Making Stock Market Charts Accessible through Provision of Textual Information in a Common Interface

By

Hong Zou

Submitted to OCAD University
in partial fulfillment of the requirements for the degree of

Master of Design

in

Inclusive Design

Toronto, Ontario, Canada, April, 2015

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Abstract

While sophisticated interactive charts provide a host of advantages to the majority of stock market investors, they also create a significant barrier to individuals with visual impairments. This paper describes exploration and usability testing of three proposed alternative accessibility solutions aimed at improving the accessibility and usability of stock market charts for visually impaired screen reader users. The findings revealed that although a dropdown menu solution was favoured over an auditory and text input solution, users prefer having as many options as possible; they would rather choose appropriate solutions according to their personal preferences and the task they wish to accomplish. In conclusion, a one-size-fits-all model is not ideal in meeting diverse users' needs within the widest context possible. Providing options while enabling users to personalize the interface through flexible configurations is indeed the ultimate goal of a design.

Key words: Stock market charts; screen reader; non-visual; multi-modal; inclusive design; usability; accessibility; visual impairment; financial literacy.

Acknowledgements

I would first like to thank my Primary Advisor, Dr. Jutta Treviranus, and my committee members Dr. Vera Roberts and Dr. Sambhavi Chandrashekar. You rescued me countless times from seemingly unsolvable queries – researching, writing, and editing this work would not have been possible without your penetrating insights and compassionate hearts. I would also like to thank Dr. Peter Coppin for being so encouraging at the initial stage of this project.

The true designers behind this project are the usability testing participants who proposed wonderful design ideas. The trust you placed in me, coupled with your heartfelt enthusiasm lifted my spirits during the more stressful periods of producing this work. The MRP's ingenious developers, my colleague, Jonathan Chiu, and friend David Liu, deserve special recognition for creating **ChartMaster** under a tight deadline.

Many thanks to Julia Foster for facilitating usability testing participant outreach. Bert Shire's technical support and Aileen O'Dowd's administrative know-how facilitated what could have been a very frustrating process. I would also like to thank my manager at CIBC, Amelia Myers for her unwavering support. Julie Anne Buelow kept my head up through the difficulties that were an inevitable part of the research process. Thank you, my friend.

For having lovingly looked after my family during this project, my dear mother has once again earned my eternal gratitude. Her infinite kindness will always surpass my imagination. My sweet three-year-old Sophie also deserves acknowledgment for having let mommy work, even when she wanted to play. And finally, to my husband, Richard Kovacs…Your endless sacrifices are a testament to your unconditional love. This work may be written in my name, but it definitely belongs to you…if not in content, then in spirit.

Dedication

To all those who love and care

Table of Contents

List of Tables

List of Figures

1 Introduction

Our understanding of disability has shifted in the past few decades from a traditional bio-medical perspective[1] to a socially-based perspective[2]. Thus, disability is no longer considered a medical or health condition associated with the individual, but rather the result of social, physical, or political barriers that prevent or hinder an individual's ability to participate fully in society. This shift reflects a common recognition and appreciation of diversity, and in turn helps to drive the design and implementation of inclusive policies, services, and products[3] that fit the needs of a "full range of human diversity with respect to ability, language, culture, gender, age and other forms of human difference" (IDRC, 2013).

With this shifting notion of disability comes a re-orientation of design, from designing for the majority, to designing to provide sufficient flexibility that takes into account the range of human diversity. This notion of inclusion thus inspired the design research described

[1] One typical sample for this bio-medical approach can be seen in the Ontario Human Rights Code. Section 10 (1) of the *Code* defines "disability" as follows: 1. any degree of physical disability, infirmity, malformation or disfigurement that is caused by bodily injury, birth defect or illness and, without limiting the generality of the foregoing, includes diabetes mellitus, epilepsy, a brain injury, any degree of paralysis, amputation, lack of physical co-ordination, blindness or visual impediment, deafness or hearing impediment, muteness or speech impediment, or physical reliance on a guide dog or other animal or on a wheelchair or other remedial appliance or device, 2. a condition of mental impairment or a developmental disability, 3. a learning disability, or a dysfunction in one or more of the processes involved in understanding or using symbols or spoken language, 4. a mental disorder, or 5. an injury or disability for which benefits were claimed or received under the insurance plan established under the *Workplace Safety and Insurance Act, 1997* (OHRC, 1990)

[2] A typical sample for social approach can be seen in Inclusive Design Research Centre. "The IDRC reframes disability within the design context. Rather than a personal characteristic or a binary state (disabled vs. non-disabled), disability is framed as: a mismatch between the needs of the individual and the design of the product, system or service."(IDRC, 2013)

[3] For example, Accessibility for Ontarians with Disabilities Act (AODA) provides mandatory accessibility standards that identifies, removes and prevents barriers for people with disabilities in five areas of daily life: Customer Service, Employment, Information and Communications, Transportation, and Design of public spaces. In addition, Human Resources and Skills Development Canada published Federal Disability Reference Guide with four key guiding principles to ensure that federal programs, policies and services maintain or enhance the social and economic inclusion of people with disabilities: 1) Full Participation in society, the economy and the community; 2) Equality of opportunity to remain in his or her local community and receive needed supports from mainstream education, health, employment, and social services, as well as specialized services and supports where required; 3) Opportunity for independent living to self-actualize and fulfill their rights and responsibilities as Canadian citizens; 4) Economic self-sufficiency (Canada, 2013)

in this paper: an exploration of accessible input that aims to improve the accessibility and usability of stock market charts for visually impaired screen reader users. Although the target of this study is the visually impaired screen reader user, it is expected that with innovative design solutions, we will be able to improve financial inclusion and digital inclusion not only for this specific social group, but also for a much broader population who will also benefit from stock market charts that are easier to understand and that provide information highlights for users. This greater benefit is a common phenomenon associated with inclusive design.

This paper provides background information of related research; this includes the cost of a lack of financial literacy at both the individual and socioeconomic levels, as well as the gap preventing individuals from participating in financial activities. It then examines stock market charts, a major stock market research tool to demonstrate the barriers people face while accessing critical information needed to make informed investment decisions. The focus of this research is resolving this design challenge: improving the usability and accessibility of stock market charts, with a focus on visually impaired screen reader users. Design concepts and approaches used in the study are outlined and followed by descriptions of the research carried out to address the challenge:

1. An investigation of the accessibility and usability issues of existing stock market charts, and related research that focuses on helping visually impaired users to access charts and graphs.
2. Iterative design and usability testing of accessible stock market chart interface solutions: verbal input, text input, and dropdown menu input.

Findings from this research are presented and design implementations are then explained in great detail. The paper concludes with a discussion around the limitations of the design and future work.

Figure 1: The scope of the research project

2 Financial Literacy and Education

Over the past decades, there has been growing world-wide interest in financial literacy and investor education, particularly after the 2009 global financial crisis. Many people and institutions are increasingly recognizing the costs of financial illiteracy on "financial and economic stability as well as on individual's or households' wellbeing, especially among low-income groups"(OECD, 2013).

International economic organizations such as OECD and the Board of the International Organization of Securities Commissions (IOSCO) have been developing international guidance on principles and best practices to support policy makers and public authorities to design and implement strategies in financial literacy and investor education(IOSCO, 2014; OECD, 2005, 2011)[4]. Meanwhile, countries at different income levels[5] are continuously developing and refining their respective national strategies for financial literacy to articulate priorities and identify key actions to various stakeholders in order to increase the awareness of financial literacy and to enhance financial education efficiency (F. C. A. o. Canada, 2014; Commission, 2014; Zealand, 2014). Financial institutions are encouraged to not only provide information and advice on financial issues, but to also promote financial awareness, especially in areas presenting a long-term impact on clients'

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[4] For example, *Recommendation on Principles and Good Practices for Financial Education and Awareness* published by OECD in 2005, recommended eight principles and good practice specifically for public action, financial institutions education and programs, and retirement savings education(OECD, 2005). In 2011, OECD published *Measuring Financial Literacy: Questionnaire and Guidance Notes for Conducting an Internationally Comparable Survey of Financial Literacy(OECD, 2011). The questionnaire and guidelines were created to enable public authorities and other organizations to collect financial literacy data in a standardized process. In 2014, the IOSCO released a consultation report, Strategic Framework for Investor Education and Financial Literacy in 2014, with the aim of describing "IOSCO's role in investor education and financial literacy, the role of research, particularly the field of behavioural economics, and C8's initial areas of focus and strategic approach to fulfilling its primary mandate"(IOSCO, 2014).*

[5] By 2013, 45 countries have engaged in the development of national strategies(OECD, 2013).

financial well-being(OECD, 2005). Financial education programs are increasingly integrated into elementary and secondary school curricula of many countries, either through mandatory financial literacy courses or optional courses[6]. In addition, not-for-profit organizations have also joined forces to provide financial education standards[7], resources and practical information to people at all financial levels[8].

2.1 Financial Literacy Level Remains Low Across the Nation

Despite the collaborative efforts to improve financial literacy, numerous studies suggest that low levels of financial literacy are prevalent among all age groups around the world (FINRA, 2009; Lusardi & Mitchell, 2005, 2013; Mandell, 2008; Mandell & Klein, 2009; NCEE, 2005; OECD, 2013, 2014; OECD/INFE, 2013). Some of the main concerns revealed by these studies include the following:

- Individuals lack active, informed market participation
- Individuals lack knowledge of basic financial and economic concepts, particularly those relating to investment items such as bonds, stocks, mutual funds, and borrowing products
- Individuals acutely suffer from an inability to properly save and plan for their financial future

6 For example, by 2008 in the US., twenty-eight states had mandatory financial literacy content standards for high school students; many other high schools offered optional courses by that same year (Cole & Shastry, 2008). In Canada, several provinces, including British Columbia, Ontario, Quebec, and Saskatchewan have added financial literacy components for Students in grades 4-12(Education, 2013; Loriggio, 2014).

7 For example the National Standards in K-12 Personal Finance Education published by the Jump$tart Coalition

8 For example, in US, individuals at various financial literacy level can find practical guidelines through organizations, such as the High School Financial Planning Program by NEFE, National Endowment for Financial Education, and Institute for Financial Literacy in US. In Canadian, investors and find resources at Canadian Centre for Financial Literacy, Canadian Foundation of Advancement of Investor Rights, Investor Education Fund, ABC Life Literacy Canada, and The MoneyMinding Foundation.

- Individuals inability to perform calculations involving issues such as compound interest and investment return

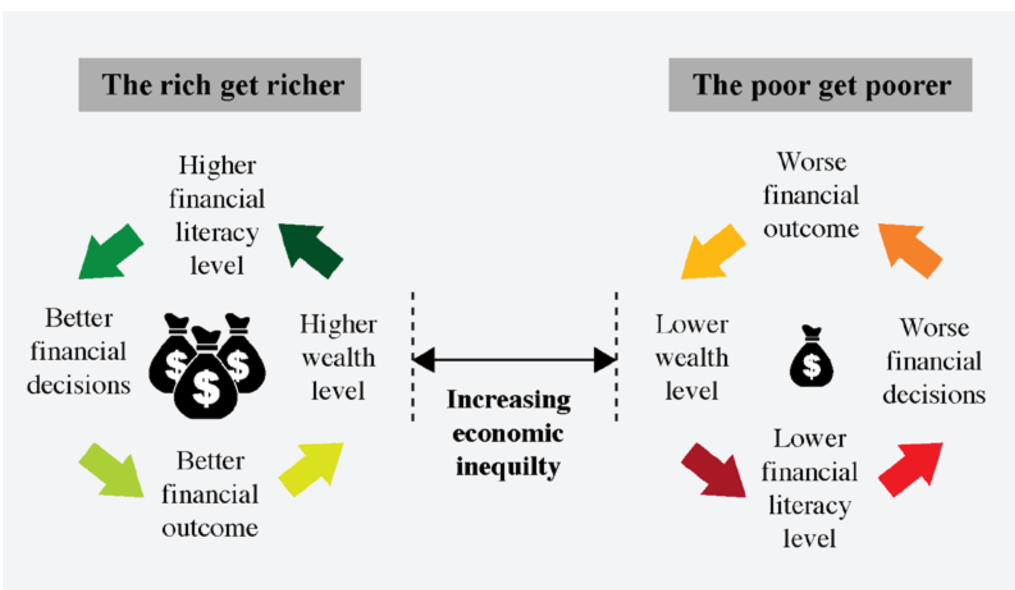
Canadians' financial knowledge is also limited despite the fact that Canada possesses one of the world's largest proportion of shareholders (37.52%) (Grout, Megginson, & Zalewska, 2009). For example, as part of the 2014 Canadian Financial Capability Survey, participants were asked to answer a series of 14 questions concerning their knowledge of topics such as inflation, debt repayment, banking fees and credit reports. Only 2.7% provided correct answers to all the questions, while two-thirds of the survey participants failed to answer seven questions or more (S. Canada, 2014).

2.2 The Cost of Financial Illiteracy in Socio-economic Inequality

The cost of financial illiteracy is seen in both personal financial well-being and socioeconomic levels due to a strong correlation between an individual's financial literacy level, financial decision-making, and economic outcomes. On the one hand, financial illiteracy tends to be concentrated among specific social groups, such as youth and the elderly, women, minorities, immigrants, people with lower incomes, those with little education, and those living in rural areas (Lusardi & Mitchell, 2013). Consequently, individuals in these subgroups are more likely to neglect investing opportunities and invest inefficiently when they do participate (Calvet, Campbell, & Sodini, 2007; Kimball & Shumway, 2006). They also tend to fail at managing their debt and liabilities and end up paying excess interest rates and fees (Agarwal, Driscoll, Gabaix, & Laibson, 2009). Conversely, researchers discovered that individuals with higher financial literacy levels consistently behave in the way that financial economists would recommend (Kimball & Shumway, 2006). They are more likely to proactively get involved in financial activities, make smarter financial decisions, and achieve a much higher wealth level than those who are financially illiterate (Behrman, Mitchell, Soo, & Bravo, 2012; Calvet et al., 2007; Lusardi, Michaud, & Mitchell, 2011; Lusardi & Mitchell, 2007).

It is clear that failing to improve financial literacy, especially for those socioeconomically disadvantaged subgroups, will not only have negative impacts in personal financial well-being, but also initiate a vicious cycle of poverty and economic inequality, both in wealth and in earnings. Making financial research tools more accessible to all individuals will help improve the financial outcomes of those who choose to participate in financial investments. Doing this will remove the artificial barriers imposed by financial illiteracy upon those who have been denied access to stock market chart information because they cannot perceive it through a screen reader.

Figure 2: Financial illiteracy initiates a vicious cycle of poverty and economic inequality



2.3 The Gap in Improving Financial Literacy and Education

In recent years, quite a few scholars and researchers have analyzed the specific cultural, social, and structural barriers faced by the aforementioned subgroups, i.e., those with low income, aboriginals, seniors, women, new immigrants, etc. (Barcellos, Smith, Yoong, & Carvalho, 2012; F. C. A. o. Canada, 2014; Collin, 2011; Donohue, 2011; Frenette & Robson, 2011). However, little attention has been paid regarding the barriers individuals face from the human-computer interaction perspective, despite the critical role digital information and communication (ICT) plays in improving an individual's financial knowledge, skill-set and access to financial information and research tools.

Many studies reveal that conducting research about a financial product's features and risks, and the overall financial context is the first knowledge-seeking step individuals must take before making effective and responsible investment decisions (Akhtar, Rehman, & Hunjra, 2011; ECCE, 2007). In the *Information Age*, advanced information and communication technology (ICT) enables people to access overwhelming amounts of information on the Web ranging from product features to economic outlooks to expert insights. This digital financial information and communication enables us to gain a sufficient understanding of financial products and services, driving our perceptions, sense-making and decision-making processes in financial and investment activities. ICT access is not only an important part of our daily life, but also more frequently, the *only* means of accessing or participating in important functions and services (Treviranus, Stolarick, Denstedt, Catherine, & Ascunsion, 2010).

An increasingly prevalent phenomenon in digital media is the use of infographics or data visualization. This modality will not only "allow us access to huge amounts of data in ways that would not be otherwise possible", but also communicate this specialized knowledge "quickly, efficiently, and effectively", according to Noah Lliinsky, author of "*Beautiful Visualization* and *Designing Data Visualizations"*. Data visualizations, such as stock market charts and graphs, are ubiquitous sources of financial and investment information. In fact, technical analysis, one of the two major methods investors use to predict the future trend of a given stock, is entirely based on the study of stock market charts.

While digital information and data visualization have provided a host of advantages to investors, they tend to create significant barriers to individuals who do not use visual interfaces to access digital information or who are less investment savvy. Because stock market charts are so important when making investment decisions, this research focuses on ways to improve the accessibility of these infographics not only for screen-reader users but also for individuals with less comfort and skill in understanding how to use and analyze stock market charts. This focus requires an understanding not only of the physical barriers to access but also, the cognitive and emotional barriers individuals might encounter in the stock market context, where charts are frequently used to communicate critical investment information to millions of investors globally. These barriers are described further in the next section.

3 The Barriers Individuals Face while Accessing Stock Market Charts

3.1 The Stock Market: a Major and Rapidly Growing Investment Vehicle

The last few decades have seen dramatic growth in the stock market. “Between 1983 and the end of 2007, the capitalization of the world stock markets grew by 1,800% and the volume of share trading increased almost 100-fold, from $1.22 trillion in 1983 to $111.2 trillion during 2007”(Grout et al., 2009). Meanwhile, the stock market has become increasingly complex as investment products evolve and innovate (OECD/INFE, 2012). For example, since first launched at the American Stock Exchange in 1989 (Gastineau, 2002), the Exchange-Traded fund’s (ETF) family has expanded to cover various asset classes: domestic or international, value or growth, large-cap or small, whole sectors or specific industries (BlackRock, 2012); this is in addition to a full spectrum of ETF types that track indices, stocks, commodities, fixed income and currency. (Bentley, McCann, & Ireland, 2014)[9]. Providing better tools that support investors’ decision-making process when it comes to the features and risks associated with a given product will help prevent them from making serious financial blunders.

[9] For example, some commodity-based ETFs can be very volatile as they track multiple or triple of a commodity price. In addition, some index EFT use leveraged, inverse, volatility, and spread strategies, and therefore may not be suitable for buy-and-hold investors. Investors who lack sophisticated knowledge are in danger of losing their assets in a short time period.

3.2 Stock Market Investors: a Large and Diverse User Base

Along with the growth of the stock market is the rapidly increasing number of shareholders. It has been estimated that there were approximately 382 million direct shareholders globally in 2009. Among them, there are an increasing number of self-directed investors who rely on their own research and judgment to make financial decisions without the involvement of a financial advisor. In the U.S., the number of self-directed investors reached over 40 million by 2012, despite unpredictable and challenging economic conditions in the preceding years (Camargo & Fonseca, 2013). In Canada, the percentage of investors with self-directed brokerage accounts increased from 21% in 2012 to 33% percent in 2013 (J.D.Power, 2013).

Contrary to popular belief, many stock market investors are not active traders with extensive investment knowledge; rather they have varying degrees of financial literacy and trading experience. In fact, various studies reveal that the majority of investors are as financially illiterate as the overall population; they lack understanding of the most basic yet critical investment knowledge items, such as risk and return (Bebee, 2014; Carpentier & Suret, 2012). Moreover, approximately 40% of self-directed investors do not consider themselves actively engaged in monitoring and managing their households' investments on a regular basis (Cogent, 2014), while 50% of self-directed investors trade less than three times per year (Camargo & Fonseca, 2013). These facts suggest that the majority of stock market investors are novice investors who lack sufficient knowledge and skills, and might not be familiar with essential research tools such as stock market charts.

Another interesting characteristic of stock market investors is that middle-aged, and older adults (45 years-old and up) make up approximately 50% of the total percentage of self-directed investors. The percentage is even higher for so called “premiere” investors, who possess higher net worth, account balances and higher trading frequency. It is, however, practically inevitable that many members of this influential demographic will eventually encounter various forms of minor disabilities, especially visual impairment, one of the greatest causes of disability for older people(WHO). With an aging population, the number of investors with vision loss is projected to increase dramatically in the future as the elderly are more susceptible to age-related macular degeneration or glaucoma, and other factors related to vision loss such as obesity and diabetes[10].

In short, investors vary in their financial literacy levels and means of accessing digital media. As a result, it is important to design perceivable, understandable, operable, and robust stock market charts, to enable and empower all investors to participate in financial and investment activity.

3.3 Stock Market Charts: a Popular Tool Assisting Investors to Predict Stock Trends

There are two major methodologies investors use to predict the future trend of stocks: fundamental analysis and technical analysis. Fundamental analysis studies the “intrinsic value” of a company by analyzing everything from the overall economy and industry outlook to financial conditions and management of companies. Technical analysis, on the

[10] According to the Canadian National Institution of Blind, if nothing is done to ameliorate the situation, the number of Canadians with vision loss has the potential to double within the next 25 years. By 2038 more than one in six Canadians over age 65 and more than one in four over age 75 will experience severe vision loss that cannot be corrected with standard eyeglasses (CNIB, 2013).

other hand, focuses on the statistics generated by market activity, such as past prices and volume, which are primarily presented through stock market charts (Investopedia).

Figure 3: A typical stock market chart

Five components are in general included in a typical stock market chart: 1) a line graph presenting the price change 2) a bar graph presenting the volume change 3) options to define the time frame through which the chart will be rendered 4) identifiers for events such as stock split, dividend 5) functions to enable a comparison with other stocks or indices. Resource: Google Finance.

Traditionally, technical analyses were performed almost exclusively for institutional investors or professionals due to the availability of the data. Enhanced information technologies, such as HTML5, script languages and the capability of pulling live market data, caused a major shift in investor research behaviour. Technical analysis, or charting, has gained momentum since early 2000 and has become more popular than ever (Murphy, 2012). Nowadays, any investor can log onto the Internet and see a dazzling array of visual market information; they can acquire both real-time and historical prices through online interactive stock market charts. As Gail Bebbee, author of *No Hype – the straight Goods on Investing Your Money*, points out: “the reams of financial information and tools are just a few mouse clicks away” (Bebee, 2014). The distance, however, is much further for individuals who have various impairments or less investment or computer savvy, when these resources are not inclusively designed. As a result, these individuals are at risk of missing critical financial information needed to make informed investment decisions confidently, and thereby being excluded from fully participating in economic life.

3.4 Physical Barriers

Physical barriers prevent individuals from perceiving or interacting with the chart. Physical barriers can be caused by the visual design of the chart. For example, if colour is the only differentiator for all the line graphs presented in a single chart to enable the comparison of multiple stock prices at once, individuals with colorblindness might not be able to properly identify which line graph stands for which stock. Another common physical barrier stems from the way the chart is coded. For example, some interactive charts use Flash or advanced script language, which are not always compatible with a user’s computer, browser settings, or the assistive technology installed; the user will therefore not be able to perceive the charts. One of the most profound physical barriers stock market charts impose, stem from the visual nature of the chart’s presentation. This factor might cause users who experience vision loss or who are fully blind, great difficulties when attempting to perceive the information, and can potentially exclude them from the critical information they need to participate in investment activities.

3.5 Cognitive Barriers

Cognitive barriers are notable when individuals evaluate, analyze, and comprehend a chart. As mentioned earlier, a majority of investors do not have sufficient investment knowledge and skills. Consequently, they are likely to have difficulties understanding the chart if the label is written using ambiguous terminologies. Additionally, when they are looking for guidance and information, they might often "find themselves struggling to locate their desired information"(J.D.Power, 2013), due to the complexity of the interface. Studies also suggest a large percentage of populations have low statistical literacy and graph literacy (Galesic & Garcia-Retamero, 2011; Schield, 2006)[11]. This low level of literacy can potentially prevent these individuals from effectively assimilating critical information from charts. Furthermore, individuals who rely on assistive technology to access charts might have to exert extra cognitive effort to interact or comprehend the chart. For example, when charts are represented in textual format, such as in a summary or a numeric table, screen reader users typically suffer from a heavy cognitive load while attempting to interact with or comprehend the information presented.

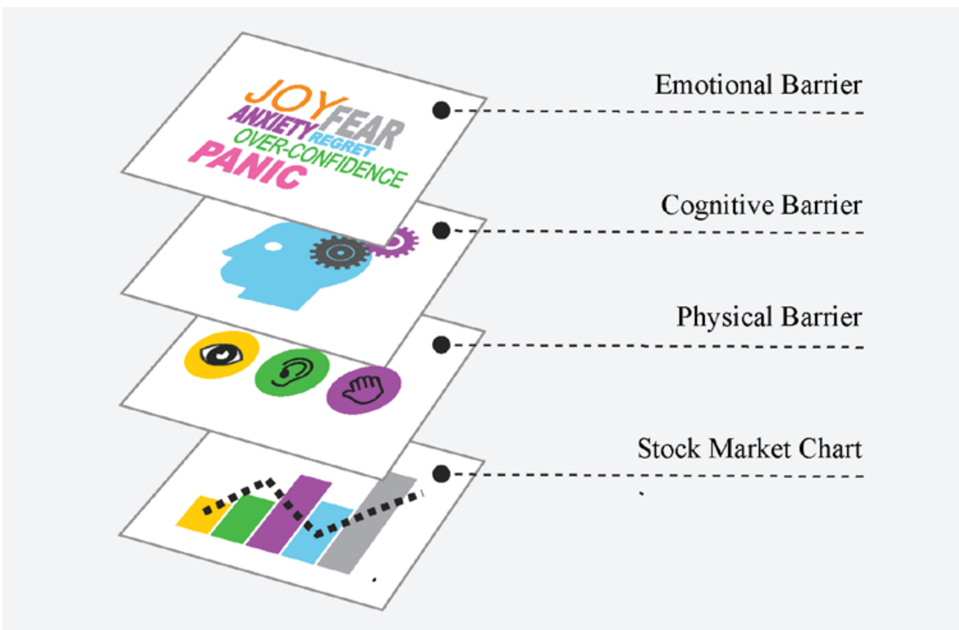
3.6 Emotional Barriers

Financial decision-making typically involves great uncertainty about the future, whether about future income, cash (liquidity) needs, or interest rates (Bank, 2015). As a result, individuals often experience various emotional reactions, such as panic, anxiety, regret, fear, and over-confidence when considering investment strategies. Studies in behavioural

[11] Based on data from United States and Germany, approximately one third of the population in both courtiers had low graph literacy (Galesic & Garcia-Retamero, 2011). A research conducted by Schield discovered that that 19% of students misread a description of a pie chart, while 62% of students fail to compare two slices within a pie chart (Schield, 2006).

finance confirm that these emotional reactions might cause serious financial mistakes, such as chasing high performing stocks without being aware of the risk, or avoiding selling stocks that have declined in value (Bechara, Damasio, & Damasio, 2000; Brave & Nass, 2003; Ricciardi & Simon, 2000). In other words, even if there is no barrier to accessing, interacting with, and comprehending stock market charts, an individual might still be unable to make responsible financial decisions. A vicious cycle might ensue because the emotional reaction can impact physical and cognitive capabilities. Conversely, barriers that reduce physical and cognitive capabilities ameliorate negative emotional reactions.

Figure 4: The layers of barriers while accessing stock market charts



It is apparent that financial institutions might be able to provide the most sophisticated charting tools to help consumers make informed decisions; however, if we don't remove the physical, cognitive and emotional barriers faced by individuals while accessing stock market charts, then all the efforts will be unfortunately wasted.

4 Design Challenge

Over the past decades, worldwide interest in financial literacy and investor education has intensified. Despite a collaborative effort through governments, public authorities, financial institutions and educators, financial literacy remains low in various economic contexts. Failing to solve this problem will potentially exacerbate or even cause a vicious cycle of poverty and economic inequality.

In recent years many studies have analyzed the barriers for financial literacy from cultural, social, and structural perspectives; however, little attention has been paid to the barriers individuals face from the human-computer interaction perspective. This is so despite the critical role information and communication technology (ICT) play in providing access to not only financial research tools and information, but also to web interfaces where transactions are made.

In this MRP the charts that communicate information required to invest in stock are used to begin to explore this critical gap. It is hoped that insights gained can guide further research in this domain. Hopefully the insights gained through the investigation can guide further research in this important area.

The stock market, one of the most popular investment vehicles, attracts hundreds of millions of investors worldwide. Interactive stock market charts are essential tools for investors to predict the future trend of stocks. However, physical, cognitive, and emotional barriers can form when attempting to read and understand stock market charts. For individuals with visual impairments, a disability that has an impact on a large percentage of investors, stock market charts are particularly challenging. This barrier is expected to have an increasing negative impact as the number of individuals with vision impairments will dramatically increase in the future.

My design challenge therefore focused on improving the usability and accessibility of stock market charts, with a focus on visually impaired, screen reader users. My plan was to design an interface that would enable screen readers to interact with stock market charts and acquire useful and comprehensible information based on their needs and interests in a user-friendly way.

The study applied inclusive design and user-centred design approaches, and used iterative design research methods. Usability testing was conducted throughout the design process to evaluate the design concept and thereby refine the solution. The iterative design approach resulted in three different interface solutions being developed as users provided input on each prototype. The initial verbal input interface evolved to a text input interface and finally a dropdown menu interface.

It is expected that with innovative design solutions, we will be able to create financial inclusive and digital inclusive models, not only for this specific social group, but also for a much broader population due to curb-cut effect.

5 Concepts and Approach

My research is informed by two key theoretical frameworks: Human-Computer Interaction and Inclusive design, in addition to the principles of the HAAT model (Human, Activity, Assistive Technology).

5.1 Human-Computer Interaction

Human-computer interaction (HCI) is an interdisciplinary field, drawing on and influencing diverse areas such as computer science, human factors, cognitive science, information science, and psychology (Booth, 2014; Butler & Jacob, 1997; Grudin, 2012; Hewett et al., 2009). It is a field of study, according to David Stearns at University of Washington, which can "improve the interaction between humans and technology. It strives to create user interfaces that are intuitive and a joy to use."

In his legendary book, *"Introduction of Human-Computer Interaction (Psychology Revivals)"*, Paul A. Booth explores five concerns that are part and parcel of the HCI design. Firstly, he explores how input and output technologies (including the new techniques such as speech recognition and generation) affect interaction, and in what situations these technologies and techniques might be put to best use. Secondly, Booth looks at how well the computer system's model matches the model used through user processing information and performing tasks. Thirdly, he investigates how the computer system fulfills users' "tasks" without excessive effort on their part. Fourthly, he explores how a design process takes account of the user and enables a shift from system-centred to user-centred design. And finally, Booth looks at how design and implementation techniques can potentially impact individual users as well as user groups within an organization (Booth, 2014).

To address these concerns, HCI professionals have established a wide range of theories, methods, and approaches. The list below highlights the key concepts applicable to my study.

5.1.1 Cognitive Perspective

Since its emergence in the late 1970s, HCI has evolved alongside the development of cognitive science. Human-computer interaction takes place through computers; however, human beings are not primarily interacting with a machine, but rather "interacting with information, program logic, knowledge, [and] another intelligence…It is essentially cognitive and … the most important issues are cognitive"(Storrs, Rivers, & Canter, 1984). Therefore, it is critical for HCI designers to understand human cognitive processing, especially how people solve problems, make decisions, perceive information, remember patterns, and learn. Another concept arising from the study of cognition is the idea of the user mental model. It is commonly accepted in the HCI field that people form mental models of tasks and systems during cognitive processing, and that these models are used to guide user behaviours while interacting with the interface(Booth, 2014). Identifying user modeling will help "map" a system's facilities to the user's needs, improve learnability, guide design decision and design process, and set the appropriate evaluation (Booth, 2014).

5.1.2 Usability Perspective

The concept of usability is central to the study of HCI. A system that provides sophisticated functionality (utility) is worthless unless users are able and willing to use it. According to Eason, usability is related to the interaction of eight variables grouped in three categories: system, task and user. “System” needs to be able to provide the “user“ with a “task” match; this means that it should provide utility that is easy to use and learn, thus providing a benefit to the user (Eason, 1984). This concept set the foundation for some of the later framework and criteria established for usability. The most noteworthy insights regarding usability can be garnered from the work of Nielsen, Shackel and Booth. In “*Usability Engineering*”, Nielsen identified five usability attributes: learnability, efficiency (productivity), memorability, errors (less errors or easy to recover from errors), and satisfaction(Nielsen, 1994). Shackel suggested four operational criteria for usability: effectiveness, learnability, flexibility and attitude (Shackel, 2009). Realizing the difficulty of specifying and testing flexibility as well as the importance of usefulness, Booth later amended Shackel’s usability criteria to usefulness, effectiveness (or ease of use), learnability and attitude (or likeability)(Booth, 2014). My study used the following criteria drawn from the above studies:

- Usefulness: A system needs to help users achieve their goals.
- Effectiveness: A system needs to enable users to operate the system productively in a number of environments, within a certain timeframe and without too many errors.
- Learnability: A system needs to provide sufficient training or supporting material to enable users to learn and relearn how to use the system.

- Likeability: A system should earn a high level user's subjective satisfaction and minimize tiredness, discomfort, frustration and personal efforts.

5.1.3 User-Centred Design

In his book, "*The Design of Everyday Things*", Norman defines user-centred design (UCD) as a philosophy "based on the needs and interests of the user, with an emphasis on making products usable and understandable"(Norman, 2002). He provided seven design principles, including:

1) Use both knowledge in the world and knowledge in the head. People learn better and feel more comfortable when their internal model (an item's function and how to use the system) aligns with the design model (how a system is supposed to work as defined by the designer) and the system image (the functionality, manuals, and documentations that the system provides).
2) Simplify the structure of tasks by providing mental aids, thus minimizing the cognitive load. These include remembering, planning, and problem solving. Technology should simplify tasks; however, it should not take away too much control from the user.
3) Make things visible so that people know what is possible to execute and what the outcome will be.
4) Get the mappings right by providing information/feedback that not only matches the user's intention, but is also in an easy to understand form.
5) Exploit the power of constraints, both natural and artificial, so that the user feels as if there is only one possible thing to do.

6) Design for errors. Plan for any possible errors that can be made, and try to find a solution to support, not fight, the user's responses.
7) When all else fails, standardize. Enable consistent and standardized actions, outcomes, layout, and displays throughout the system to help improve usability (Norman, 2002).

Nowadays, HCI is also used to imply a design process that "focuses on usability goals, user characteristics, environment tasks, and workflow"(Henry, 2007). A variety of well-defined methods and techniques have been established to ensure that the user is at the centre of every design stage, from planning to research, design, development, and evaluation. My study took an iterative process through which the user requirements and design are continuously being refined and evaluated. The study implemented the following user-centred design methods and techniques:

- On-site observation: Collecting information by conducting usability testing in an environment in which the artifact will be used.
- Simulations (Wizard of Oz): Evaluation of design concept and gaining insight about users' needs and preferences without creating a working prototype.
- Usability testing: Collecting user feedback using measureable usability criteria mentioned in the previous section.

5.2 The Principles of Assistive Technology and the HAAT Model (Human, Activity, Assistive Technology)

Since my study is geared at improving the accessibility to stock market charts for people who use assistive technology like screen reader, it is worth reviewing some concepts and studies that explore the interaction between humans and assistive technologies.

Achieving accessibility and usability can be challenging, especially with the involvement of assistive technologies, as they add another layer of complexity to the HCI. In "*Assistive Technologies: Principles & Practices*" Cook and Polgar proposed five principles that foreground assistive technologies service deliveries: 1) Assistive technologies are not "about fitting the person to the technology." Therefore, getting consumers involved throughout the design process and having the knowledge of how the technology will be used are the keys for higher consumer satisfaction. 2) The focus of assistive technologies is not about providing "functions." It should act as an "extension" of the person and support how the user wants to engage with that function. 3) Implementing an "evidence-informed" process will enable evaluation and refinement of the design, as well as identifying necessary training and support for users. 4) An ethical process is essential to ensure people with disabilities are provided with competent, honest, and respectful service. 5) Assistive products and services need to be accessible in a timely and consistent manner to ensure the effective use of assistive technologies (Cook & Polgar, 2014).

In light of the principles undergirding assistive technology, numerous models have been developed to guide practitioners in their search and daily work. Among them are the HAAT model introduced by Cook and Hussey. It describes the four components of an assistive technology system in the following order: “someone (*human*) doing something (*activity*) in a *context* using *assistive technology*”(Cook & Polgar, 2014). This statement sets humans in a focused activity, while assigning assistive technologies a role to help users fulfill their needs and goals. In the HAAT model, the human component not only includes users’ abilities in physical (motor, sensory), cognitive, and psychological areas, but also includes the distinctive roles/identifications users assume within different contexts and experiences with technology. In addition, HAAT considers activities to be dynamic and concurrently existing. Knowledge of where and how the activity occurs will reveal the contextual influences on activity performance and the effectiveness of using assistive technologies. Furthermore, HAAT recognizes how disability can be created within the physical, social, cultural, and institutional contexts, mostly due to social perception, attitude, and policies. It implies that assistive technologies alone are not sufficient to ensure social inclusion and equality; achieving a barrier-free society requires collaborative efforts. Finally, HAAT views assistive technologies as an “enabler,” supporting users’ activities through the interconnection between the human/technology interface (HTI), the processor (reacting to human input and producing or controlling the activity output), the environmental interface, and the activity output.

The principles of assistive technology and the HAAT model helped me understand how a screen reader, as an assistive technology, can potentially add another layer of difficulty on top of the ones users already face. Also, during usability testing, these concepts enabled me to identify the role of a user’s expertise with the screen reader (AT) in completing the tasks.

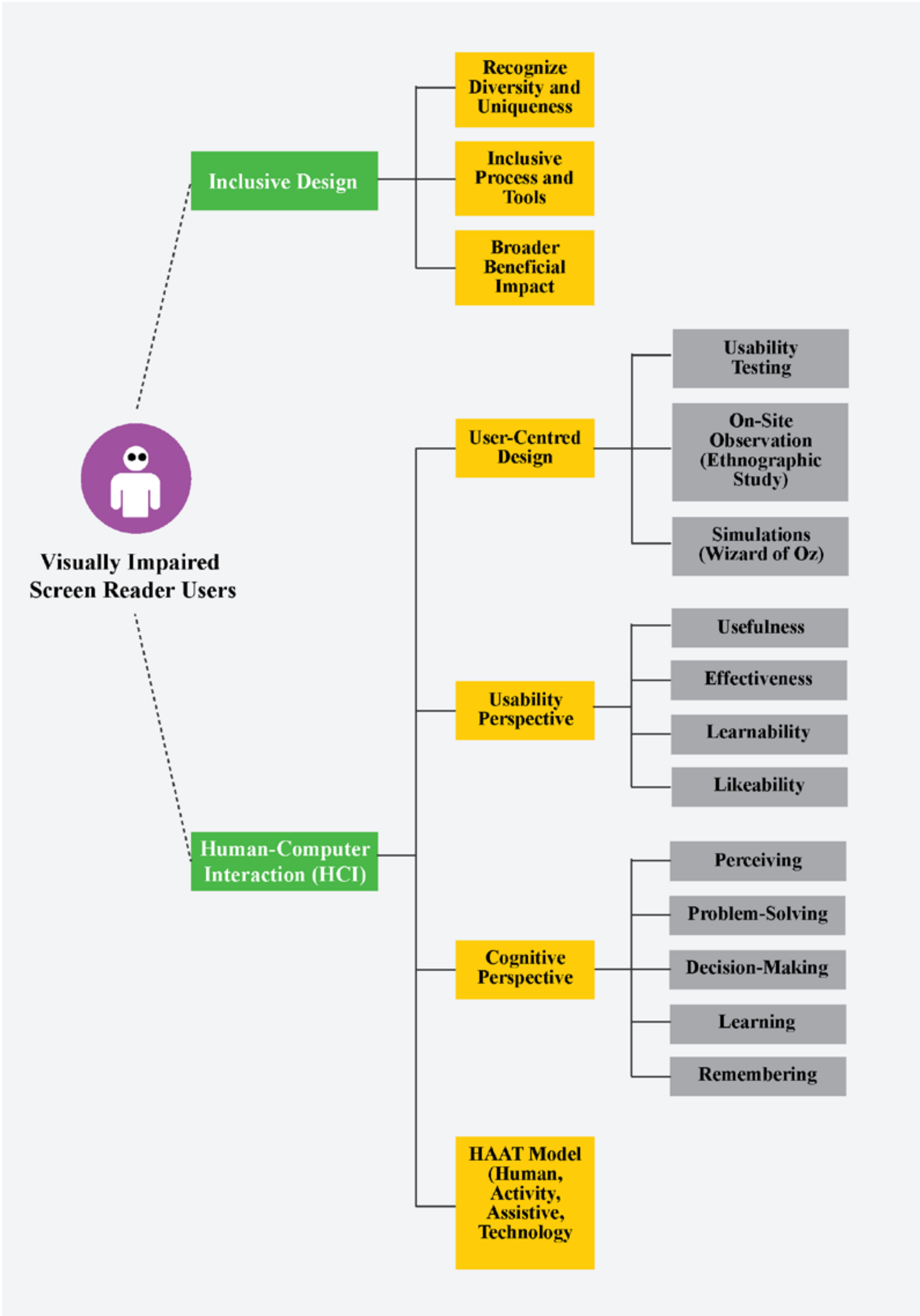
5.3 Inclusive Design

The British Standards Institute (2005) defines inclusive design as “the design of mainstream products and/or services that are accessible to, and usable by, people with the widest range of abilities within the widest range of situations without the need for special adaptation or design” (Institute, 2005). This definition clearly suggests that design must accommodate the needs of a diversified user base without the implementation of separate, specialized or segregated solutions.

A later definition given by Inclusive Design Research Centre (IDRC) and the Inclusive Design Institute, further explored the three dimensions of inclusive design. First of all, they suggest that the optimal inclusive design should integrate personalization and flexible configurations while supporting “self-determination and self-knowledge.” Secondly, inclusive design encourages an inclusive design process that enables diverse designers and “extreme” users to participate in the design process through accessible and usable tools. Thirdly, it urges designers to look beyond the intended beneficiary of the design to the systemic impact of the design, and create a design that can trigger a “virtuous cycle of inclusion,” which in turn will lead to both social and economic benefits (IDRC, 2013).

Insights drawn from inclusive design acted as the principle guidelines through my entire research process, from the initial design requirement gathering to design process, to user participation and evaluation.

Figure 5: Principles and best practices discussed in the "Concepts and Approach" section



6 Preliminary Research on 10 Popular Investment Research Websites Using Screen Reader Jaws

The goal of the preliminary research was to analyze the accessibility of existing stock market charts using Web Content Accessibility Guideline (WCAG 2.0) and identify the issues that can be addressed in my design. According to this goal, the following research objectives are determined.

1) To examine if existing stock market charts meet the four WCAG principles: perceivable, operable, understandable, and robust for screen reader users. These principles would allow users to perceive, operate, and understand the information and user interface regardless of the device, platform or assistive technology they use.

2) To check if existing stock market charts support accessibility using WCAG practical technical guidelines. To ensure the accessibility of non-text content, such as a chart, WCAG recommends providing both short and long text alternatives that "serves the same purpose and presents the same information as the original non-text content." The short alternative identifies the non-text content, such as "Average Stock Price for Apple Inc. from June 2014 to December 2014," or "Daily Stock Price for Apple Inc. in 2014", while the long alternative provides the detailed information. Depending on the nature of the chart, the long description can be a few sentences describing the data points or a numeric data table that was used to generate the graph.

6.1 Materials and Method

Ten popular investment research websites were chosen to conduct the research, including Yahoo Finance, Google Finance, Bloomberg, Wall Street Journal, Bloomberg, Morning Star, The Street, CNBC, MSN Money, Financial Post, and The Globe and Mail[12]. All 10 websites do not require client permission (non-member based), and can be accessed by the public for free. The choice of these websites was based on the following procedures:

Step 1: Find a pool of “best” stock research websites using the keyword “best stock market research tool” and “best stock market charts” in Google search.

Step 2: Narrow down the websites by picking the websites that have been mentioned by more than one resource.

Step 3: Focus on the websites that have comparable functionality; for example, all charts are interactive and allow the user to select a time frame or compare with other symbols/indices.

There are abundant tools to perform automated checks of web pages for accessibility issues; however, since this research focuses only on one element of the page, i.e. the chart, it is therefore more effective to check the accessibility manually to avoid going through all accessibility issues on the page. In addition, accessibility tools can only partially check accessibility through automation. Human judgment is not only required (WebAIM, 2013) to ensure the accuracy, but to also help observe the challenges from the users’ perspective.

[12] The screenshots of these charts can be seen in Appendix B: Stock Market Charts Tested for Preliminary Research

The screen reader used was Jaws Version 15.A series of studies have indicated that Jaws by Freedom Scientific is the most popular desktop/laptop screen reader (WebAIM, 2014)[13]. An HP laptop with the Windows 7 operating system was used to conduct the research.

6.2 Findings

The preliminary research reveals serious accessibility and usability issues for stock market charts[14].

First of all, stock market charts are not perceivable by screen reader users. Screen readers cannot detect 6 out of 10 charts at all; this means that screen reader users are unaware of the charts existence. For the other four charts, screen readers can only present partial information, specifically only the chart legend. In addition, it is commonplace for alternative text descriptions to be insufficient or completely absent while interacting with screen reader. Nine out of ten charts fail to provide a short text description. Yahoo Finance is the only website that provides alternative text for the stock market chart; however, its short text description is comprised of only one short sentence telling user it is an interactive chart. This terse statement is effectively meaningless to visually impaired users. In terms of long text description (the numeric table), four out ten websites place the numeric table on a separate page, which can only be accessed through the navigation menu. The other six websites do not include a numeric table at all, which means visually impaired users are completely excluded from acquiring critical information about the price and volume of a stock.

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[13] In the WebAIM 2014 Screen Reader Survey, 50% of the respondents considered JAWS their primary desktop/laptop screen reader, which is 3 times higher than NVDA, the second on the list.

[14] The preliminary research was conducted between June 2014 to July 2014, thus the findings reflected in this paper might not applicable due to the later updates of the website.

Secondly, stock market charts are not operable. Advanced script language enable sighted users to interact with the chart and acquire specific data points by hovering over the chart. However, this function is completely useless for screen reader users, because screen reader can perceive none of the actual chart.

Thirdly, stock market charts are not intelligible. Abbreviations are commonly used in the legend of a chart; however, messages are communicated in an idiosyncratic way because <abbr title=""> tag is missing from the code. As a result, "Jun", which stands for June, is read out as like Jone; and "min", which stands for minute sounds like mean. In addition, when the sequence of the code does not align with the logical order of content, information becomes very confusing, as screen reader reads the content based on the order of the code. For example, part of the Globe and Mail chart includes a text string indicating four variations of the stock price: "Open: 91.11, High: 91.40, Low 90.85, Close 90.92"; however, when it is communicated through screen reader, it is read out as "90.92 close 90.85 low 91.40….", which is completely impossible to understand, especially when there is no pause between each data element. Stock market charts are hard to understand even when represented through a numeric table, where the information for each data point can be accessed. If each data cell in the numeric table does not include appropriate "ID" or "headers" to associate the data with its corresponding column header, the screen reader will then be unable to communicate the table in a meaningful way to the user, as all one can hear is number after number without knowing what the number is meant to represent. Also, for very complex charts, the large number of data points makes the chart impossible to comprehend.

Finally, it is apparent that stock market charts are not robust enough to be interpreted reliably by screen reader.

7 Related Research

Over the past few decades, there have been serious attempts at providing blind and visually impaired people with solutions to accessing graphical information. These non-visual interfaces can be grouped into four categories: natural language interfaces, haptic interfaces, sonification interfaces, and hybrid interfaces (Ferres, Lindgaard, Sumegi, & Tsuji, 2013). This investigation helped me gain insights from the past and current research in the field of accessible charts and graphs, identifying the available approaches, key findings, and limitations with the aim of bridging the research gap.

7.1 Natural Language Interface

The natural language interface normally uses pattern recognition technology to generate a summary that enables visually impaired individuals to perceive high-levels of knowledge one would apprehend from viewing charts and graphs. In general, the summary[15] includes: the particular type of chart, structure of the axis, overall trends (such as rising, changing, change-trend-return, big- jump), details behind each sequence of trends, maximum and minimum, etc. Although these tools achieve satisfying accuracy rates in terms of capturing the key features of the graph, these tools ultimately lack the flexibility to enable users to quickly navigate and access data according to their needs and interests (Wall & Brewster, 2006). Other observable limitations include: 1) the system only works

[15] For example, a typical summary generated by iGraph is “This is a vertical bar graph, so categories are on the horizontal axis and values on the vertical axis. The title of the chart is "Percentage change over 12 months in the Bank of Canada's core index." There are in total 13 categories in the horizontal axis. The vertical axis starts at 0.0 and ends at 3.0, with ticks every 0.5 points. There is only one series in this graph. The vertical axis is % change. The title of series 1 is "Canada" and it is a series of bars. The minimum value is 1.4 occurring in January. The maximum value is 2.5 occurring in June.

A typical summary generated by SIGHT can be “This bar chart titled ‘Credit-card debt leaps higher’ shows that there is an increase in Jan ’99 in the dollar value of 6-month growth in consumer revolving credit in contrast with the decreasing trend from July ’97 to July ‘98” with static graphs 2) the system can only process certain types of graphs. For example, both iGraph and SIGHT only work with line graphs and bar graphs 3) the system is tied to certain browsers or screen reader4) the system requires installation 5) users need to learn and memorize keystrokes designated to the tool in order to manipulate the system. For details related to iGraph and SIGHT, see Appendix C1 for the two most significant works in developing natural language interface in the last few years.

7.2 Haptic Interfaces

In addition to natural language interface, there have been serious attempts at utilizing haptic devices to help visually impaired users perceive graphical information. Haptic devices "allow users to 'touch' and feel the simulated objects with which they interact (Berkley, 2003)."

One of the most commonly used methods is to utilize *tactile feedback* to enable users to perceive graphical information through tactile sensations, such as the texture of surfaces, temperature and vibration. For example, a proposed TSR (Terminate and Stay Resident) hard-copy system translates colour pixels on the screen into embossed dots on paper through Braille printer plotter(Ina, 1996). Krufka & Others developed an application to automatically convert vector-based graphics into raised-line images based on a graphic's hierarchical structure (Krufka, Barner, & Aysal, 2007). Although evidence has shown signs of improvement in terms of discrimination, identification, and comprehension, there are some pitfalls that cannot be overlooked: 1) It requires special software and hardware, such as Braille printer, Tactile Printer, swell-touch paper, which can be expensive for ordinary users 2) It focuses on conveying the shape of the graph, other than the underlying data (Paneels & Roberts, 2010) 3) It is restrained by the complexity of the graphs and the tactile sensitivity of individuals (Ferres et al., 2013; Yu, Kangas, & Brewster, 2003) 4) The output is static and impossible to update (White & Harwin, 2012) 5) It is not sustainable as it would "fade" after use (Ferres et al., 2013; Ferres et al., 2007) 6) It is time consuming for users to perceive the graph (White & Harwin, 2012). For a high-level overview of Ina and Krufka's haptic projects, please refer to Appendix C.

Another method to enable haptic interface is by utilizing *force feedback,* such as through a joystick. This method is normally used in combination with audio (non-speech sonification or speech), which will be discussed in the Hybrid Interface Section.

7.3 Sonification Interfaces

In addition to natural language and haptic data visualization, researchers also try to "translate" graphical information into music or varying sound frequencies (Alty & Rigas, 1998; Ben-Tal et al., 2002; Brown & Brewster, 2003; Cohen, Yu, Meacham, & Skaff, 2005; Flowers, Buhman, & Turnage, 2005). Although it is possible to enable users to identify trends or compare different sets within a graph, interpreting graphs through sonification interface generally takes more training, time and effort on the user's side. In addition, it has significant disadvantages in terms of acquiring accurate and precise information. For an overview of Alty, Brown, and Flowers' work, please see Appendix C.

7.4 Hybrid Interfaces

Realizing the limitations of using natural language, haptic, or sonification methods alone, more recent works have focused on developing a multimodal visualization system to assist users to perceive graphical information; for example, the systems developed by Yu, Kangas & Brewster (Wall & Brewster, 2006; Yu et al., 2003), and White and Harwin

(White & Harwin, 2012). Using a combination of haptic (forced haptic feedback), audio and synthesized speech (both speech and non-speech sound), these researchers have demonstrated that using multiple sensory modalities enables users to perform tasks, such as comparing graphs or identifying the largest maximum. These tasks can be accomplished much faster and more accurately than using swell-paper alone. However, this approach requires an additional number of costly force feedback devices, which is normally not accessible or familiar to many visually impaired users.

8 Design Research

After the preliminary research and review of related work, I considered the following four design goals, which influenced the form and functionality of the proposed design solutions:

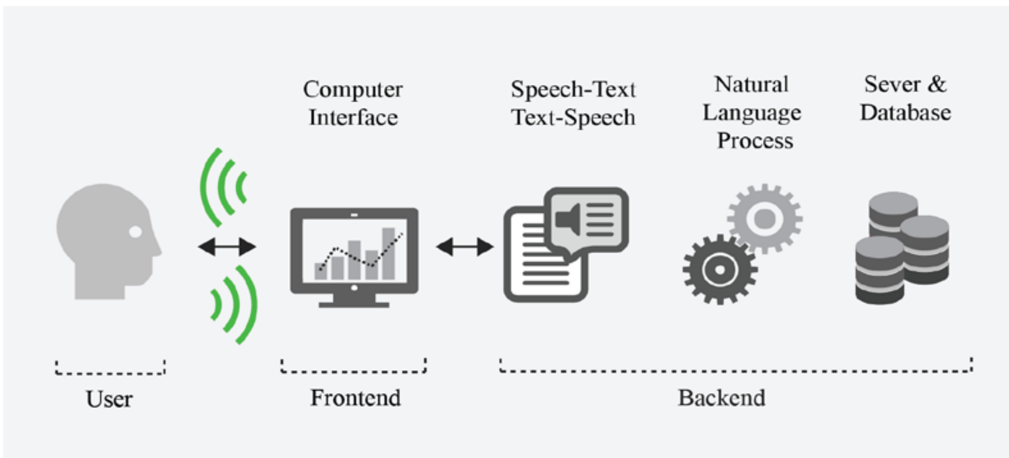
1) The system should be able to have the *flexibility* to *accurately* communicate both high-level information (i.e. overall trend) and particular data points (i.e. closing price on a certain day). Stock market charts are an essential tool for investors to predict the future trend of a stock and to identify selling and buying opportunities. Accuracy is the key to ensure investors make confident investment decisions.
2) The system should be usable by as many visually impaired individuals as possible, regardless of the browser or operation system they use.
3) The system should be integrated into an existing stock market research interface without the installation of any additional program.
4) The system should not require the use of any special external equipment to eliminate the extra financial burden on visually impaired individuals.

My design takes a user-centred approach, using iterative methods, though which the design solutions were constantly being evaluated and refined through usability testing. During the course of the design research, three iterations evolved: auditory solution, text input solution, and dropdown menu solution.

8.1 Auditory Solution

The initial design concept, the auditory solution, enabled the interaction between the user and the system using auditory input and output. The user first acquires information related to the stock market chart by verbally "asking" the system questions, such as "Highest price in the past 6 months", or "what's the average volume?" The system then returns an audible answer. The mechanism of this auditory solution is very much like Siri used in the iPhone.

Figure 6: System architecture of the auditory input solution[16]



8.2 Text Input Solution

After putting the initial design concept to test, a second design concept, the text input, soon emerged. Instead of letting users verbally communicate their inquiry, this solution enables users to type their questions manually through keyboard. The mechanism of the text input solution is very much like IBM's Watson Supercomputer, an artificial intelligence (AI) system that gained wide spread public attention through the popular TV show Jeopardy. In the same way as IBM Watson, the text input solution provides voice output and an audio representation, to communicate the answer.

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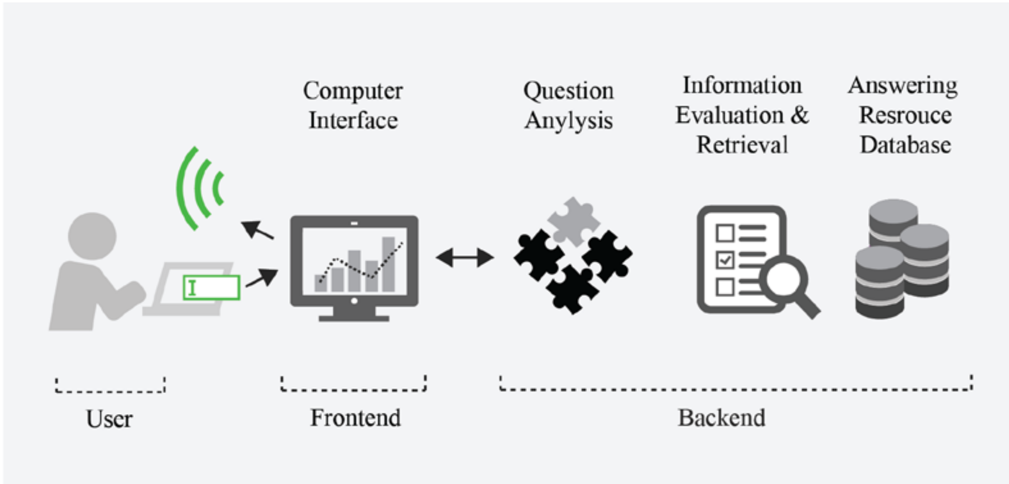
[16] The illustration is inspired by Dean Rutter's diagram *How Siri works*

Figure 7: System architecture of the text input solution[17]



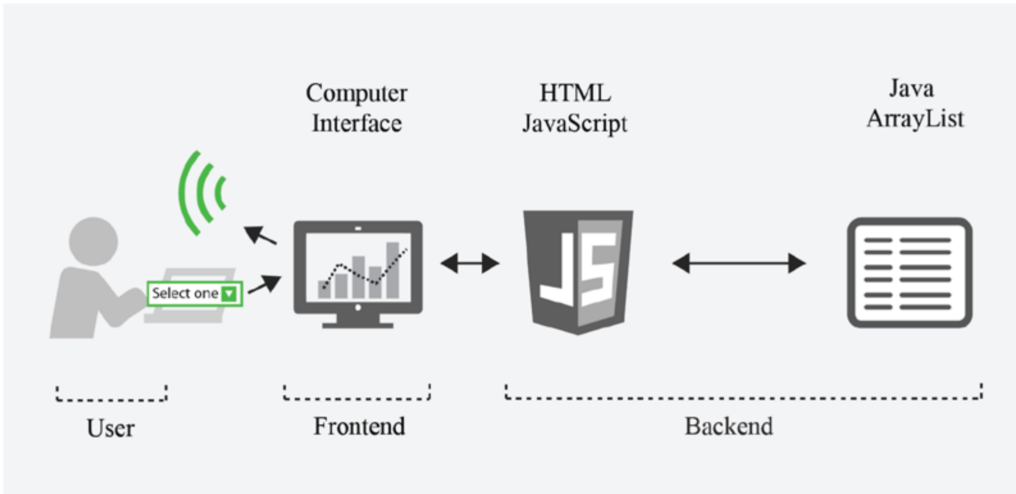
8.3 Dropdown Menu Solution

Both text input and voice input concepts were immediately evaluated and compared during later usability sessions. This spawned the third design solution, **ChartMaster,** a tool that employs a series of dropdown menus to enable users to acquire key data points of a stock market chart, such as price, volume and events (ie. divident or splid) for one or multiple stocks.

ChartMaster was developed using HTML and JavaScript. While HTML is used to generate the frontend interface, JavaScript is used to control the backend data retrieval and calculation. Unlike all other solutions mentioned earlier in the Related Research section that only work with static graph images, **ChartMaster** works with underlying real data stored in Java ArrayList which is the same data set used to generate the graph.

[17] The illustration is inspired by *The AI Behind Watson – The Technical Article* written by David Ferrucci & Others

Figure 8: System architecture of dropdown menu input solution



The following section demonstrates how **ChartMaster** provides greater flexibility for the user to acquire accurate and precise information according to their needs and interests.

By default, **ChartMaster** is a link, grouped with other commonly used stock chart tools and placed at the top of a stock market chart (See Figure 9). Once activated through the keyboard, the tool is then expanded, pushing the chart down onto the page and enabling the user to acquire information by interacting with a series of dropdown menus. The answer is displayed as a textual summary at the bottom of the dropdown menus after the user submits his or her request (See Figure 10).

Figure 9: A screenshot of **ChartMaster** in default setting

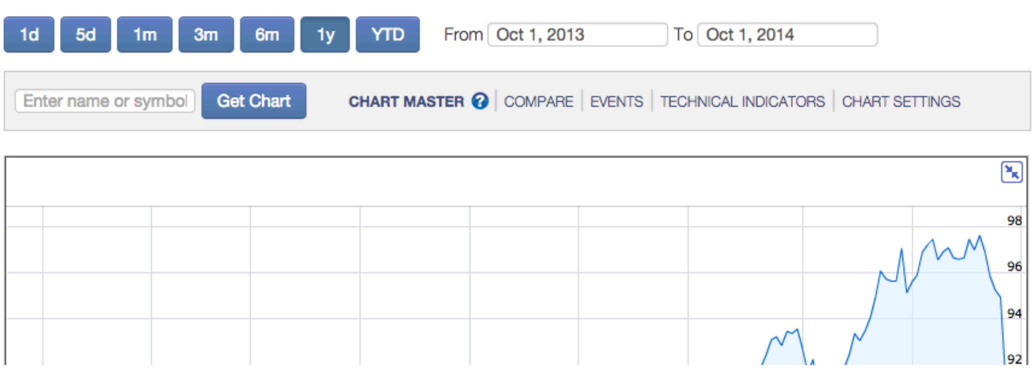
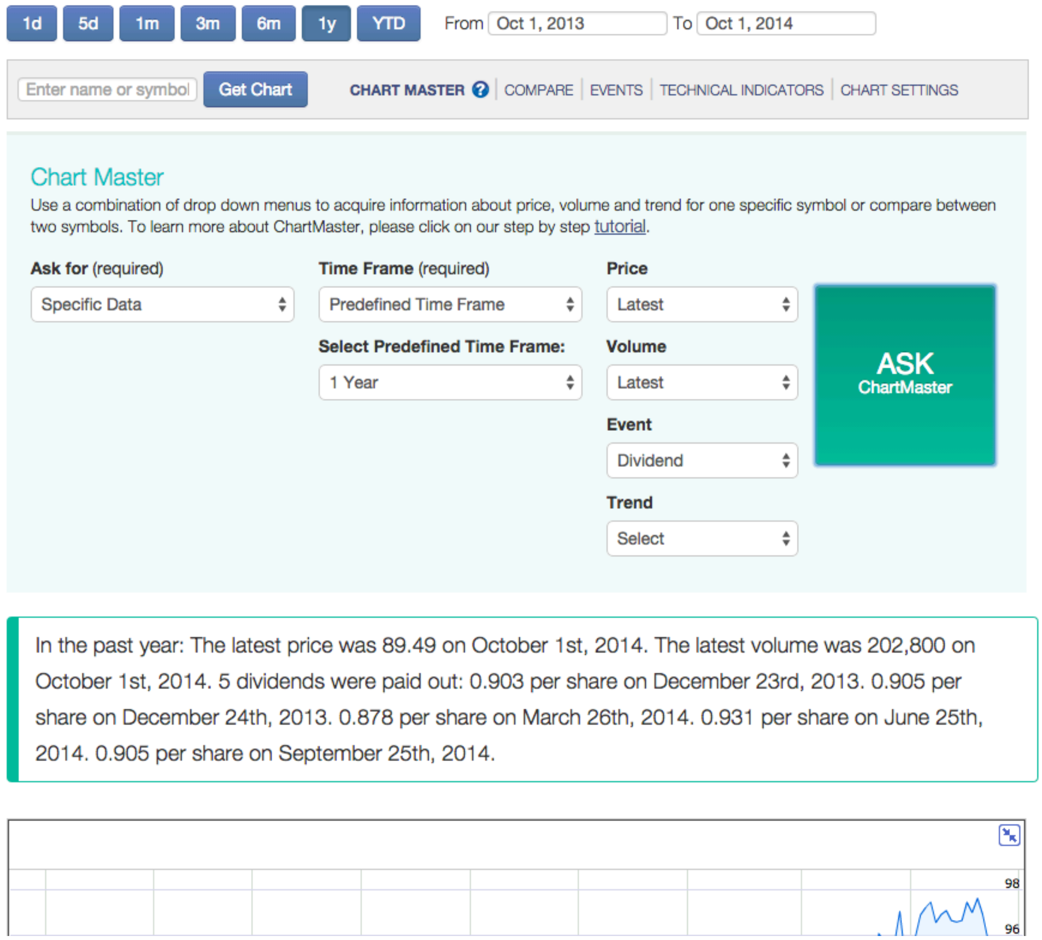


Figure 10: A screenshot of **ChartMaster** once it is expanded



The dropdown menus are grouped into three categories: 1) information type (as shown using label "Ask for") 2) time frame 3) specific data set. The information type dropdown menu allows users to decide what type of information they want to acquire: is it one particular data point about one specific stock, or mulitple data points for one stock at different time frames, or multiple data points for different stocks. The time frame dropdown menus allow users to define a time frame for the data. When combined with text input fields, these dropdown menus provide options, such as which users can choose one particular day, or picking from a preset time frame, such as 5 days, 1 month, 6 months, etc, or defining a random custom time frame. The specific data category provides four dropdown menus: Price (ie. open, close, day high, day low), Volume (ie. latest, highest, lowest, and average), Event (ie. split, dividend), and Trend (ie. overall trend, technical pattern). Currently, ChartMaster only allows the user to select one option from each specific data category; However, the function of selecting multiple options will be developed in a future version.

Options within each dropdown menu are dynamic according to a hierarchy that makes sense to stock market data: the choice of information type will determine the options in time frame, while the selection of the time frame will define the options in the specific data set. For example, when Specific Data is selected as information type, there are three options under time frame: Predefined Time Frame, Custom Time Frame, and Specific Day; whereas, if "Compare wth Current Symbol" is selected as information type, then the options under "Timeframe" will change to "Different Days" and "Different Months". Similarly, when "Predefined Time Frame" and "1 Year" are selected under time frame dropdown menu sets, the options under price will then be: Latest, Highest, Lowest, Median, and Average; However, if specific day is selected, then the option under volume will change to: Open, Close, Day High, Day Low.

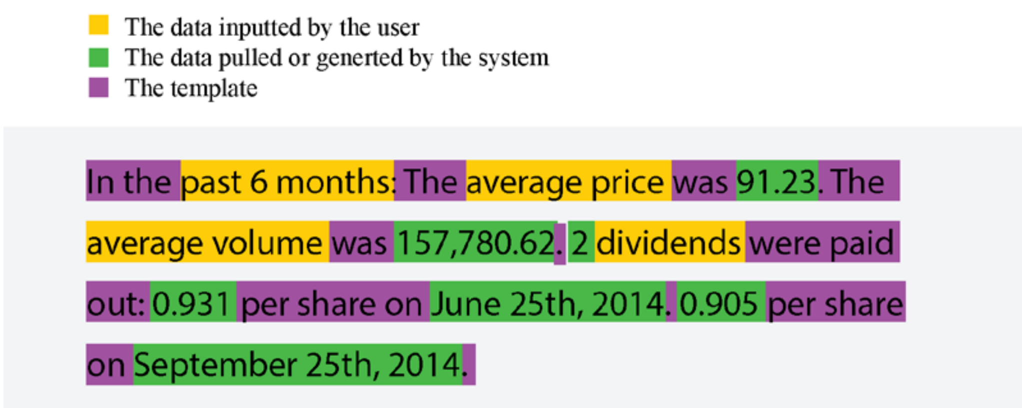
Once the choice is made for information type, time frame, and specific data set, the user can then click on "**ChartMaster**" button and receive a text summary of the information acquired. This will also be read out by screen reader software. Below are a few answers generated by the system demonstrating that **ChartMarket** provides greater flexibility for users to acquire information according to their needs and interests.

- **One data point for one stock on a particular day**: "For May 27th, 2014: The closing price was 91.02".

- **Mutiple data points for one stock on a custom defined time range**: “Between June 27th, 2014 and December 10th, 2014: The highest price was 97.61 on September 18th, 2014. The highest volume was 427,000 on August 28th, 2014”.
- **Compare data points for two stocks on a particular day**: “For May 27th, 2014: The closing price for ABC was 91.02. The closing price for XYZ was 100.96. The volume for ABC was 95,300. The volume for XYZ was 5,124,900. No dividends were paid out for ABC [name of the symbol]. No dividends were paid out for XYZ [name of the symbol being compared]”.

These answers are composed of three key components: 1) the data inputted by the user through the dropdown menus and associated text input fields, such as “6 months” and “average price” 2) the data pulled or generated by the system according to the data inputted by the user 3) a template (including the wording and puntuaction marks) which arranges and presents all the data mentioned above in a meaningful, yet grammatically-correct way to the user.

Figure 11: The output of ChartMaster consists of three components



The system is smart enough to give a clear explanation when there is no data available, according to users' request. For example, when the user requires data for a day that has no trading activities, the system will inform the user that "Sorry, there was no trading activity on September 21st, 2010". And when the user asks for certain events that are not applicable to the chosen timeframe, the system will return the answer "In the past 6 months: No stock splits occurred."

In addition to specific data points, future versions of **ChartMaster** will communicate the visual characteristics of the chart, such as the structure of the chart, technical patterns[18], and overall trend of the chart. This information requires sophisticated mathematical algorithms that haven't been fully developed in the current version. However, the front-end interaction has been included in this version, allowing usability participants to make choices in the relevant dropdown menus.

8.4 Usability Testing

Usability testing was conducted throughout the design research from August 2014 to February 2015 with the following key objectives:

- To capture the accessibility and usability issues of existing alternative solutions, the numeric table
- To evaluate the proposed solutions
- To collect suggestions on potential solutions

[18] According to investopedia.com, a technical pattern (chart pattern) is a "distinct formation on a stock chart that creates a trading signal, or a sign of future price movements. Chartists use these patterns to identify current trends and trend reversals and to trigger buy and sell signals" (Janssen, Langager, & Murphy).

8.4.1 Participants

There were a total of 18 participants (ten male, eight female) who participated in the usability testing. Participants were varied in age, ranging from individuals in their earlier 20s to individuals close to retirement age. 16 participants had visual impairments and two had no visual impairments. Of the 16 visually impaired individuals, nine used only a screen reader, six used both screen reader and screen magnifier users, and one used only a screen magnifier.

12 of the visually impaired participants have more than 15 years of hands-on experience with the primary assistive technologies they are using, while the rest of the three participants each had 10-15 years, 5-10 years, and less than three years of experience respectively.

Participants also had various levels of financial and investment experience. Among the 16 visually impaired participants, one had advanced stock market knowledge and worked as a customer service representative in an investment brokerage, while the other four had a moderate understanding of personal financial management and investment (e.g. they conducted currency exchange, bitcoin trading, and stock market trading either online by themselves or through an investment advisor). The other 11 visually impaired participants had low financial literacy or none whatsoever. The two sighted participants had high financial literacy levels and trading experience as they work in an investment brokerage.

Participants were mainly recruited through several mailing lists specifically focused on visually impaired individuals, including Vision Technology Service (IDRC), Alliance for Equality of Blind Canadians (AEBC), National Educational Association of Disabled

Students Forum (NEADS), and Blindwebbers. In addition, two sighted participants were invited at the very early stage of the study. Participants were paid $15 for each session. All participants had no prior exposure with the study or proposed design.

8.4.2 Material and Method

There were a total of 18 usability testing sessions; each lasted approximately one hour. All usability tests were conducted in a one-on-one format. Sixteen tests were done in person, and two were done over Skype. Participants were also encouraged to choose a location they preferred. Fifteen users chose their home, one chose the public library, one chose his office, and one chose my home. All participants used their own computer and the assistive technology they typically use to participate in testing, except the one participant who did the testing in the public library. All but one participant used the Windows operating system.

The usability testing focused on collecting qualitative data, such as what challenges the users had, what features they needed and wanted, and their preferences to achieve their goal. The testing script was used more like a guideline rather than a must-do list, as spontaneous questions were asked according to participants' responses to previously asked questions or assigned tasks[19]. In addition, users were encouraged to talk aloud and share their thoughts with the facilitators while interacting with stock market charts and graphs. This explicitly expressed feedback combined with observations of the participants' physical and emotional expressions (i.e. body language, tone of voice,

[19] For more details about usability testing, please see Appendix C1-C4.

pauses while speaking or completing a task, etc.) observed during the testing session, are the main sources for the findings.

Before starting usability testing, participants were given a brief introduction of the study and some guidelines for the testing. They were informed that they could ask questions whenever they wanted to, and that the testing is not about them but about the proposed solution. Afterwards, participants were asked to sign the consent form, which was sent to the participants a couple of days before the testing. The two participants who tested remotelywere required to sign back the consent form through email prior to the testing.

The usability testing began once the participants signed the consent form. Participants were first asked to self-describe their usage and experience with assistive technology and computers, in addition to their knowledge of the stock market. The usability testing then moved to cover the following three major tasks: 1) to assess the usability of numeric table using the assistive technologies they typically use 2) to evaluate the proposed design 3) to rate the proposed solution(s) and the typical assistive technology solution using usability criteria such as effectiveness, likelihood of usage, ease of use, and ease of learning. Since three design solutions evolved through the course of the design research, the usability testing also took an interactive approach to ensure appropriate material was used in usability testing to support the progress of the design. In total, there were four iterations of usability testing. Depending on the stage of the testing, either a *Wizard of Oz* method or real prototypes were used.

During the first stage of the usability testing, the research applied a *Wizard of Oz* method to collect feedback on the initial design solution (auditory solution) as quickly as possible before jumping into a full cycle of development. The facilitator acted like the computer interface to demonstrate the proposed solution and interacted with the user. *The Wizard of Oz* method was also used to evaluate the accessibility and usability issues of numeric table. Because there were no real prototypes used at this testing stage, this method was a very cost-and-time effective way to explore ideas and support an iterative design approach that was fundamental to the work.

For the second stage of the usability testing, the researcher continuously used *The Wizard of Oz* methods to evaluate the initial design solution and the newly designed text input solution that had been proposed by participants in the first stage of the testing. However, to observe the challenges visually impaired users had while attempting to access the charts using their typical assistive technology, the researcher used two real prototypes. One tested on screen reader participants through a webpage developed by the researcher with a static image of a chart and a numeric table that included all the data used to generate the chart. Appropriate visual treatment and HTML attributes were assigned to the static image chart and the numeric table to ensure they met WCAG accessibility standards[20]. The one tested with screen magnifier users was an interactive chart on the Yahoo Finance page.

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[20] The numeric table was developed according to the following WCAG principles and techniques:

WCAG 1.3.1 Info and Relationships: Information, structure, and relationships conveyed through presentation can be programmatically determined or are available in text. (Level A); **Technique H51**: Using table markup to present tabular information; **Technique H39**: Using caption elements to associate data table captions with data tables; **Technique H43**: Using id and headers attributes to associate data cells with header cells in data tables; **Technique H63**: Using the scope attribute to associate header cells and data cells in data tables

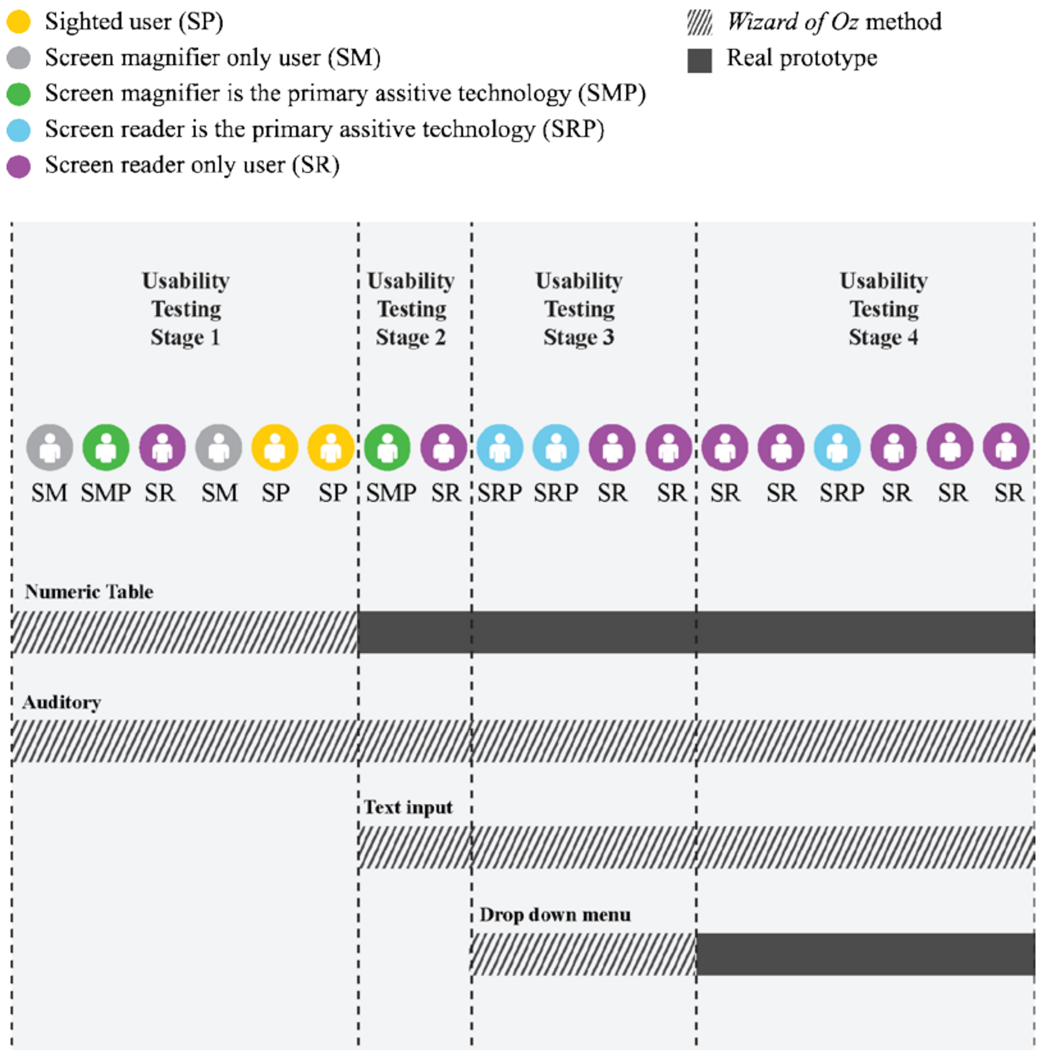
The third iteration of the usability testing focused on an evaluation and comparison between the auditory solution, text input solution, and a new dropdown menu solution that emerged through the previous testing. Again, the study used *The Wizard of Oz* method to test the proposed solutions to accelerate the process. Typical solutions were also tested using the prototypes mentioned in testing stage 2.

The last stage of the usability testing was about testing the dropdown menu using a real prototype. Through previous testing, participants had confirmed that the dropdown solution was able to provide additional features that auditory and text input solutions failed to achieve, and that the dropdown solution was considered a preferred solution in most of the contexts by the majority of users. Therefore, a real prototype was developed and used to assess the accessibility and usability of the tool by observing how participants actually interacted with the dropdown menu. Auditory and Text input solutions were also tested and compared with the dropdown menu; however, these features were tested using *The Wizard of Oz* method. The same numeric table tested in the third testing stage was now integrated to the interface where the dropdown menu existed, so that the users could compare both solutions using one interface.

WCAG 1.4.4: 1.4.4 Resize text: Except for captions and images of text, text can be resized without assistive technology up to 200 percent without loss of content or functionality (Level AA);

WCAG 1.4.6: Contrast (Enhanced): The visual presentation of text and images of text has a contrast ratio of at least 7:1. (Level AAA); **Technique G17**: Ensuring that a contrast ratio of at least 7:1 exists between text (and images of text) and background behind the text.

Figure 12: Participants, materials and methods used for each usability testing



8.5 Findings

8.5.1 Numeric Table Is Accessible but Not Usable for Screen Reader Users

W3C's Web Content Accessibility Guidelines (WCAG) recommend using numeric tables as an alternative solution for non-text content for individuals who cannot perceive information visually. The usability testing, however, revealed that although accessing data points through numeric table is a "fairly straightforward task," it can be "very time consuming," and take "enormous cognitive effort" when the task evolves analyzing information based on a comparison of multiple data points. For example, when asked to answer questions such as "which date has the highest closing price in the past three months?" or "which date has a 30% higher than average volume in the past 6 months?" most users felt it to be very challenging because unless going through a tedious process to record or memorize a large amount of data, they would not be able to answer the question. In addition, identifying trends through a table was considered nearly impossible for all users. These tasks became even more challenging for individuals with cognitive impairments such as a learning disability. As one participant noted, "A lot of users have cognitive and reading problem, learning disabilities…They can't work with numbers." Errors also became inevitable when accessing the large data table with a screen reader. Quit a few participants said that they would simply give up or ask for sighted people to assist them, which means they would be at risk of missing the opportunity to acquire critical financial information, or losing their independence unwillingly.

The usability testing revealed that both technical constraints and users' expertise have an impact on the usability of the numeric table. The following paragraphs will further explain these constraints and how they impact the user experience.

The primary technical constraint is that although the numerical data, represented by a series of dots on a line chart, points on a time series line and bars on a volume chart, is fully accounted for in a table, the meaning of this information, however, is not properly conveyed to the user. The way the information is presented would be analagous to expecting the individual to know the taste of a dish, by eating the ingredients one at a time. One of the major purposes of an interactive stock market chart is to convey the overall view of the data points; however, this macro-level information is lost when stock market charts are converted back to their numeric table origins and accessed by screen reader. The result is that the user encounters significant cognitive barriers when trying to compare different data points, to find out outliers, or to identify the overall trend. For example, one participant stated, “I can Google a specific data, such as price or exchange rate, but I can’t acquire overall trend.…It’s also hard to compare, such as finding out the highest, lowest or average. I would have to write down all the numbers and then compare.”

The second technical constraint is that screen reader is a linear output device, i.e. it can only read information within a table, cell by cell, one at a time; as a participant pointed out, this is onerous: “There is no quick way reading it. You can’t skim the table.” This linear progression, which may be likened to a manufacturing line where workers wait for the next component, severely limits users’ options regarding not only *how* to process information but even *what* information will eventually be included in the tally before all things are considered for the final decision. For example, in order to answer “which date has the highest price in the past six months,” users need to first go through each and every cell in the closing price column, trying to memorize and compare the data before being able to identify the highest price. They will then need to go back to the row that contains that price before being able to check the date associated with it. The overall experience can be so frustrating that users simply avoid doing it as demonstrated by the comments of three different participants:

> "Of course, I can tab through each cell, but it will take so much time….I will give up easily."

> "I am not going to read 420 lines and find [the answer] I have better things to do in my life."

> "The fact is you can "look at" it; the reality is it's a tedious task."

In addition, when a chart is presented as a numeric table, users are challenged with the quantity of the data points available to them. It might be possible to memorize or track different data points when there is a small set of data; however, it becomes nearly impossible when the user faces hundreds of rows and thousands of cells, which is typical when a stock market chart is presented in a numeric table.

> "By the time it reads the second or third column, I have already forgot what's in the first column….I get lost of where I am and there is no short cut available. [I am not] someone who has great memory and also can visualize things….I just lost my attention and give up."

It is challenging even when participants work with statistics on a daily basis. "It's too much information to digest in this linear approach. I had quit a lot experience working with charts, but it's still challenging."

Including appropriate "ID" or "headers" for each cell, as recommended by WCAG best practice, does little to improve the usability of the numeric table. Although users can differentiate data points in the same row, instead of just hearing number after number without knowing what the number is meant to represent, users still need to make a huge cognitive effort to process data. As one participant noted, "This is the problem I have with this format, even if they tell you the column header with the number, because you need to go through all the numbers, trying to remember them."

The third technical constraint came from the way the numeric table is coded. For example, users pointed out that the table tested lacked a sorting by column header function; this made tasks like finding the highest price or volume nearly impossible to accomplish unless the participant exported it to Excel.

Furthermore, the command (some users refer to it as hot keys or short cut) to enable the user to quickly navigate through the numeric table is too complicated and hard to master. In fact, five out of 12 users who used screen readers as their primary assistive technologies could not use the screen reader's table mode or use shortcuts to navigate through the table. This is the case even though all of them have more than 10 years of screen reader experience. One participant, after knowing that the study was about the numeric table, prepared a document listing all of the short cuts so she could refer back during the testing, because she "can't memorize all these commands." However, even with her notes by her side, she was still challenged. "Let's see if …[trying to use some sort of short cut] Alt + Control…That's not right. Let's go back to my notes. I can't remember…I tried a lot of these commands and they didn't work, many of them."

Participants who were skilled at using screen reader commands were able to accomplish the activity much faster and accurately than those who did not have the same skill level. Similarly, participants, who in general skip reading tables in real life, had a hard time to even figure out the structure of a table; they failed to complete any tasks during the usability testing. The testing also showed that participants who have a higher financial literacy level or have had stock market experience feel much more comfortable in using the table than the ones who don't possess this knowledge.

Users' language level was another factor that had an impact on the efficiency of understanding numeric table. For example, two participants each had 18 years of screen reader experience, advanced computer technology experience and were able to use Jaws hot key for tables; however, it took the participants who were native English speakers much less time to find the answer, because they were able to set the screen reader voice output speed very high.

8.5.2 Auditory Solution

The auditory solution was considered a "robust" and "more effective" approach than the traditional numeric table approach. Many of the participants expressed their enthusiasm once they heard the solution. "This is superior comparing with screen reader!" "This is much more understandable!"

Users believed the auditory solution enables the user to acquire information with considerably less effort and time: "It makes the tasks easier." Users also appreciated that the approach allowed them to quickly acquire and perceive information they were interested in, instead of being restrained by the numeric table's linear approach. Participants made these comments about the auditory solution:

> "This approach allows the flexibility. As a user, I can manipulate the way I read the data. I ask for the data I want."

> "It saves my time because I can acquire the part of the information I am interested in reading without going through the entire numeric table."

> "It will allow [people], especially people who are not computer savvy or people who are in a hurry to actually tell the machine what they want."

Despite the initial excitement about the auditory solution, many immediately expressed their doubts regarding the auditory approach, which might prevent them from using the system. One of the biggest concerns was the capability of the voice input system: “Can the computer recognize my voice? Can the computer recognize my question? Can the computer answer my question?” These were three of the most commonly raised concerns.

1) Users with speech disabilities or users who speak English as a second language, were particularly worried that the system would not recognize their voice:

> “I have multiple disabilities, including speech disability. I have tried so many voice recognition systems, however none of them works.”
>
> “The problem with voice [input] is that it doesn’t always recognize people’s voice….Have you tried the bell phone, the 411? They don’t understand what you are saying.”

2) Many users also shared their frustration when the system made phonetic word confusions.

> “The problem I am running into is that sometimes it autocorrects you, or it says something you didn’t say and you have to say it again and again. For example, I am saying, ‘I am going to the store’, but it thought I am saying ‘I am going through the door’. So I have to say it again and again.”
>
> “It gets a word wrong every now and then. And in general, if you are trying to say something too long it doesn’t like it.”

3) Users questioned the system’s capability to provide answers as well. A couple of users actually brought out their iPhone to demonstrate the experience when the system failed to return the answer users asked for.

> Participant: “Highest price of Apple in the past six months?”
>
> iPhone Siri: “Sorry, I don’t know”

> Participant: “What’s the price of Apple in June 24, 2014?”
>
> iPhone Siri: “OK, I found this on the web for ‘what’s the price of Apple Inc. into an 24th 20 14.” (The screen displayed a list of news for Apple)

Users said that when the system failed to provide the answer they required as demonstrated above, they had no idea of the reasons behind it; it can be that the user didn’t phrase the question appropriately, or the system is unable to interpret the questions, or simply because the answer is not in the database. Without knowing the actual cause for the error, users do not know how to solve the problem.

An additional concern raised by participants is the implementation of the tool. Users were concerned the tool might not be apparent to users: “Visually impaired users are very into habit,” said a participant who used to train other visually impaired individuals to use assistive technology. “You need to make the new function obvious to blind users.” Users also implied that they will only use the tool if “it’s easy to get and easy to install,”; ideally, the system should be able to automatically run when it detects a numeric table or a chart.

Users also pointed out that the synthesized speech is not “pleasant to hear,” and also causes challenges for users who speak English as a second language. “I HATE HATE HATE it. I am listening to real human’s voice during real life. Why does this [the voice output from the screen reader] have to be like this?” responded one participant intensely. He further added that “synthesis speech or speech with accent will be very hard for someone who came to Canada and don’t speak English that well.”

Another disadvantage that was pointed out by almost all participants is that the auditory solution could potentially interfere with their privacy, especially in public places, such as the hospital or on public transit: “I am concerned with my privacy. Sometimes, when I want to text message my Dad, then I say, ‘Text Dad’, but then everybody knows what I am going to do and what I am saying.”

The environmental context can also potentially stop a user from using the tool. “Noise can be another problem. If you are in a train, the wind was picking up outside, in a situation like that, it is just useless.” Finally, some users just don’t feel comfortable talking to a machine.

8.5.3 Text Input Solution

Several participants suggested using text input instead of voice input during the earlier stage of testing. “Can I type my question?” asked one participant. “I think the computer should be able to understand my typed question as well. Probably [it] will be more accurate.”

Later testing confirmed that text input not only improved accuracy, but also solved the privacy issues and could be implemented in a way that users are familiar with:

> “We just can’t see, but if we are using computer, we can type. We have the keyboard skills. No problem!”
>
> “Typing [the question] is helpful. Before typing, you have a chance to think, which ensures the accuracy of your questions. Being precise is more important than other things.”
>
> “[Text input] is going to be more accurate than speech recognition. So you should get better information…and more private if you are at a public place.”

However, similar to using voice input, users were still not sure if the system was able to successfully “decode” text input in various formats, and sometimes grammatically incorrect content. The feedback below clearly indicates that users don't have full confidence in the text input solution:

> "I don't really like it ... No two people will phase question in the same way. So you have to build some really intelligent [system] to know what the person is asking for."
>
> "But the other thing, the language …let's say somebody puts the year, and then puts the highest price. How about he puts 2014, and then the highest price? So what would happen? Does the system recognize it? How would a person know which way to input their question? The program needs to recognize user's question no matter which way the user input the question."

8.5.4 Dropdown Menu Solution

Usability testing provided a perfect platform to discover new ideas. A couple of users suggested using dropdown menu input to solve the disadvantages brought up by the auditory approach and text input approach. "Is there a filter I can use without me asking questions?" one participant asked after expressing his unwillingness to talk to a machine. Similarly, in between a discussion of how to ensure the system produces an accurate interpretation, another participant said, "How about using dropdowns? For example, I can first select "Price," and then start typing a symbol in the box. When the dropdown option comes up, I will quickly click and switch (within the dropdown menu) until I heard Gooo, then I enter. It will be very fast and accurate."

8.5.4.1 Overwhelmingly Positive Feedback

After the potential of the dropdown menu approach was realized, it was quickly introduced in later usability testing. The feedback was overwhelmingly positive. Users were thrilled after trying the tool: "This is so cool!" "That is great! I can't believe that nobody has developed something like this before!" "I think that's it!" When asked to compare between the numeric table and dropdown menu, many users simply think these two approaches are not even comparable. For example, one participant said, "This provides a lot of information otherwise won't be there. You can't even say it's an improvement because it's virtually nothing there right now." In summary, observations of the usability testing and users' feedback clearly demonstrate that the dropdown menu is easier to understand, educational, and able to address users' key concerns regarding the auditory and text input approach, while maintaining the flexibility feature of the two other approaches.

One of the most surprising findings is that users think the dropdown menu approach is educational, enabling users to discover information or look at the data in a way they were not aware of initially. "Part of the problem ... is that you don't always know what you want to know." As a result, users might be at risk of missing critical information. In addition, "there are different ways to look at a graph and you will learn different things when you change your perspective" said a participant. Thus, it is the responsibility of the designer to "communicate it (the objective of the graph) to the users and show people how to interpret data." It is clear that the dropdown menu approach was able to fulfill user's needs by guiding them through a series of dropdown menu options. "People would know the sort of questions [that] could be handled and answered, which might not be considered by them at the first place," said a different participant. "This is a way to educate the user what this tool can do, what kind of questions they can ask and what kind of answers they can get."

Secondly, dropdown menus also solved three key issues that users encountered regarding the auditory approach and text input approaches: cognitive load, accuracy, and intuitiveness of the tool.

1) The tool dramatically reduced the cognitive load required for operation when the user accessed the information through numeric table. Users no longer need to try and memorize a large quantity of data. “The thing I like about it is you don’t need to search all the way (in the table)!” said a participant. “It can answer specific questions with the dropdown menu.”

2) Users think the dropdown menu enables a more accurate and precise interaction between the system and the user. “It is more precise than typing or using voice,” one participant pointed out. “It can ensure the users get the answer they are expected.” Not only does it help the system capture the user’s request, it also “allows user to precisely define what they want to know … before they do it” as another participant pointed out. This will in turn, ensure a higher success rate for users to get the information they want.

3) Users feel more comfortable and confident using the tool, as it is more intuitive. “If there is a dropdown, I know exactly what the program expects me to choose,” said a participant. “While, if it’s an edit box (text input box), I risk typing something that the program is not expecting.”

4) Users confirmed that the dropdown menu maintained the flexibility that the auditory and text input approach have; this allows users to acquire and perceive information based on their needs and interests. For example, one participant said “This is useful for me, because I can do it by time, by rate, by volume.”

Thirdly, the concept of using dropdown menu is very easy to understand. “I get it!” said another participant right after a short initial exploration of the tool. “You put the right information, and then you click on go button, then it will tell you right away.” Three other participants with advanced technology skills were even able to start using the tool with minimum instruction. “What you have done is that you take the information I gave you,” said one of them after trying the tool with literally no instruction. “It provided me with the textual description of what exactly I asked.”

8.5.4.2 Recommendations and Suggestions

In addition to the consistent positive feedback demonstrated above, users also provided constructive feedback to improve the accessibility and usability of the dropdown menu solution:

1) Users want instructions and education material to help them use the tool more effectively. Users suggested including tutorials, instructional text, or self-explanatory labels, to inform users of the overall concept of the tool, how it works, where to find the results, which fields are required and which are optional. Users also emphasized the impact of financial literacy on the effectiveness of using the tool. For example, as a participant with no financial experience, one participant said “I don’t know what open means here, there is stock market close, what volume means … I don’t know how to interpret this. So we may need something … explaining how to interpret it.”

Although it’s a common request to have instructional content, users do have different preferences. For example, one participant with a background in education training strongly recommended a tutorial that provided a step-by-step process because “if you put it in paragraph, people get confused," she said. Another participant, an IT specialist on assistive technology, disliked the idea of a formal tutorial and much preferred to make the tool "as self-explanatory as possible" instead of using a separate tutorial section, because "most of people won't bother to read the help information,"; he further explained that this behaviour is quite common among people who are technical enough to be able to read the manual. "Probably only 10-20% will read the manual," he added. It is obvious that the user's financial literacy level, learning style, and comfort with technology all play an important role here.

2) Users want to be able to easily navigate through the tool. A large percentage of users had difficulty locating the result after clicking on the *Ask* ***ChartMaster*** button. It is because the cursor stays with the button instead of automatically jumping to the result textbox. Not knowing the placement of the result textbox, participants tried to use various shortcuts to search for the result. For example, one participant clicked on T as she assume the result would be associated with the numeric table, while a different participant was using H, a short cut jumping between headers to find the answer, as he thought there would be a header included in the result. Users also found navigating around challenging when they attempted to choose or change dropdown menu options. Since there are no attributes associated with dropdown menu titles, it normally took users a long time to go through every single dropdown menu item before locating the menu they wanted to interact with. Errors occurred sometimes, because of the similarity of the options within Price and Volume dropdown menus.

3) Users prefer to have high-level information upfront rather than at the end. “It’s better for blind people to have the description first,” said one participant. “You can identify the type of the chart, the name of the chart and a brief description of what the chart is.”

4) Users would like the system to provide a “preference setting,” saving most frequently searched criteria and allowing them quick access to the information they are most interested in. A couple of users also mentioned using Cloud technology to help the user access both the tool and the settings in any location. “These applications should be portable,” said one participant, “so I can use it on somebody else computer.”

5) Many users expressed their need to control what to hear and how to hear the result. “When the speech read the content, it should allow me to stop, repeat the previous sentence, or slow down.”

6) A couple of users suggested exploring the use of other user interface elements, such as radio buttons and checkboxes other than dropdown menus.

8.5.5 The Winning Solution Is…

One of the most profound discoveries in this study is that users want options instead of one winning solution. During the entire course testing, users were asked to compare numeric table, auditory approach, text input approach, and dropdown menu. It would be a reasonable assumption to say that the user would always pick the solution they consider easier or better; however, the reality is that users prefer to include as many options as possible so they can choose appropriate option according to a series of facts, such as the tasks, the context, and the knowledge in computer and assistive technologies.

Sometimes, the need to have options was based on user concerns over physical capabilities or technological expertise. For example, one participant suggested the system "provide alternative options so if they can't type or use keyboard, then they can use voice input or vice versa. So that people who are not verbal, have the option to type." Another participant also considered the auditory approach a good alternative, because "it allows especially people who are not computer savvy or people who are in a hurry to actually tell the machine what they want."

A user's learning style was another reason for having options. For instance, when responding to the question regarding the preference between auditory approach and dropdown menu approach, one participant, a visually impaired user with a PhD in Education said,

> "People learn and work in different ways, so they need as many as alternative ways possible. (This is) what is called method of learning, people learn in different ways. One way of learning or comprehension is not enough. So you need both voice and the text to type in (refer to dropdown menu here)…and people with LD, they might need both…So do not limit to one mode, do both."

For other users, especially those with advanced computer knowledge, providing options means being able to accomplish tasks in the most effective way according to the task a user would like to accomplish. For example, when one participant was asked whether the numeric table or dropdown menu was easier to use, he said,

> "The answer of this question will depend on the question. If the question is what's close price for a stock on Oct 14, I would say the traditional one is easier. If you want to find out what's the highest price in the middle of few hundreds of values, then the dropdown menu will be easier."

Another participant expressed similar comments when asked to rate the likelihood of using the numeric table over the dropdown menu.

> "Actually I will use both … If I use the table, I would be able to get more information, for example which day, what' was going on…you know, not just the data I retrieve.…But if I need specific information, or if I want to find something very fast, I will then use the combo box....Personally I will use both.

Users requested multiple options even when they had concerns over the option or have difficulties using the option. For instance, one of the participants would like to have both auditory input and text input available, although she was not confident that the auditory approach was able to return the answer. She even suggested keeping the numeric table, "Let them read the column, or row to compare, and at the same time providing the alternative ways. Give them the flexibility." She did claim, however, that she would give up using the numeric table as it is "very time consuming" and hard to use.

8.5.6 User's Insights in Accessibility and Inclusion

During usability testing, users also shared their understanding of accessibility and inclusion. There is a common understanding that businesses have to take the first step to make their product or service accessible before seeing more visually impaired users become their customers. "The charts and graphs are not accessible, that's why people are not using it," said a participant. "If they can make it accessible, then more blind people will come and use it." Similar to that participant's comments, an additional participant also argued that business couldn't use a small customer base as an excuse to not providing accessible service. "Business might say 'we don't have the service because nobody is asking for', however, the reality is that "you don't have it available why should

I go to your place?" She further commented that for her, accessibility is far more important than price advantages. "iPhone is expensive, but we still buy it, because it is accessible. We will buy if it works."

In addition, users pointed out that creating accessible and inclusive charts and graphs is a "mutual benefit" for individuals who need to access critical information to participate in financial and social activities and for business, advocacy groups, and government, who need to use chart to effectively "sell product" or "promote ideas."

As expected, good design enables curb-cut effects by improving the accessibility and usability of the charts. Participants expressed this benefit while providing their feedback, and often stressed that their recommendation would benefit people with speech, mobility, and learning disabilities, or people whose activity might be restrained by the environment, or sighted people with low financial literacy. For example when one of the participants was talking about auditory input, he said, "For someone who has problem with their hands, sometimes they would need to user voice command." Another example can be seen when another participant suggested including a summary of the chart upfront. She said, "Even for sighted people, that will benefit them; because some people are not good with math and statistics. So for people who are not financial people, or people who don't have background in charts and maps… You can explain to them what it [the graph] means."

9 Implication for Design

9.1 Moving Away from the Notion of Providing One Ultimate Solution

The usability testing revealed that users choose how to interact with computers and acquire information based on their computer expertise, financial literacy level, learning style, as well as the task and the context. Therefore, the design should move away from the notion of providing one ultimate solution, and hope it will work for a wide range of users and in a wide range of contexts; instead, it should offer individualized designs both across and within specific users; for example, providing designs with flexible configurations that evolve with the user's skill level and respond just-in-time to the situation and goals the user faces. The future design will need to explore the possibility of integrating all four possible options (numeric table, auditory solution, text input solution, and dropdown menu solution) into one design. Options should be easily found and easily switched. In addition, users should be able to save their preference settings, such as searching criteria that they are particularly interested in or solutions they prefer to use.

9.2 Providing Various Levels of Educational Materials to Close Financial Literacy Gap

This study also revealed that users knowledge of the stock market played an important role in determining how quickly they could understand the design concept and how comfortable and confident they were while trying the tool. Users were also aware of the impact of this knowledge gap, and suggested that the next design should provide educational material to help them understand the key investment terminologies as well as how to interpret the data.

The table below outlines the three levels of educational materials that will be added to the design and how it provides in context, or just-in-time help to satisfy the needs of users with different knowledge levels and appetites for learning. This enhancement echoes with the design implication, that the design needs to include various options to support users' "self-determination and self-knowledge" (IDRC, 2013).

Table 1: Three levels of educational materials can be added to **ChartMaster**

	Tool tips	**Glossary**	**Education Centre**
Placement	Right beside each dropdown menu header	A separate page	An individual section of a site
Access	Immediate access to information	Access through quick links or through main navigation menu	Access through main navigation menu
Scope	One specific definition	Multiple glossaries	Multiple topics
Features	Brief explanation	Short and straightforward explanation Organized into categories and also allow to sort by alphabet Enable Keyword search	Length and detailed explanation, normally include case studies or video Organized into categories Enable Keyword search
Knowledge level suited	Novice	Moderate	Advanced

9.3 Align with Users' Mental Model

The study shows that users have certain expectations in terms of how the system *should* communicate the information to them, and how they *should* interact with the system. When the design doesn't match the user's mental model, users are much less likely to accomplish their tasks.

Two design improvements can be made to better align the user's mental model with the design model. First of all, a revision will be made to allow a screen reader to automatically read the answer after the user clicks on the *Ask* ***ChartMaster*** button. In the current design, the system doesn't allow the focus to jump to the result after the user submits the question. As a result, quite a few users became stuck as they had anticipated that the answer would be read out automatically or be accessed through using the short cut for Header or Table. Secondly, a "Summary" dropdown menu will be added as the first set of data point to help users to be mentally prepared before starting to perceive and analyze data. This is in response to users' expectation of having high-level information before drilling down to detailed information. The "Summary" menu will house information such as the name of the chart, the type and structure of the chart, and what the chart is about, in addition to a description of the overall trend.

9.4 Minimize the User's Cognitive Load and Reduce Errors

The usability testing also showed that users were struggling to accomplish their tasks when they were facing unfamiliar tools, labels and functionalities that the design failed to clarify. Additional cognitive effort was required, such as remembering, planning or problem solving, which in turn had a negative impact on the overall usability. The following design revisions will be made to minimize the user's cognitive load and reduce errors.

1) The design should implement straightforward and self-explanatory labels and menus to help the user get the idea quickly. For example, the label "compare with current symbol" caused confusion for the majority of the participants, as it didn't align with the

knowledge users already have, and thus needs to be reconsidered with a term that users are familiar with.

2) The design also needs additional instructional aides to guide user interaction with the system, and minimize system errors. For example, instructional text such as “required” or “optional” can be placed right beside the header of each input box or dropdown menu, giving users a clear indication of how the system is supposed to work; this can potentially reduce system errors caused by missing required fields. Major headers should also include appropriate ID or attributes to help screen reader users quickly navigate through the tool.

3) In addition, the choices in the user interface should not only allow users to accomplish their task, but should also act as a constraint that prevents faulty input. For example, instead of letting users type dates in free-form, the system should employ dropdown menus to ensure users input the correct format for that field. In addition, the entire inquiry process can be designed in a step-by-step fashion. For example, in step 1, users choose the type of information they want to know, and then choose time frame in step 2 before the system jumps to step 3 and allows users to select detailed metrics. As users interact with the system in a pace that is determined by the system, there is much less chance for errors.

4) Finally, the system will need to provide sufficient training or supporting material to enable users to learn. It is expected that adding tutorials will provide detailed instructions in a way that can be understood and interacted with by users with different levels of expertise in language, computer and assistive technology, and financial literacy.

10 Contributions, Limitations, and Future Work

10.1 Contributions

From an academic perspective, particularly the field focusing on non-visual representation of charts and graphs, this research presented **ChartMaster**, a novice solution that enables visually impaired screen reader users to access stock market charts through provision of textual information through dropdown menus. Compared with other related works, this sophisticated solution has the following advanced features that bridge the research gaps:

1) **ChartMaster** is able to provide accurate and precise data points regardless of the complexity of the chart. The Natural Language Interface can only achieve a satisfying accuracy rate while working with “simple” charts because the system is interpreting an image graph. Similarly, haptic interface is not effective when dealing with complex charts due to the limitation of the output device and the capability of human sensation. Conversely, **ChartMaster** works with underlying real data stored in java ArrayList that is used to generate the graph instead of the graph image, allowing the system to return as many data points possible with no chance for error. In fact, the capability of **ChartMaster** goes beyond the data point used to generate the chart. It also provides additional yet critical data points that can only be perceived by calculating or comparing the data, such as average, unusual value, median, highest, and lowest. These data provide a benchmark that users can use while analyzing and comparing data.

2) **ChartMaster** provides users with great flexibility to acquire information about a chart based on their needs and interests. Other tools either don’t allow users to navigate through

the textual summary at all (ie. SIGHT project), or force the user to interact with the information in a linear approach (ie. iGraph project).

3) Developed using simple and straightforward java script and commonly used interface elements (dropdown menus and text input fields), **ChartMaster** is compatible with a wide range of browsers, operation platforms, and screen reader applications.

4) **ChartMaster** can be integrated into any existing interface without any additional installation on the user side, and is absolutely compatible with any operation platforms and screen reader due to the simplicity of the technology.

5) To interact and perceive information using **ChartMaster**, users don't need to learn any extra keyboard control, which help improve the learnability.

From the Human computer interaction perspective, this research clearly demonstrates the physical, cognitive and emotional barriers that visually impaired users face while interacting with stock market charts. In addition, while other research has revealed that "online interaction proficiency [for screen reader users] is a composite concept" and is closely tied to the individual's "expertise", "experience", "training" and "trouble shooting skills" in using the computer, the Internet, and the screen reader (Chandrashekar, 2010), this research discovered other aspects related to online interaction proficiency for screen reader: the proficiency of individual's English level if English is not the first language, and the knowledge level related to the particular content and topic communicated through the interface. This knowledge will guide Web designers in creating a more accessible and usable interface with the consideration of the addressed barriers.

In addition, the research proves the power of the co-design approach. Through the iterative process, users were getting involved during several stages of the design process: they helped identify the problem, evaluate the initial concept, and provided design solutions raised by them or by other users. One blind participant even assisted in writing the code for accessible numeric table. Getting users involved in the design process is extremely effective in terms of generating and refining ideas. In fact, two out of three design concepts were directly inspired by usability testing participants' recommendations. The positive feedback received from the dropdown menu solution has proved that a successful design needs to rely on the expertise of people who actually use it.

The experience of conducting usability testing at users' homes also had a profound impact on the design. Counter to traditional research methods, which encourage researcher objectivity and neutrality, close engagement with research participants fosters insight into important socio-emotional factors and help to recruit participants into the co-design process. It also allowed the researcher to have a much more realistic view of how the artifact will be used within a particular environment unique from user to user. It helped capture customer needs that otherwise could have been missed if evaluated in a standard testing room. For example, researchers were able to observe how many computers or monitors users use at the same time and where and how users set up their computer and various assistive technologies. All of this information enables researchers to look at the challenges users face within a realistic context. Ethnographic study also has benefit on participants. As the research was conducted in an environment users were familiar with, they were much more relaxed and felt more comfortable to provide feedback. Besides, the researcher gained tremendous respect and empathy towards visually impaired people by recognizing their skills and expertise in various professional fields, their positive attitude towards life, and the efforts they have to give in order to achieve their goal. A strong emotional bond was therefore established between the researcher and the users, continuously encouraging the researcher throughout the course of the research.

Finally, from the inclusive design perspective, this study confirmed that one-size-fit is not ideal to meet diverse users' needs within the widest range of context. Providing options and enabling users to personalize the interface through flexible configurations is indeed the ultimate goal of a design.

10.2 Limitations and Future Research

A stock market chart is not static; rather, it is constantly changing in a given trading day according to trading activities. Thus, it is critical to provide investors with access to dynamic, real-time intraday trading data. At the current stage, **ChartMaster** is able to provide information for "historic" stock market chart, meaning a chart that represents data for any past trading days; however the capability of providing information for a "live" chart with real-time data being constantly added during the time that the market is still operating is still unknown and needs further exploration.

It is also worth investigating applying the proposed solution to other types of charts and graphs, especially knowing that charts and graphs are becoming increasingly pervasive in all sorts of communication material we encounter every day. Many users also noticed the potential of this application, saying that the proposed solution "is good for any quantitative data" and thus suggested to "extend the research to all charts and graphs, not just stock market charts, so it can impact a wide range of daily life activities, such as at school and at work". This can result in a customizable **ChartMaster** API solution that enables the creator of any chart and graph to create their own **ChartMaster** module by simply uploading a data spreadsheet to the system. The user can then “plug” the module into a Webpage, a PowerPoint presentation or a research paper to allow visually impaired readers access to the charts and graphs.

The study only focused on providing textual information to individuals who are visually impaired and use screen readers. A couple of users already expressed their desire of adding tactile solutions to the system. “We need something we can touch, not just something we read,” said one participant. “When you are low vision you need to learn from other senses.” Other research already confirmed that some graphical or visual information couldn’t be adequately described in text. This especially applies to spatially linked information, such as charts and graphs (Mynatt, 1997; Mynatt & Weber, 1994). This theory also aligns with participants’ feedback. One of the two sighted users, a business analyst at a self-directed brokerage firm, shared his concern about textual information at an earlier usability testing. “It can be very hard to describe things like support and resistance, even just to describe up and downs, unless you’re very visual.” Therefore, it is the researcher’s intention to explore hepatics or tactile presentation.

Thirdly, the targeted user for this study is limited to visually impaired screen reader users. While the usability findings suggested that the dropdown menu solution is “educational” as it guides users to acquire key information communicated through the chart, it then makes sense to include sighted novice investors to participate in future study. The evidence from this future work will expand the application of the design to a much boarder audience base.

11 Conclusions

Over the last few decades, the stock market has seen dramatic changes, featuring a rapid growth in capitalization and trading activities, as well as the number of self-directed investors worldwide. The stock market chart, one of the major tools investors use to predict the future trend of stocks, has gone through a major makeover in the past decades due to advanced technologies. Static charts are replaced with dynamic, real-time, interactive ones, enabling users to perceive, compare and analyze data points in literally just a few clicks. However, these advanced charts might present physical, cognitive and emotional barriers for a wide range of users, for example, users with low financial or computer literacy, or people with learning disabilities or those who have difficulties interpreting charts. Stock market chart are particularly challenging for visually impaired screen reader users; because, in addition to all the barriers mentioned above, screen reader users can only acquire information textually, such as through a numeric table, which in turn further limit their capability to perceive, digest, and analyze information.

The impact of these barriers faced by screen reader users can be profound at both individual and socioeconomic levels. From the individual perspective, these barriers exclude visually impaired users from participating in investment activities, and prevent them from becoming financially literate and able to make informed financial decisions. From the socioeconomic perspective, they potentially intensify the vicious cycle of poverty and economic inequality.

This challenge has prompted an exploration of non-visual design solutions that enable visually impaired screen readers to perceive and analyze stock market charts and graphs in an easier, quicker and more effective way than the existing numeric table solution.

The design research takes a user-centred approach and uses iterative methods, through which the design solutions were constantly being evaluated and refined through usability testing. During the course of the design research, usability participants were encouraged to co-design, as they provided design solutions regarding the design challenges that arose from their own experience or the experiences of other users. There are a total of three iterations evolved: auditory solution, text input solution, and dropdown menu solution. The design research suggests that the one-size-fits-all approach is insufficient to provide design solutions that can meet users' needs regardless of their knowledge in financial and investment concepts, expertise in computer and assistive technology, language and education background, as well as the specific goal they want to achieve in a certain context or situation. It is apparent that the final design solutions should follow an inclusive design approach, providing options and enabling users to make personalized adjustment through flexible configurations, rather than trying to find one ultimate solution for everyone.

In *The Information Age*, advancing computer and Internet technologies provide a great opportunity for users to access charts and graphs through multiple senses: visual, textual, audio, tactile and haptic. The transformation from graphical modality into the nonvisual modality, together with the possibilities to let users choose from a wide range of options to fit their needs, presents an optimal inclusive design solution that will not enhance the usability of every possible user. As one participant remarked, "Accessibility is for everyone, not just for people with disabilities."

12 References

Agarwal, S., Driscoll, J. C., Gabaix, X., & Laibson, D. (2009). The Age of Reason: Financial Decisions over the Life Cycle and Implications for Regulation.

Akhtar, M. N., Rehman, K. u., & Hunjra, A. I. (2011). Determinants of Short-term Investment Decision-making.

Alty, J. L., & Rigas, D. I. (1998). *Communicating graphical information to blind users using music: the role of context.* Paper presented at the Proceedings of the SIGCHI conference on Human factors in computing systems.

Bank, W. (2015). World Development Report 2015: Mind, Society, and Behavior. Washington, DC: World Bank.

Barcellos, S. H., Smith, J. P., Yoong, J. K., & Carvalho, L. (2012). Barriers to Immigrant Use of Financial Services: The Role of Language Skills, U.S. Experience, and Return Migration Expectations.

Bebee, G. (2014). Is self-directed investing right for you? *The Globe And Mail*. Retrieved from http://www.theglobeandmail.com/globe-investor/is-self-directed-investing-right-for-you/article20555144/

Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral cortex, 10*(3), 295-307.

Behrman, J. R., Mitchell, O. S., Soo, C. K., & Bravo, D. (2012). How financial literacy affects household wealth accumulation. *The American economic review, 102*(3), 300.

Ben-Tal, O., Berger, J., Cook, B., Daniels, M., Scavone, G., & Cook, P. (2002). *SonART: The sonification application research toolbox.* Paper presented at the Proceedings of the 2002 International Conference on Auditory Display, Kyoto, Japan.

Bentley, N., McCann, L., & Ireland, J. (2014). Regulating complex products - is further regulatory reform on the horizon?

Berkley, J. J. (2003). Haptic Devices.

BlackRock. (2012). 7-minute Guide to ishares ETFs.

Booth, P. A. (2014). *An Introduction to Human-Computer Interaction(Psychology Revivals)*. New York, NY.

Brave, S., & Nass, C. (2003). Emotion in human–computer interaction. *Human-Computer Interaction*, 53.

Brown, L. M., & Brewster, S. A. (2003). *Drawing by ear: Interpreting sonified line graphs*.

Butler, K. A., & Jacob, R. J. K. (1997). *Human-computer interaction: introduction and overview*. Paper presented at the CHI '97 Extended Abstracts on Human Factors in Computing Systems, Atlanta, Georgia.

Calvet, L. E., Campbell, J. Y., & Sodini, P. (2007). Down or Out: Assessing the Welfare Costs of Household Investment Mistakes. *Political Economy, 115*(5).

Camargo, A., & Fonseca, I. (2013). The Race for Self-directed Investors - Developments in Online Trading Among Brokers and Banks.

Canada, F. C. A. o. (2014). Toward a National Strategy For Financial Literacy

Phase 1: Strengthening Seniors' Financial Literacy: Financial Consumer Agency of Canada.

Canada, H. R. a. S. D. (2013). *Federal Disability Reference Guide*.

Canada, S. (2014). Canadian Financial Capability Survey, 2014. 2015, from http://www.statcan.gc.ca/daily-quotidien/141106/dq141106b-eng.htm

Carberry, S., Elzer Schwartz, S., Mccoy, K., Demir, S., Wu, P., Greenbacker, C., . . . Moraes, P. (2012). Access to multimodal articles for individuals with sight impairments. *ACM Transactions on Interactive Intelligent Systems (TiiS), 2*(4), 21.

Carpentier, C., & Suret, J.-M. (2012). Financial knowledge and rationality of Canadian investors. *Available at SSRN 2038930*.

Chandrashekar, S. (2010). *Is Hearing Believing? Perception of Online Information Credibility by Screen Reader Users who are Blind or Visually Impaired*.

Cogent. (2014). Uncovering Opportunities in the Self-Directed Marketplace.

Cohen, R. F., Yu, R., Meacham, A., & Skaff, J. (2005). *PLUMB: displaying graphs to the blind using an active auditory interface.* Paper presented at the Proceedings of the 7th international ACM SIGACCESS conference on Computers and accessibility.

Cole, S. A., & Shastry, G. K. (2008). *If You are So Smart, why Aren't You Rich?: The Effects of Education, Financial Literacy and Cognitive Ability on Financial Market Participation*: Citeseer.

Collin, D. (2011). Aboriginal Financial Literacy in Canada: Issues and Directions.

Commission, A. S. I. (2014). National financial Literacy Strategy

Cook, A. M., & Polgar, J. M. (2014). *Assistive technologies: Principles and practice*: Elsevier Health Sciences.

Donohue, M. A. (2011). *Financial Literacy and Women: Overcoming the Barriers.*

Eason, K. D. (1984). Towards the experimental study of usability. *Behaviour & Information Technology, 3*(2), 133-143.

ECCE. (2007). Use of Extra-financial Information by Research Analysts and Investment Managers.

Education, O. M. o. (2013, August 4, 2013). Financial Literacy Education in Ontario Schools. Retrieved January 31, 2015, from http://www.edu.gov.on.ca/eng/surveyliteracy.html

Elzer, S., Schwartz, E., Carberry, S., Chester, D., Demir, S., & Wu, P. (2008). *Accessible bar charts for visually impaired users.* Paper presented at the Fourth Annual IASTED Intl. Conf. on Telehealth and Assistive Technologies.

Elzer, S., Schwartz, E., Carberry, S., Chester, D., Demir, S., & Wu, P. (2009). I in.: Bar Charts in Popular Media: Conveying Their Message to Visually Impaired Users via Speech, Book chapter in Advances in Intelligent Information Systems. *Studies in Computational Intelligence Series, Springer*.

Ferres, L., Lindgaard, G., Sumegi, L., & Tsuji, B. (2013). Evaluating a tool for improving accessibility to charts and graphs. *ACM Transactions on Computer-Human Interaction (TOCHI), 20*(5), 28.

Ferres, L., Verkhogliad, P., Lindgaard, G., Boucher, L., Chretien, A., & Lachance, M. (2007). *Improving accessibility to statistical graphs: the iGraph-Lite system.* Paper presented at the Proceedings of the 9th international ACM SIGACCESS conference on Computers and accessibility.

FINRA. (2009). Financial Capability in the United States.

Flowers, J. H., Buhman, D. C., & Turnage, K. D. (2005). Data sonification from the desktop: Should sound be part of standard data analysis software? *ACM Transactions on Applied Perception (TAP), 2*(4), 467-472.

Frenette, M., & Robson, J. (2011). Financial Literacy of Low income Students: Literature Review and Environmental Scan.

Galesic, M., & Garcia-Retamero, R. (2011). Graph Literacy A Cross-Cultural Comparison. *Medical Decision Making, 31*(3), 444-457.

Gastineau, G. (2002). *The Exchange-Traded Funds Manual*: John Wiley and Sons.

Greenbacker, C. F., Wu, P., Carberry, S., McCoy, K. F., Elzer, S., McDonald, D. D., . . . Demir, S. (2011). *Improving the accessibility of line graphs in multimodal documents.* Paper presented at the Proceedings of the Second Workshop on Speech and Language Processing for Assistive Technologies.

Grout, P. A., Megginson, W. L., & Zalewska, A. (2009). One Half-Billion Shareholders and Counting-Determinants of Individual Share Ownership Around the World. *Available at SSRN 1364765*.

Grudin, J. (2012). A Moving Target—The Evolution of Human-Computer Interaction.

Henry, S. L. (2007). *Just ask: Integrating Accessibility throughout Design*: Lulu.com.

Hewett, Baecker, Card, S. K., Carey, Gasen, Mantei, . . . Verplank. (2009). ACM SIGCHI Curricula for Human-Computer Interaction: Chapter 2: Human-Computer Interaction. from http://old.sigchi.org/cdg/cdg2.html - 2_1

IDRC. (2013). What is Inclusive Design. from http://idrc.ocad.ca/index.php/about-the-idrc/49-resources/online-resources/articles-and-papers/443-whatisinclusivedesign

Ina, S. (1996). Computer graphics for the blind. *ACM SIGCAPH Computers and the Physically Handicapped*(55), 16-23.

Institute, B. S. (2005). *British Standard 7000-6: Design management systems: Guide to managing inclusive*. London, UK: British Standards Institute.

Investopedia. Fundamental Analysis. Retrieved July 29, 2014, from http://www.investopedia.com/terms/f/fundamentalanalysis.asp

IOSCO. (2014). Strategic Framework for Investor Education and Financial Literacy.

J.D.Power. (2013). 2013 Canadian Discount Brokerage Satisfaction Report_Summary.

Janssen, C., Langager, C., & Murphy, C. Technical Analysis: Chart Patterns. Retrieved April 5, 2015, from http://www.investopedia.com/university/technical/techanalysis8.asp - ixzz3WS8wjMyj

Kimball, M., & Shumway, T. (2006). Investor sophistication, and the participation, home bias, diversification, and employer stock puzzles. *Unpublished Manuscript, University of Michigan*.

Krufka, S. E., Barner, K. E., & Aysal, T. C. (2007). Visual to tactile conversion of vector graphics. *Neural Systems and Rehabilitation Engineering, IEEE Transactions on, 15*(2), 310-321.

Loriggio, P. (2014). 'Focused' financial education program needed in Canada's schools: money guru. Retrieved January 31, 2015, from http://www.ctvnews.ca/business/focused-financial-education-program-needed-in-canada-s-schools-money-guru-1.2147279

Lusardi, A., Michaud, P.-C., & Mitchell, O. S. (2011). Optimal Financial Literacy and Saving for Retirement.

Lusardi, A., & Mitchell, O. S. (2005). Financial Literacy and Planning: Implications for Retirement Wellbeing.

Lusardi, A., & Mitchell, O. S. (2007). Baby boomer retirement security: The roles of planning, financial literacy, and housing wealth. *Journal of monetary Economics, 54*(1), 205-224.

Lusardi, A., & Mitchell, O. S. (2013). The economic importance of financial literacy: Theory and evidence: National Bureau of Economic Research.

Mandell, L. (2008). The Financial Literacy of Young American Adults: Results of the 2008 National Jump$tart Coalition Survey of High School Seniors and College Students.

Mandell, L., & Klein, L. S. (2009). The Impact of Financial Literacy Education on Subsequent Financial Behavior. *Journal of Financial Counseling and Planning, 20*(1), 15-24.

Murphy, J. (2012). *Charting Made Easy*: Wiley.

Mynatt, E. D. (1997). Transforming graphical interfaces into auditory interfaces for blind users. *Human–Computer Interaction, 12*(1-2), 7-45.

Mynatt, E. D., & Weber, G. (1994). *Nonvisual presentation of graphical user interfaces: contrasting two approaches.* Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.

NCEE. (2005). What American Teens & Adults Know About Economics.

Nielsen, J. (1994). *Usability Engineering*. London: Academic Press.

Norman, D. A. (2002). *The Design of Everyday Things*

OECD. (2005). Recommendation on Principles and Good Practices for Financial Education and Awareness.

OECD. (2011). Measuring Financial Literacy: Questionnaire and Guidance Notes for Conducting an Internationally Comparable Survey of Financial Literacy.

OECD. (2013). Advancing National Strategies for Financial Education.

OECD. (2014). PISA 2012 Results: Students and Money: Financial Literacy Skills for the 21st Century (Volume VI).

OECD/INFE. (2012). OECD/INFE High-Level Principles on National Strategies for Financial Education.

OECD/INFE. (2013). Financial literacy and inclusion: Results of OECD/INFE Survey Across Countries and by Gender.

OHRC. (1990). What is disability? . Retrieved Feburary 9, 2015, from http://www.ohrc.on.ca/en/policy-and-guidelines-disability-and-duty-accommodate/2-what-disability

Paneels, S., & Roberts, J. C. (2010). Review of designs for haptic data visualization. *Haptics, IEEE Transactions on, 3*(2), 119-137.

Ricciardi, V., & Simon, H. K. (2000). What is Behavioral Finance? *Business, Education and Technology Journal*.

Schield, M. (2006). *Statistical literacy survey analysis: Reading graphs and tables of rates and percentages.* Paper presented at the Proceedings of the Sixth International Conference on Teaching Statistics.

Shackel, B. (2009). Usability–Context, framework, definition, design and evaluation. *Interacting with Computers, 21*(5-6), 339-346.

Storrs, G., Rivers, R., & Canter, D. (1984). The future of man-machine interface research: A discussion and a framework for research. *Applied ergonomics, 15*(1), 61-63.

Treviranus, J., Stolarick, K., Denstedt, M., Catherine, F., & Ascunsion, J. (2010). Leveraging Inclusion and Diversity as Canada's Digital Advantage. Retrieved March 10, 2015, from http://idrc.ocad.ca/images/stories/DraftInclusionSSHRCreportFinal)-first32.pdf

Wall, S., & Brewster, S. (2006). *Feeling what you hear: tactile feedback for navigation of audio graphs.* Paper presented at the Proceedings of the SIGCHI conference on Human Factors in computing systems.

WebAIM. (2013). Accessibility Evaluation Tools. Retrieved March 28, 2015, from http://webaim.org/articles/tools/

WebAIM. (2014, Febuary 26, 2014). Screen Reader User Survey #5 Results. Retrieved January 20, 2015, from http://webaim.org/projects/screenreadersurvey5/

White, R., & Harwin, W. (2012). *Haptics visualisation of scientific data for visually impaired users.* Paper presented at the International conference on disabilities, virtual reality and associated technologies, Laval, France, proc 9th.

WHO. 10 facts on ageing and the life course. Retrieved Feburary 1, 2015, from http://www.who.int/features/factfiles/ageing/ageing_facts/en/index3.html

Yu, W., Kangas, K., & Brewster, S. (2003). *Web-based haptic applications for blind people to create virtual graphs.* Paper presented at the Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2003. HAPTICS 2003. Proceedings. 11th Symposium on.

Zealand, N. (2014). National Strategy for Financial Literacy 2014.

13 Appendix A: Related Works

This section provides further details of some of the most significant studies that aim to make accessible charts and graphs for blind users using non-visual interfaces, such as natural language interfaces, haptic interfaces, and sonification interfaces.

Table 2: An overview of two natural language interfaces

Tool	**SIGHT**[21]	**iGraph**[22]
Graph Type	Bar graphs and line graphs	Bar graphs (including stacked), line graph, and combined bar and line graphs (for Statistics Canada's official release bulletin, The Daily[23])
Features	Works with JAWS Implemented as a browser extension (Internet Explorer) Automatically detects graphs Launched by a keystroke combination Provides a brief summary of the graphic (such as type of graph, number/label/height/colour of bars, labels of the axes); textural pieces (such as the chart caption) at the most relevant point in a multimodal article and enables the user to	Free, open source, extensible application Download required Produces short descriptions (English and French available) of graph using template-driven process according to the type of graph The description includes the most significant features, such as the minimum and maximum values as well as the general shape of the graph Allows the user to navigate all the

[21] For further details about the SIGHT project, please see the following publications: 1) *Access to Multimodal Articles from Popular Media for Individuals with Sight Impairments* (Carberry et al., 2012), 2) *Improving the Accessibility of Line Graphs in Multimodal Documents* (Greenbacker et al., 2011); 3)*Bar Charts in Popular Media: Conveying Their Message to Visually Impaired Users via Speech* (Elzer et al., 2009); 4) *Accessible Bar Charts For Visually Impaired Users* (Elzer et al., 2008)

[22] For further details about the iGraph project, please see the following publications: 1) *Evaluating a Tool for Improving Accessibility to Charts and Graphs* (Ferres et al., 2013); 2) *Improving Accessibility To Statistical Graphs* (Ferres et al., 2007)

[23] *The Daily* is Statistics Canada's official release bulletin, the Agency's first line of communication with the media and the public.

Tool	SIGHT[21]	iGraph[22]
	obtain more detailed follow-up information if desired Focuses on providing designer's intended meaning through processing communicative signals, rather than the actual number Sample summary: "This bar chart titled 'Credit-card debt leaps higher' shows that there is an increase in Jan '99 in the dollar value of 6-month growth in consumer revolving credit in contrast with the decreasing trend from July '97 to July '98"	information in a graph by means of keyboard commands. For example, the user can move right one point or move left one point, by clicking on arrow key, while using the S + digit to skip through data points Sample description: *"This is a vertical bar graph, so categories are on the horizontal axis and values on the vertical axis. The title of the chart is "Percentage change over 12 months in the Bank of Canada's core index." There are 13 categories in total on the horizontal axis. The vertical axis starts at 0.0 and ends at 3.0, with ticks every 0.5 points. There is only one series in this graph. The vertical axis is % change. The title of series 1 is "Canada" and it is a series of bars. The minimum value is 1.4 occurring in January. The maximum value is 2.5 occurring in June.*

Table 3: An overview of two haptic interfaces

Tool	**TSR**[24] (Terminate and Stay Resident) hard-copy system	**N/A**[25]
Graph Type	Bar graphs, line graphs, pie graphs	Bar graphs, line graphs
Features	TSR (Terminate and Stay Resident) hardcopy system that translates colour pixels on the screen into embossed dots on paper by braille printer plotter Colours are translated through tactile sensation Enables the blind to recognize the graphics on the screen and make colour Graphics program by oneself Requires a special program and Braille printer plotter	Automatically converts vector-based graphics into raised-line images The proposed algorithm extracts object boundaries and employs a classification process, based on a graphic's hierarchical structure, to determine critical outlines Critical outlines are embossed with Raised dots of highest height while other lines and details are embossed with a lower height Require special program and tactile printers or Braille printer

[24] For further details about the TSR project, please refer to *Computer Graphics for the Blind* (Ina, 1996)

[25] For further details about Krufka's project, please refer to *Visual to Tactile Conversion of Vector Graphics* (Krufka et al., 2007)

Table 4: An overview of three sonification interfaces

Tool	**AUDIOGRAPH**[26]	**N/A**[27]	**N/A**[28]
Graph Type	Bar graphs	Bar graphs and line graphs with two data series.	"Small and relatively simple" data samples
Sonification used	Music	Piano or trumpet	Pitch
Findings	Blind participants were able to identify shapes, and approximate size of each bar within a graph Took too long and too much effort to interpret musical messages	Blind participants were able to draw sketches of graphs containing two data series after listening to sonified versions of the graphs High accuracy rate (over 80%) in terms of capturing obvious trend Detailed trend or change is omitted partially or completely Features misplaced on axis	Simple auditory plots can effectively convey information about the basic characteristics of small samples of data Auditory function displays may be more efficient and accurate than tactile displays, if the user were given enough training

[26] *Communicating Graphical Information to Blind Users Using Music : the Role of Context* (Alty & Rigas, 1998)

[27] *Drawing by Ear: Interpreting Sonified Line Graphs* (Brown & Brewster, 2003)

[28] *Data Sonification from the Desktop: Should Sound be Part of Standard Data Analysis Software?* (Flowers et al., 2005)

14 Appendix B: Stock Market Charts Tested for Preliminary Research

Ten popular investment research websites were chosen to conduct the research, including Yahoo Finance, Google Finance, Bloomberg, Wall Street Journal, Bloomberg, Morning Star, The Street, CNBC, MSN Money, Financial Post, and The Globe and Mail.

Figure 13: The screenshot of the stock market chart from Yahoo Finance

Figure 14: The screenshot of the stock market chart from Google Finance

Figure 15: The screenshot of the stock market chart from Wall Street Journal

Figure 16: The screenshot of the stock market chart from Bloomberg

Figure 17: The screenshot of the stock market chart from MorningStar

Figure 18: The screenshot of the stock market chart from The Street

Figure 19: The screenshot of the stock market chart from MSN

Figure 20: The screenshot of the stock market chart from Financial Post

Figure 21: The screenshot of the stock market chart from Globe and Mail

Figure 22: The screenshot of the stock market chart from CNBC

15 Appendix C1 – Usability Testing Stage #1 Script

QUESTION

1. Do you use any specialized equipment or software to access your computer and mobile devices? How long have you been using them? And how often do you use them?

2. What types of activities do you do that require online access?

3. Have you ever tried to access and interpret charts and graphs online? What's your overall experience when working with charts and graphs? Does it matter to you? What are the greatest challenges for you?

4. Are you familiar with investment and stock market charts?

(If not, explain the data normally presented in a stock market chart)

ACTIVITY 1

Now, I am going to act like a screen reader and read a numeric table, which includes information about the price and volume of the stock Yahoo.

(Facilitator starts to read the following content)

Graphic Chart for Yahoo Inc. Yahoo! Inc. (YHOO) NASDAQ GS. 33.68, Graphic, Up, 0.04 (0.12%) 12:49PM EDT – NASDAQ Real Time Price.

Table with 5 columns and 20 rows.

Date (column 1 of 6), Open Price (column 2 of 6), Close Price (column 3 of 6), Day High (column 4 of 6), Day Low (column 5 of 6), Volume (column 6 of 6)

Row 2 of 20, (Date) May 28, (Open Price) 35.46, (Close Price) 34.21, (Day High) 36.02, (Day low) 33.72, (Volume) 16,294,000

(Following the same process for more rows)

Table 5: Historic price and volume of a stock

Date	Open Price	Close Price	Day High	Day Low	Volume
May 26	35.46	34.21	36.02	33.72	1,629,400
May 27	34.72	33.78	34.78	33.62	1,305,700
May 28	35.50	35.41	36.05	34.91	1,696,000
May 29	35.40	34.54	35.16	33.47	9,780,000
May 30	34.73	33.80	34.45	33.45	1,315,300
June 2	33.58	34.25	34.25	33.45	9,152,000
June 3	33.81	33.40	34.33	33.25	6,557,000
June 4	32.75	33.48	34.00	32.50	9,434,000
June 5	34.16	34.75	35.13	34.01	1,119,200
June 6	35.76	34.50	35.52	34.05	1,869,100
June 9	35.74	34.62	35.89	34.55	1,439,000
June 10	34.58	33.98	34.75	33.71	9,179,000
June 11	35.25	34.26	35.48	33.96	1,329,900
June 12	33.55	34.50	34.98	33.20	1,238,100
June 13	32.74	33.06	32.51	34.03	1,289,900
June 16	34.03	35.26	35.52	33.75	3,162,700
June 17	36.02	35.03	36.68	35.05	2,440,200
June 18	35.02	34.30	35.56	33.61	1,783,600
June 19	33.20	34.91	34.98	33.58	1,620,000
June 20	33.50	35.02	35.09	33.43	2,159,300
June 23	36.11	34.25	36.48	34.11	2,618,100

QUESTIONS (Continued)

5. Now that I have acted as a screen reader and have communicated the numeric table to you, can you tell me what you think about this approach? Do you like it or dislike it? What challenges did you have when I demonstrated this approach? And what are the things you wish to improve?

6. Now, I am going to demonstrate an alternative solution. This approach will start like this: “Graphic chart for Yahoo Inc. This graph presents information about the price and volume for Symbol Yahoo in the past 1 month. You can ask data about any specific day or the trend overall. What would you like to know?”

(Facilitator acts like a computer interface and let the participants ask a few questions. The facilitator will then answer the questions).

7. So, what do you think of this solution through which you can use your voice access graph? What do you think of this solution compared with the traditional screen reader solution? What do you like about it? What do you dislike about it?

8. Would you please rate the the propsed solution in terms of helping you get access and interpreting stock market charts and graphs online?

Effectivness

O 5 - High effectiveness

O 4

O 3

O 2

O 1 - Not at all Effective

Usefulness

- O 5 - Very useful
- O 4
- O 3
- O 2
- O 1 - Not at all useful

Likelyhood to use?

- O 5 - Very likely
- O 4
- O 3
- O 2
- O 1 - Not at all likely

9. Have you used any kind of voice recognition application before?

   - O Yes
   - O No

   (If Yes) What was the experience like? What do you like about it? What are the things you wish could be improved?

10. Can you describe your vision impairment?

16 Appendix C2 – Usability Testing Stage #2 Script

QUESTION

1. Do you use any specialized equipment or software to access your computer and mobile devices? How long have you been using them? And how often do you use them?

2. What types of activities do you do that require online access?

3. Have you ever tried to access and interpret charts and graphs online? What's your overall experience when working with charts and graphs? Does it matter to you? What are the greatest challenges for you?

4. Are you familiar with investment and stock market charts?

(If not, explain the data normally presented in a stock market chart)

ACTIVITY 1

(For screen magnifier users)

We will now ask you to go to your computer. You will be visiting a Yahoo Finance webpage that contains investment information and a stock chart, that represents the price and volume of Google Inc. Please take a few minutes to get familiar with the chart/numeric table. I will then ask you to complete a few tasks related to the chart/numeric table.

http://finance.yahoo.com/echarts?s=GOOG+Interactive#%7B%22scale%22%3A%22linear%22%7D

(For screen reader users)

We will now ask you to go your computer. You will be visiting a webpage that contains a stock market chart, which represents the price and volume of Google Inc. Since the graph is an image, the webpage also provides a numeric table that contains all the data points used to generate the chart. Please take a few minutes to get familiar with the chart/numeric table. I will then ask you to complete a few tasks related to the chart/numeric table.

http://www.hongzou.com/REB/pilotstudy

Are you ready to start the task? Please speak aloud and share your thoughts while completing your task. We are interested to know your opinions on both the positive and negative features of the pages.

QUESTIONS (Continued)

5. What is the highest volume in the past 6 months and when did it happen?

6. What's the closing price for Google on June 27 and May 27? How much did the price change by? Please answer in percentage and amount?

7. Can you describe the overall trend in the past 6 months?

8. You just tried to access charts and graphs using XXX. What do you think about this approach? What do you like about it? What do you dislike about it?

ACTIVITY 2

Now I am going to demonstrate an alternative solution to presenting graph information. This approach will have a text input box near the chart/numeric table, and you will be able to type your questions about the chart and then get the answer.

(Facilitator acts like a computer interface and let the participants ask a few questions. The facilitator will then answer the questions.)

QUESTIONS (Continued)

9. I just demonstrated an alternative solution through which you can access the stock market charts and graphs by using text input. What do you think about this approach? What do you like about it? What do you dislike about it?

10. Would you please rate the the propsed solution in terms of helping you get access and interpret stock market charts and graphs online?

Effectivness

O 5 - High effectiveness

O 4

O 3

O 2

O 1 - Not at all Effective

Usefulness

O 5 - Very Useful

O 4

O 3

O 2

O 1 - Not at all Useful

If this solution were available on the next graph you encountered, how likely would you be to use this application?

- O 5 –Extremely likely
- O 4
- O 3
- O 2
- O 1 – Not at all Likely

11. What do you think of this solution compared with the traditional Screen Reader Solution?

12. I am also thinking of using voice input methods. For example, you can ask "highest price of Yahoo in the past 6 months" or "overall trend from May 27 to June 27", etc. What do you think about this solution?

13. Have you previously used any sort of voice recognition application? (Provide examples if necessary: using your voice to dial a number in a car, Siri on your phone, or Dragon Naturally Speaking)

    - O Yes
    - O No

    (If Yes) What was the experience like? What do you like or dislike about it? What are the things you wish could improve?

14. Please describe your vision impairment

17 Appendix C3 – Usability Testing Stage #3 Script

QUESTION

1. Do you use any specialized equipment or software to access your computer and mobile devices? How long have you been using them? And how often do you use them?

2. What types of activities do you do that require online access?

3. Have you ever tried to access and interpret charts and graphs online? What's your overall experience when working with charts and graphs? Does it matter to you? What are the greatest challenges for you?

4. Are you familiar with investment and stock market charts?

(If not, explain the data normally presented in a stock market chart)

ACTIVITY 1

(For screen magnifier users)

We will now ask you to go to your computer. You will be visiting a Yahoo Finance webpage that contains investment information and a stock chart, that represents the price and volume of Google Inc. Please take a few minutes to get familiar with the chart/numeric table. I will then ask you to complete a few tasks related to the chart/numeric table.

http://finance.yahoo.com/echarts?s=GOOG+Interactive#%7B%22scale%22%3A%22linear%22%7D

(For screen reader users)

We will now ask you to go to your computer. You will be visiting a webpage that contains a stock market chart, which represents the price and volume of Google Inc. Since the graph is an image, the webpage also provides a numeric table that contains all the data points used to generate the chart. Please take a few minutes to get familiar with the chart/numeric table. I will then ask you to complete a few tasks related to the chart/numeric table.

http://www.hongzou.com/REB/pilotstudy

Are you ready to start the task? Please speak aloud and share your thoughts while completing your task. We are interested to know your opinions on both the positive and negative features of the pages.

QUESTIONS (Continued)

5. What is the highest volume in the past 6 months and when did it happen?

6. What's the closing price for Google on June 27 and May 27? How much has the price changed by? Please answer in percentage and amount?

7. Can you describe the overall trend in the past 6 months?

8. You just tried to access charts and graphs using XXX. What do you think about this approach? What do you like about it? What do you dislike about it?

ACTIVITY 2

Now I am going to demonstrate an alternative solution to presenting graph information.

Let's say you landed on the same page you just tried a moment ago; however, this time, the graph provides a series of dropdown menus through which you can "ask" questions you have regarding the stock market charts and graphs.

To start using this tool, you need to first choose what you want to do:

- Do you want to know a specific data point, like what I explained before, highest price, lowest volume, overall trend? Or do you want to compare metrics between different symbols? Or compare with data points of the same symbol but within a different timeframe.

- After that, you need to choose the timeframe. For example, do you want to know the highest price within the past 6 months or the past week, or between two specific data points?
- Finally, you can choose to acquire information about price, volume and trend.

Let's say you want to know the highest price in the past 12 months, you would need to choose "Specific Data" in "Ask for" dropdown menu, and then "1 year" in "Time Frame" dropdown, and then "Highest" in "Price" dropdown.

And if you want to know how your stocks perform between Aug 24, 2013, to September 24, 2013, then you need to choose "Compare with the same symbol" in "Ask for" dropdown, and then "From Aug 24, 2013 to September 24, 2013" in "Time Frame" drop down, and then "Closing" in "Price" dropdown.

Any questions? How about I act as a computer interface and you can interact with me in order to find out some information about the graph?

(Facilitator acts like a computer interface and let the participants ask a few questions. The facilitator will then answer the questions.)

9. I just demonstrated an alternative solution through which you can access the stock market charts and graphs by using dropdown menus. What do you think about this approach? What do you like about it? What do you dislike about it?

10. Would you please rate the the propsed solution in terms of helping you get access and interpreting stock market charts and graphs online?

Effectivness

O 5 - High effectiveness
O 4
O 3
O 2
O 1 - Not at all Effective

Usefulness

- O 5 - Very Useful
- O 4
- O 3
- O 2
- O 1 - Not at all Useful

If this solution were available on the next graph you encountered, how likely would you be to use this application?

- O 5 – Extremely likely
- O 4
- O 3
- O 2
- O 1 – Not at all Likely

11. What do you think of this solution compared with the traditional Screen Reader solution?

12. I am also thinking of using voice input methods. For example, you can ask “highest price of Yahoo in the past 6 months” or “overall trend from May 27 to June 27”, etc. What do you think about this solution?

13. Have you previously used any sort of voice recognition application? (Provide examples if necessary: using your voice to dial a number in a car, Siri on your phone, or Dragon Naturally Speaking)

    - O YES
    - O No

    (If Yes) What was the experience like? What do you like or dislike about it? What are the things you wish could improve?

14. In addition to voice input, I was also thinking of letting the user type their questions instead of using dropdown. What do you think about this solution?

15. Among dropdown menu, voice input, and text input, which one is your favourite method?

16. Please describe your vision impairment.

18 Appendix C4 – Usability Testing Stage #4 Script

QUESTION

1. Do you use any specialized equipment or software to access your computer and mobile devices? How long have you been using them? And how often do you use them?

2. What types of activities do you do that require online access?

3. Have you ever tried to access and interpret charts and graphs online? What's your overall experience when working with charts and graphs? Does it matter to you? What are the greatest challenges for you?

4. Are you familiar with investment and stock market charts?

(If not, explain the data normally presented in a stock market chart)

ACTIVITY 1

(For screen magnifier users)

We will now ask you to go to your computer. You will be visiting a Yahoo Finance webpage that contains investment information and a stock chart, that represents the price and volume of Google Inc. Please take a few minutes to get familiar with the chart/numeric table. I will then ask you to complete a few tasks related to the chart/numeric table.

http://finance.yahoo.com/echarts?s=AAPL+Interactive#

(For screen reader users)

We will now ask you to go to your computer. You will be visiting a webpage that contains a stock market chart, which represents the price and volume of Apple Inc. Since the graph is an image, the webpage also provides a numeric table that contains all the data points used to generate the chart. Please take a few minutes to get familiar with the chart/numeric table. I will then ask you to complete a few tasks related to the chart/numeric table.

http://www.zouhong.com/REB/Prototype/V2/chart_master.html

Are you ready to start the task? Please speak aloud and share your thoughts while completing your task. We are interested to know your opinions on both the positive and negative features of the pages.

QUESTIONS (Continued)

5. What is the highest volume in the past 6 months and when did it happen?

6. What's the closing price for Google on June 27 and May 27? How much has the price changed by? Please answer in percentage and amount?

7. Can you describe the overall trend in the past 6 months?

8. You just tried to access charts and graphs using XXX. What do you think about this approach? What do you like about it? What do you dislike about it?

ACTIVITY 2

Now I am going to demonstrate an alternative solution to present graph information.

On the webpage you just visited, you will find a tool "ChartMaster". This tool uses a combination of dropdown menus to acquire information about price, volume and trend for one specific symbol or to compare between two symbols.

Let's say you landed on the same page you just tried a moment ago; however, this time, the graph provides a series of dropdown menus through which you can "ask" questions you have regarding the stock market charts and graphs.

To start using this tool, you need to first choose what you want to do:

- Do you want to know a specific data point, like what I explained before, highest price, lowest volume, overall trend? Or do you want to compare metrics between different symbols? Or compare with data points of the same symbol but within a different time frame.

- After that, you need to choose the timeframe. For example, do you want to know the highest price within the past 6 months or the past week, or between two specific dates?
- Finally, you can choose to acquire information about price, volume and trend.

Let’s say you want to know the highest price in the past 12 months, you would need to choose “Specific Data” in “Ask for” dropdown menu, and then “1 year” in “Time Frame” dropdown, and then “Highest” in “Price” dropdown.

And if you want to know how your stocks perform between Aug 24, 2013, to September 24, 2013, then you need to choose “Compare with the same symbol” in “Ask for” dropdown, and then “From Aug 24, 2013 to September 24, 2013” in “Time Frame” drop down, and then “Closing” in “Price” dropdown.

Any questions? How about you play with the alternative solution a little bit? I will then ask you to find out some information presented on this page, like the activity we just did using XXXX?

QUESTIONS (Continued)

9. What is the highest volume in the past 6 months and when did it happen?

10. What’s the closing price for Apple on June 27 and May 27? How much did the pricechanged by? Please answer in percentage and amount?

11. Can you describe the overall trend in the past 6 months?

12. You just tried to access the stock market charts and graphs by using dropdown menus. What do you think about this approach? What do you like about it? What do you dislike about it?

13. Would you please rate and compare the the propsed solution and the XXX solution (the typical solution) in terms of helping you get access and interpret stock market charts and graphs online? (*5 highly agree, 1 totally disagree)

Table 6: Rate the typical solution and dropdown menu solution

	Typical solution*	Dropdown menu solution*	Comments
Easy to use	O 5 O 4 O 3 O 2 O 1	O 5 O 4 O 3 O 2 O 1	
Easy to learn	O 5 O 4 O 3 O 2 O 1	O 5 O 4 O 3 O 2 O 1	
Effectivness	O 5 O 4 O 3 O 2 O 1	O 5 O 4 O 3 O 2 O 1	
Usefulness	O 5 O 4 O 3 O 2 O 1	O 5 O 4 O 3 O 2 O 1	
Likelihood to use	O 5 O 4 O 3 O 2 O 1	O 5 O 4 O 3 O 2 O 1	

	Typical solution*	Dropdown menu solution*	Comments

14. I am also thinking of using voice input methods. For example, you can ask “highest price of Yahoo in the past 6 months” or “overall trend from May 27 to June 27”, etc. What do you think about this solution?

15. Have you previously used any sort of voice recognition application? (Provide examples if necessary: using your voice to dial a number in a car, Siri on your phone, or Dragon Naturally Speaking)

    O Yes
    O No

    (If Yes) What was the experience like? What do you like or dislike about it? What are the things you wish could improve?

16. In addition to voice input, I was also thinking of letting the user type their questions instead of using dropdown. What do you think about this solution?

17. Among dropdown menu, voice input, and text input, which one is your favourite method?

18. Please describe your vision impairment.

19 Appendix D: Accompanying Material

This MRP contains accompanying material: a CD of the latest version of the **ChartMaster** prototype developed and tested during the study[29].

To run **ChartMaster**, please copy all files in the CD into a computer harddrive, and then open chart_master.html in a web browser such as Internet Explorer, Firefox, or Chrome.

You need to have a screen reader application, such as JAWs or NVDA installed in your computer to see how **ChartMaster** works with screen reader.

[29] Accompanying material: The following accompanying material is available upon request from the OCAD University Library: **ChartMaster** Prototype. Anyone requesting the material may view it in the OCADU Library or pay to have it copied for personal use.