the social attention towards the stock based on Twitter data. The horizontal positions of the blobs were fixed in order to help users maintain orientation in the visualization during their absence. By restricting the blobs from migrating horizontally, lamp-view allows users to quickly spot the blob representing the stock of their interest without needing to search the whole screen. These design decisions were made based on considerations in how people tend to interpret visual representations [13] and the feedback gathered from our pilot users[2].

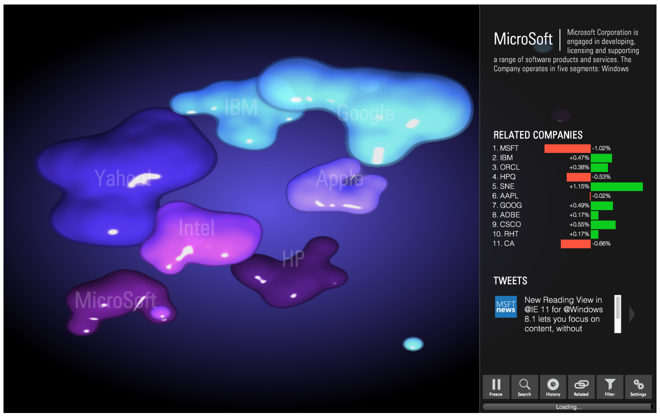

Figure 1: A screenshot of lamp-view.

Figure 2: The visual encoding of stock data in lamp-view.

The retractable side-panel displays small pieces of textual information about a featured stock to supplement the figurative lava lamp metaphor. This side-panel consists of four components: description, related, tweets, and controller. The description component displays the featured company's name and its description. The related component displays the stock information of the companies that are related to the featured company. The tweets component displays tweets that contain content associated with the featured company. The controller component provides a simple user interface for controlling animation settings and customizing the content displayed in the side panel. These pieces of information are based on what other web sites (e.g., [1, 5]) display for individual stock.

Since the contents displayed in this side panel are descriptive and require the user's full attention, the side-panel is hidden by default when users are in Periphery-Passive mode.

[2]Three university employees: a data-specialist, a visualization developer, and a graphics designer volunteered as pilot users for this research. All three were familiar with the data, and two had experience in part-time stock investment.

This helps the lamp-view to maintain a simple view allowing users to appreciate the visualization's artistic aesthetics without feeling the need to analyze the information when they glance at the display while working. The side-panel appears when the system detects that the users are in Focus-Passive or Focus-Active mode. The featured company is randomly selected by the system for the users in Focus-Passive mode, or manually selected by the users in Focus-Active mode.

In order to warn users the occasional sudden changes in stock market, the blobs in lamp-view would also jiggle rapidly and emit pulsing lights to catch the user's attention when certain data values exceeded some threshold set by the user.

Info-View

Info-view presents detailed information about a specific company through a series of infographics-like visualizations. Figure 3(a) shows a screenshot of info-view. After selecting a particular company, the info-view displays a set of visualizations that show different aspects of the company's data.

There are four types of information available in the Stock Lamp's info-view: history, related companies, news, and people. These different aspects of the company are presented to the users in small widgets referred to as info-cards. Each info-card portrays one aspect of the specified company based on the most recent data.

Figure 3 shows the four different types of info-cards: history-card, related-card, news-card, and people-card. History-card portrays the history of the company's stock and important news published over the last three months. In this card, the line chart depicts the temporal history of the stock's price and the flags in the chart link the past news articles that are considered to have had an effect on the stock prices listed on the right. To provide users with an idea of the content of the news article, this list includes the headline of the news article and users can click on the text to review the full article. Related-card displays a set of companies that are related to the company and the current stock prices of those companies. News-card displays a list of the most recent online news articles relevant to the company. This card also provides access to the full article by clicking on the listed items. People-card presents a summary of the tweets associated with the company by listing the top ranking Twitter users (with the most favorited/re-tweeted tweets) and their most popular tweets.

In info-view, these four types of info-cards are generated per company and are individually displayed on the screen. The number of info-cards visible to the users depends on the screen real estate and the user settings. In our example of Stock Lamp, info-view displays two info-cards simultaneously (see Figure 3). To explore other info-cards, users can either scroll to the info-card of their interest or call it out by specifying the company and the card type in the control-panel on the right. This control-panel also allows users to return to lamp-view by clicking on the snapshot of the blobs at the top.

Since these info-cards all contain pieces of information that are more contextual than abstract, the visualizations in info-view are more descriptive than figurative and tend to require the user's full attention. Thus, info-view mainly targets users

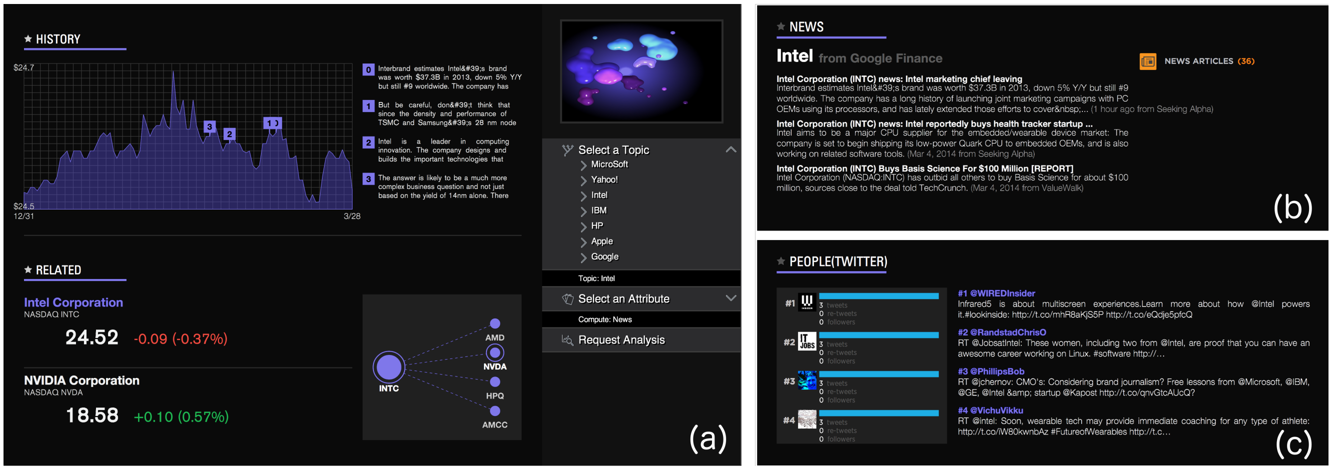

Figure 3: (a): A screenshot of info-view. The displayed info-cards are (top) history-card and (bottom) related-card. (b): An example of news-card. (c): An example of people-card.

in Focus-Passive and Focus-Active modes. In order to keep providing all users with fresh and updated information, the info-view scrolls a new info-card into view automatically after a set period of time when the users are in Focus-Passive mode. Otherwise, it will wait for input from the user.

Implementation

The implementation of the visual components for Stock Lamp uses two web-based graphics programming technologies, WebGL [4] and D3 [9]. We chose WebGL over other web-based graphics because it was the only graphics language that could take advantage of the GPU and maintain a frame rate for smooth animation without compromising graphical resolution. We used D3 for implementing the visualizations seen in info-view. We chose D3 for generating the info-cards because D3 is one of the most simple graphics languages and has a great built-in library for managing user interactions with visual entities. This simplicity helped us design and develop a variety of info-card templates for testing on pilot users, and also allowed us to easily add new info-card designs as new data attributes are introduced to the data.

For detecting the user's engagement mode, Stock Lamp combines two pieces of information: the user's attention (derived by a simple eye detection/tracking system [23] using the webcam video stream) and interaction (based on the use of the mouse or touchscreen). Any sort of interaction with the system indicated that the user was in Focus-Active mode. Otherwise, Focus-Passive mode or Periphery-Passive mode was determined based on whether the user's eyes were directed to the visualization or not. This simple engagement detection mechanism worked well for our simple case study. However, we believe that future engagement detection mechanisms will need to be modified and designed accordingly to the system's deployed environment and to its target audiences.

USER STUDY

In order to evaluate Stock Lamp for its usability with respect to the three user engagement modes, we conducted a user study consisting of three tests, one for each engagement-mode. Each test contained a unique set of tasks specifically designed to simulate situations that would prescribe the respective engagement-mode to the users. Participants in the user study were asked to take all three tests twice: once using Stock Lamp, and once using *Dashboard*. In order to avoid any learning effects, half of the participants were asked to test Stock Lamp first and Dashboard next, and the other half were asked to test in the reversed order.

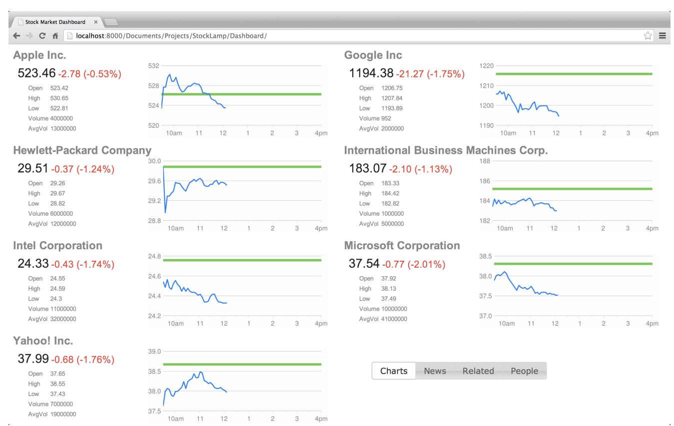

Figure 4: A screenshot of Dashboard showing the stocks' history data. Each widget contains basic market information, including price, transaction volume, and a market price chart.

Dashboard is another real-time visualization system we developed that emulates a more traditional stock visualization style. The data used in Dashboard is exactly the same data as in Stock Lamp, and the difference between these two systems is solely based on their styles of presentation. Dashboard displays a set of widgets portraying a company's data based on one of four attributes: history, related companies, news, and people. Figure 4 shows a screenshot of Dashboard displaying the history attribute. Users can switch the displayed information to a different attribute using the buttons in the bottom right corner. Dashboard's visual design is based on a more traditional presentation style for stock data, and its visual elements are mostly borrowed directly from major web-sites that provide real-time stock data [1, 5].

The data used in this user study was pre-collected for 5 consecutive weekdays, from March 2 to 7 2014, at 20-second intervals during the stock market's open hours. This collected data consisted of seven stocks whose stock symbols are AAPL, GOOG, HPQ, INTL, YHOO, MSFT, and IBM. The number of stocks to display was determined based on a series of financial articles which recommended non-professional investors to maintain portfolios comprising of no more than 10 stocks [14, 24]. In addition to this recommendation, we also believe that seven is a suitable number to visualize on Stock Lamp considering the lamp-view's scalability with respect to the number of blobs that can fit in the limited display real estate and be viewed effortlessly within the people's attention capacity [16]. We used pre-collected data instead of real-time data for this user study in order to prevent the participant's local time zone and the stock market closing time from affecting the user experience while taking the tests.

Procedure

All participants of in the user study were asked to follow a specific procedure consisting of four steps.

Step-1: Introductory Tutorial

Step-2: Focus-Passive Test Session

Step-3: Periphery-Passive Test Session

Step-4: Focus-Active Test Session

Each test session contained two tests with the exact same tasks. The first round using Stock Lamp, and the second round using Dashboard. The order of the three test sessions were determined based on the complexity of the tasks requested in the test sessions. By assigning the test sessions with simpler tasks to earlier steps, the users were able to gain enough experience in both visualization systems to carry out complex tasks in the later steps.

Introductory Tutorial

In the introductory tutorial, users were given an online presentation which introduced the two visualization system, Stock Lamp and Dashboard. The presentation explained the basic concept and how to visually interpret the displayed information in these two systems. Once the users were done with the presentation, the tutorial gave a quick comprehension check by prompting a set of simple questions, each coupled with a screenshot of a visualization. Overall, the introductory tutorial took users approximately 5 minutes.

Focus-Passive Test Session

In the first test session, the users were asked to analyze the displayed information by gazing at the visualization system without any interaction. The task for this test was to identify the four companies that answer the following four questions:

Q-FP-1: Which company had the best price growth rate?

Q-FP-2: Which company had the worst price growth rate?

Q-FP-3: Which company had the largest transaction volume?

Q-FP-4: Which company had the least transaction volume?

Here, the price growth rate indicated the percentile growth of the stock price, and the transaction volume indicated the current transaction volume relative to the respective company's daily average transaction volume. For all four questions, the users were prompted to select one response out of eight options. The options consisted of the seven company names and an additional answer "Not sure" for participants who were not sure of the correct answer.

After establishing the task objective, the users were shown the respective visualization system (Stock Lamp or Dashboard) for 1 minute. In order to test a range of different stock market situations, the data displayed in the system was selected from a random timestamp for each test. In this test, Stock Lamp was fixed to display lamp-view with the side-panel visible, and Dashboard was fixed to display the history data as seen in Figure 4. After the 1 minute was up, the visualization was blacked out and the participants were asked to submit their responses to the four questions.

The submitted answers were then cross-examined with the data presented to the participant and were each converted into points (from -3 to 3) based on its correctness. The correctness of an answer was measured by how closely the answered company ranked to the correct answer (higher points for closer answers; 3 points for correct answer). The answer "Not sure" was worth 0 points. By measuring the correctness using a range of scores instead of employing an all-or-nothing type of scoring system, we aimed to mitigate the effects of the different displayed data on the user's performances. These four points were compiled into one correctness score (ranging from -12 to 12 with an expected value of 0), which represented how well the user performed in the task.

Periphery-Passive Test Session

In the second test session, the users were asked to analyze the information displayed in the visualization while playing a game. The task for this test was to identify the four companies that answer the same four questions (Q-FP-1–4) as in Focus-Passive test with an additional request. The additional request was to aim for a high-score in the game.

The game we used was an online Whack-a-Mole [22] where each mouse click on the correct target was awarded one point. Achieving a high-score in this game requires the user's full attention to quickly assess and react to the moving targets. Therefore, it allows us to effectively simulate a situation where the participant's engagement towards the visualization system is Periphery-Passive [31]. In order to prevent the testing order from affecting the game scores, all participants went through one trial of the game before taking this test.

After establishing the task objective, the users were asked to start playing the game for 2 minutes on their primary monitor with the respective visualization system (Stock Lamp or Dashboard) for two minutes on their secondary monitor. In order to test a range of different stock market situations, the data displayed in the system was also selected from a random timestamp for each test. In this test, Stock Lamp was fixed to display lamp-view with the side-panel retracted, and Dashboard was fixed to display the history data. After the 2 minutes elapsed, the visualization was blacked out and the participants were asked to submit their responses to the four questions and record their game scores. The four responses to the questions were then compiled into one correctness score in the same fashion as in the Focus-Passive test session.

Table 1: Test Results Summary: Mean and (Standard Deviation)

	Focus-Passive (31)	Periphery-Passive (27)		Focus-Active (31)					
	Correctness	Correctness	Game	MD	PD	TD	Ef	Pe	Fr
Stock Lamp	8.48(2.82)	8.81(2.72)	30.70(13.93)	5.77(2.35)	3.77(2.42)	4.48(2.17)	5.48(2.46)	5.13(2.42)	4.94(2.42)
Dashboard	7.30(3.31)	4.52(3.76)	26.63(12.20)	6.50(2.39)	4.20(2.78)	5.17(2.70)	6.17(2.04)	5.40(2.18)	5.47(2.43)

The reason Focus-Passive tests and Periphery-Passive tests have different durations is based on the feedback we got from the pilot users (who at this point were familiar with both visualizations). The feedback regarding Focus-Passive tests suggested that gazing at the same information for 2 minutes is too long and that the users would become bored. On the other hand, for the Periphery-Passive tests, users feel extremely hurried if they are asked to effectively execute the task while multi-tasking within 1 minute. Therefore, to allow users to comfortably execute the requested tasks, we assigned a 1 minute gazing time for the Focus-Passive test and a 2 minute multi-tasking time for the Periphery-Passive test.

Focus-Active Test Session

In the third test session, the users were asked to freely explore the data using the visualization system to make their own future investment decisions. The task for this test was to analyze the presented data and decide on one stock to sell and another stock to invest in exchange.

After establishing the task objective, the users were shown the respective visualization system visualizing data from a randomly selected timestamp for 3 minutes. In this test, all interactions and views for both Stock Lamp and Dashboard were accessible to the participants. After the 3 minutes was up, the visualization was blacked out and the participants were asked to submit two forms.

The first form contained four questions regarding the task:1.) Which stocks would you sell? 2.) What information helped decide on selling this stock? 3.) Which stocks would you buy more? 4.) What information helped decide on buying this stock? These questions were asked mainly to later confirm that the user was able to execute the requested task.

The second form contained six questions that asked about different aspects of the user experience while carrying out the task. The six questions were based on the NASA Task Load Index (TLX) [17]: Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Effort (Ef), Performance (Pe), and Frustration (Fr). The first three questions asked how mentally, physically, and temporally challenging the task was using the visualization. The next three questions asked the user's experience in executing the task using the visualization with respect to their required effort, achieved performance, and perceived degree of frustration/stress. The responses for all six questions were based on a scale from 1 to 10, where 1 indicating low and 10 indicating high. (For performance, 1 indicates good and 10 indicates poor). Intuitively, the lower value indicates that the user considered the task was easier to accomplish.

Results

A total of 31 users (6 females) consisting of students, office workers, and house wives, ranging from age 23 to 34 participated in the study. Since experienced stock investors tend to have extensive training and are often familiar with the traditional style of stock visualization, we chose participants that have little to no experience or training in stock investments. All three test sessions were conducted online and the participants were asked to take the tests in their own personal settings. Four users were not able to conduct the Periphery-Passive test session due to its system requirement (a minimum of 2 monitors). These four users were excluded from the all analyses unless specified otherwise.

Table 1 shows a summary of the collected results. The two values in each cell correspond to the mean (μ) and the standard deviation (σ) for all users who participated in the test session. The numbers of users in these test sessions are shown in the parentheses accompanying each test session's name.

First, we used these results to examine if there were statistically sound effects on the users' performances based on the difference in visualizations (system) and engagement modes (e-mode). For this analysis, we applied two-way analysis of variance (ANOVA) to the correctness score of 27 users who took both Focus-Passive and Periphery-Passive test sessions. Table 2 shows the results of this analysis. These results indicate that both the visualization system and the engagement mode individually have an effect on the user's performance. At the same time, the combination of these two attributes also shows statistical significe suggesting that the effects of the engagement mode to the user's performance are not consistent for Stock Lamp and Dashboard.

Table 2: Two-way ANOVA

	Sum of Square	df	Mean Square	F	p
System	202.81	1	202.81	20.07	$> .0001^{***}$
E-mode	40.33	1	40.33	3.99	$.0484^{*}$
System:E-mode	65.34	1	65.34	4.10	$.0125^{*}$
Error	1051.19	104	10.11		
Total	1359.67	107			

Note: The symbol * on p indicates a .01 significance level and *** indicates a .001 significance level.

To gain a deeper insight into these suggested effects, we extended our analysis by applying pairwise comparison for correlated observations to the same correctness scores. Table 3 shows the results of this pairwise comparison. Here, we denote each test by hyphenating the abbreviations of the respective visualization system (SL for Stock Lamp and D for Dashboard) and the engagement mode (FP for Focus-Passive and PP for Periphery-Passive). In this pairwise comparison, the Bonferroni per-comparison error suggests that p values need to be below .0083 to achieve the conventional .05 significance and below .0017 to achieve .01 significance level.

Based on these pairwise comparison results, we can further analyze the data and isolate what is causing the differences in the user's performance. Among these six comparisons,

Table 3: Pairwise Comparison of correctness Scores

Comparison			μ	σ	σ_{err}	$t(26)$	p
SL-FP	–	D-FP	1.19	4.05	0.78	1.52	.1403
SL-FP	–	SL-PP	-0.33	3.37	0.65	-0.51	.6121
SL-FP	–	D-PP	3.96	5.03	0.97	4.10	.0004**
D-FP	–	SL-PP	-1.52	4.72	0.91	-1.67	.1064
D-FP	–	D-PP	2.78	3.48	0.67	4.15	.0003**
SL-PP	–	D-PP	4.30	5.12	0.99	4.36	.0002**

Note: Taking Bonferroni per-comparison error into consideration, the symbol ** on p indicates a .01 significance level.

all three comparisons that contain the Periphery-Passive test using Dashboard (D-PP) show that there is a drop in the user's correctness score with significance at the .01 level. On the other hand, the comparisons that contain the Periphery-Passive test using Stock Lamp (SL-PP) show no significant evidence to indicate a decline in the user's performance. These observations suggest that Stock Lamp has a significant advantage over Dashboard in presenting information to the users who are multi-tasking. We further confirmed this hypothesis by conducting a paired two-tailed t-test on the user's Periphery-Passive test session's game scores. The results of this t-test indicated users were able to score 3.46 more in average using Stock Lamp at the significance of .05 level.

Another interesting comparison is between Stock Lamp and Dashboard in Focus-Passive mode (SL-FP−D-FP). Although our two-way ANOVA indicated that there is a relationship between system and user performance, the pairwise comparison for the Focus-Passive test session was not able to provide sufficient evidence to corroborate the ANOVA's results. This suggests that if the visualization has the user's full attention, then there might not actually be a significant difference between Stock Lamp and Dashboard. We believe this result is related to the difference in personal preferences for information presentation styles, and discuss this idea further below.

Next, using the self-reported workload measurements from the Focus-Active test session, we examined whether one visualization system was perceived as easier to use than the other by the users. For this analysis, we applied the Wilcoxon signed-rank test to each set of task load index scores. We chose the Wilcoxon signed-rank test for comparing these scores because these scores are strongly affected by each individual user's subjective interpretation of the scoring measurements. Therefore, these scores needed to be treated on an ordinal scale and paired with the score for the other visualization before comparing between users.

Table 4: Wilcoxon Signed-Rank Test of NASA TLX Scores

Question	W	N_r	z	p
Mental Demand	101	27	1.21	0.23
Physical Demand	17	19	0.33	0.74
Temporal Demand	53	24	0.75	0.45
Effort	107	26	1.35	0.18
Performance	25	27	0.29	0.77
Frustration	92	30	0.94	0.35

Table 4 shows the results of the Wilcoxon signed-rank test. These results indicate that the data showed no statistical significance; neither visualization system were perceived easier than the other to carry out task. However, as we had proposed in the case of the pairwise comparison of the Focus-Passive test session, the absence of the statistical significance in this task load feedback might have been due to the differences in personal preferences among the participating users. In other words, within the participating users, there might have been a group of users who prefer Stock Lamp over Dashboard who can score better in the Focus-Passive test session and who also consider the workload of analyzing data to be easier using Stock Lamp, and another group with the opposite preference.

To examine this hypothesis, we conducted another Wilcoxon signed-rank test on the self-reported workload measurements collected from two different groups, Group-SL and Group-D. These groups were separated based on their correctness score in the Focus-Passive test session. Group-SL consisted of 19 participants that were able to score more points using Stock Lamp, and Group-D consisted of 15 participants that were able to score more points using Dashboard. There were 3 participants that scored the same points using Stock Lamp and Dashboard. These participants were put into both groups.

Table 5: Wilcoxon Signed-Rank Test for Group-SL and -D

	Group-SL				Group-D			
	W	N_r	z	p	W	N_r	z	p
MD	85	17	2.00	.04*	-11	12	-0.41	.68
PD	25	11	1.09	.28	-17	10	-0.84	.40
TD	65	13	2.25	.02*	-26	14	0.80	.42
Ef	52	15	1.46	.14	15	13	0.51	.61
Pe	20	16	0.50	.62	5	12	0.18	.86
Fr	111	18	2.41	.02*	-35	15	-0.98	.33

Note: The symbol * on p indicates a .05 significance level.

Table 5 shows the results of Wilcoxon signed-rank test for the two groups. These results show that participants who belong to Group-SL provide sufficient evidence to conclude that the distribution of their responses regarding Mental Demand, Temporal Demand, and Frustration all shift right when using Dashboard for Focus-Active test at $p < .05$ significance. In other words, these results suggest that users who can score better in Focus-Passive test using Stock Lamp also tend to find Stock Lamp easier to use than Dashboard when analyzing stock data. On the other hand, the participants who belong to Group-D do not indicate that the opposite direction of the preference is true. That is, users who were able to score better in Focus-Passive test using Dashboard do not necessarily find Dashboard easier to analyze stock data.

In summary, we were able to draw two conclusions from our user study.

- Stock Lamp is an effective system for presenting information to users who are multi-tasking.
- Users who are able to effectively interpret the data presented by Stock Lamp also tend to find Stock Lamp easy to use for exploring and analyzing stock data.

These findings imply that our consideration towards engagement-versatile design was successful in allowing Stock Lamp to encompass users with limited attention without compromising the user experience in other engagement modes. Furthermore, the users who found that Stock Lamp intuitive and effective for making investment decisions in a limited time prove that Stock Lamp indeed has the potential of becoming a practical supplementary tool for monitoring the stock market.

In addition to these functional aspects, we also received many positive comments from the users regarding the Stock Lamp's entertaining visual aesthetics. One of the users thought that Stock Lamp would be a great visualization to display in a company's lobby to show its stocks in comparison to that of its competing companies to promote awareness to the employees. Another user said that the figurative representation of the stock data is less obvious and would be a nice camouflage for part-time investors who want to use it while working.

DISCUSSION

Stock Lamp presents certain advantages over traditional visualizations as shown by the user study. However, predicting future market trends requires comprehensive analyses, taking into account not only company performance and stock price history, but also relevant news articles, state policies, and public opinions. While we do not expect traditional visualizations to be replaced by Stock Lamp, we do anticipate Stock Lamp to be used as a supplementary tool by part-time investors. Most visualization tools need to be utilized in conjunction with other tools to provide the users with multifaceted views. Based on our findings, Stock Lamp can serve these investors as a great auxiliary source of information to maintain market awareness and conduct quick checks on data relevant to their stock portfolios.

Moreover, Stock Lamp is a simple demonstration of a grander concept: engagement-versatile design. The visual components of Stock Lamp – lamp-view and info-view – can be utilized as templates for constructing engagement-versatile visualization systems and applied to different datasets. For example, we have also been developing:

- News Lamp: A visualization that displays trending online news topics. This system aims to provide users with an online news portal where users can access news articles, blog posts, and social comments on a topic of their interest.
- Access Lamp: A visualization that displays server access information. This system aims to help system administrators monitor server access and identify potential threats.

Similarly, these engagement-versatile visualizations do not require users constant attention. This study provides an initial discussion towards categorizing engagement styles between users and visualizations. We considered two attributes, attention and participation, as preliminary components for developing the partitioning of distinct engagement styles. We anticipate the future expansion of engagement style categories by the addition of newly identified attributes. In particular, we believe that visualizations operated in environments beyond the conventional desktop settings may suggest new attributes, leading to the establishment of more engagement style categories, similar to the efforts of Jansen and Dragicevic [21].

CONCLUSION AND FUTURE WORK

In this paper, we introduce a new design concept, engagement-versatile design, for constructing visualization systems that target a wide range of users with different engagement styles. We first identify three unique modes of engagement between users and desktop visualizations, and then discuss how each mode helps derive design guidelines for constructing a visualization that can serve users with different engagement modes. We then demonstrate the feasibility of this design concept by constructing a real-time stock market visualization system called Stock Lamp.

Through an extensive comparative user study, we show that the system can effectively present market information to its users. In particular, when users are asked to multi-task, Stock Lamp was able to present information more effectively than a traditional visualization, validating the benefits of applying engagement-versatile design.

To the best of our knowledge, this study is one of the first to to establish a design concept for addressing the diverse styles of user engagement and applying them to enhance the visualization's utility – all in a systematic manner. We believe that this study will help future developers design practical visualization systems that target broader audiences, going beyond conventional application scenarios that are commonly limited to domain experts and their analyses of data.

Our future research will attempt to extend our understanding of engagement-versatile design in two different directions. One direction is to measure the success of the integration of engagement-versatile visualizations into users' daily lives. We plan to do this by opening our engagement-versatile visualization systems (including Stock Lamp) to the public and conducting a long-term user study observing user activities for an extensive period of time. Another direction is to extend our simple attention/participation engagement model to a more comprehensive taxonomy of engagement modes. We plan to do this by reviewing the variety of engagement styles users exhibit toward different systems. For example, systems with wall-sized displays, tangible interfaces, and augmented reality applications all potentially influence users' engagement styles, thus presenting potential other modes of engagement (e.g., [12]). A thorough review of existing systems and their user engagement scenarios would help us establish a rich taxonomy of engagement modes, ultimately assisting the design of practical visualizations for different audiences and situations.

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