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Citizen engagement through tangible data representation

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Citizen Engagement through Tangible Data Representation

Participación ciudadana interactiva y recíproca a través de la representación tangible de datos

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Abstract: We begin with the premise that data literacy is a fundamental facet of citizen education in this information age, and that an engaged citizenry in a democracy not only requires access to data, but also the capacity to manipulate and examine the data from multiple perspectives. The visualization of data elucidates trends and patterns in the phenomena that the data represents, and opens accessibility to understanding complicated human and natural processes represented by data sets. Research indicates that interacting with a visualization amplifies cognition and analysis. A single visualization may show only one facet of the data. To examine the data from multiple perspectives, engaged citizens need to be able to construct their own visualizations from a data set. Many tools for data visualization have responded to this need, allowing non-data experts to manipulate and gain insights into their data, but most of these tools are restricted to the computer screen, keyboard, and mouse. Cognition and analysis may be strengthened even more through embodied interaction with data. We present here the rationale for the design of a tool that allows users to probe a data set, through interactions with graspable (tangible) three-dimensional objects, rather than through a keyboard and mouse interaction. We argue that the use of tangibles facilitates understanding abstract concepts, and facilitates many concrete learning scenarios. Another advantage of using tangibles over screen-based tools is that they foster collaboration, which can promote a productive working and learning environment. We speculate that collaborative data exploration can be a productive educational activity for citizens in their communities and in the classroom, and we suggest our tool as a means to do this.

Keywords: data literacy; citizen engagement; citizen data; data sculpture; tangible user interface; democracy and education; citizenship education.

Resumen: Partimos de la premisa de que la alfabetización informativa es una faceta de la educación ciudadana en la era de la información, y que el compromiso ciudadano en una democracia no sólo requiere de acceso a la información, sino también de la capacidad de manipular y examinar la información desde diferentes perspectivas. La visualización de información dilucida tendencias y patrones dentro del fenómeno que representa la información, y abre la posibilidad de acceder a la compleja comprensión por medio de los conjuntos de datos de los procesos humanos y naturales. La

investigación señala que la interacción con una visualización amplifica la cognición y el análisis. Una visualización simple puede mostrar solo una faceta de la información. Para analizar la información desde múltiples perspectivas, los ciudadanos comprometidos necesitan ser capaces de construir su propia visualización a partir del conjunto de datos. Muchas herramientas para la visualización de información han respondido a esta necesidad, permitiendo a inexpertos en el manejo de la información, manipular y ganar conocimiento sobre su información, aunque la mayoría de estas herramientas se restringen a la pantalla del ordenador, el teclado y el ratón. La cognición y el análisis pueden ser fortalecidos aún más mediante la interacción del cuerpo y la información. Por ejemplo, con un sistema que te deje explorar datos digitales en una pantalla con el reordenamiento de objetos concretos, o con gestos expresivos. Presentamos en este trabajo el desarrollo lógico para el diseño de una herramienta que permita a los usuarios poner a prueba el conjunto de información mediante interacciones con objetos tridimensionales tangibles, que permitan ir más allá de la interacción con el teclado y el ratón del ordenador. Nuestro argumento es que el uso de objetos tangibles facilita la comprensión de conceptos abstractos, y hace accesibles escenarios de aprendizaje concretos. Otra ventaja de usar objetos tangibles en comparación con el uso de herramientas propias de la pantalla del ordenador es que fomentan la colaboración, lo cual puede promover un contexto de trabajo y aprendizaje productivo. Lo cual nos lleva a pensar que abordar la información desde una perspectiva colaborativa puede ser una actividad educativa productiva para los ciudadanos en sus comunidades y en el aula escolar, y proponemos nuestras herramientas como un medio para hacer esto.

Palabras clave: alfabetización informativa; compromiso ciudadano; información ciudadana; escultura informativa; interfaz tangible de usuario; democracia y educación; educación ciudadana.

1. Introduction

The notion that education is key to democratic institutions, where a knowledgeable electorate is vital, dates back to antiquity. The importance of an informed citizen has been reinforced by various authors in considering modern Western institutions (Dewey, 1997). John Dewey, for example, developed the notion of a relationship between democracy and education. He understood democracy as an ethical ideal, «…more than a form of government; it is primarily a mode of associated living, of conjoint communicated experience» (Dewey, 1997, p. 87), with inquiry permeating the spirit of democracy. A healthy democracy is one therefore one in which citizens are actively engaged. Citizen education is a life-long learning process that supports informed inquiry and citizen engagement.

In our information age, citizen engagement requires engagement with data. Public data collected by various levels of government can be a useful tool for education and civic participation, distributed in the service of government transparency. Most major urban municipalities and a number of provincial, state and national governments have launched open data initiatives («Open Data - Accessing City Hall | City of Toronto», 2015; «State of New York | Open Data», 2015; Government of the United Kingdom, 2015). The rationale behind these initiatives is similar and each speaks to the need for educating and mobilizing the public. The government of the United Kingdom makes public data available «to help people understand how government works and how policies are made» (Government of the United Kingdom, 2015), a goal similar to other constituencies where the belief is that by making data available to citizens, they will be able to

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better understand the information used by policy makers and legislators in the administration of government. If citizens have access to the same information that government can access, it follows that our understanding of government decisions will be more informed.

Unfortunately, there are a number of issues with open data, including limitations on the data that is available (there is currently no government that allows access to all the collected data), the proprietary nature of data formats (such as PDF or MSWord, formats owned by large corporations), and the lack of data literacy among citizens. The digitization of information has allowed citizens to access information necessary for making informed choices. However, tools are needed to bridge the data literacy gap and to render the data useable by non-experts. It is one thing to make dataset available, but it is another to expect all citizens to understand how a dataset may be accessed, manipulated, and used in the service of understanding government. Research in Human Computer Interaction (HCI) has addressed this question from multiple perspectives, from efforts to create a universal infrastructure for all open data (Espinosa *et al.*, 2014), to efforts to better communicate the data with user interface design and data visualization. The latter is the topic of our own research and of this paper.

Visualization is recognized as an effective means to understand and communicate data, particularly complex data, since visualization leverages our perceptual cognition (Ware, 2012) and can represent large quantities of data that would otherwise be incomprehensible. This makes the visualization of open data a promising endeavor. Representing data by visual means allows us to find patterns which may be obfuscated by non-visual means. With this in mind, various authors argue that the visualization of data represents a key opportunity for promoting civic engagement (Zambrano, Engelhardt 2008; Lewis, 2013; Bohman 2015), where education is a precursor of engagement.

Public visualizations have been proposed and used to help citizens better understand urban issues, with promising results (Moere, Hill, 2012) and a recent study found that visualization interfaces, situated in public spaces led to improved perception, sustained behavior change, increased social awareness and discourse (Valkanova, Jorda, Vande Moere, 2015). In addition, the authors found that public visualizations led to meaningful participation with government as well as a range of social interactions related to locally relevant topics. The visualization of data allows for heightened perception and the identification of patterns and findings. The public display of data may increase dialogue or collaboration – arguably an indication of informed civic engagement.

However, while visualizations are excellent communicators of data, the full democratization of data requires that citizens have the tools to manipulate

and explore data sets independently, because a single visualization, supplied by authorities, may show only one facet of the data. To examine the data from multiple perspectives, and in some contexts, to input their own data, citizens need to be able to examine the data set independently, either through the interactive affordances of the visualization or by constructing their own visualizations from a data set. Raw data files, particularly when available in open (non-proprietary) formats, require tools to read and manipulate. The development of tools to interactively manipulate data is therefore an important part of the movement towards data democratization.

One important recent initiative towards the democratization of data is the non-profit venture Gapminder (Rosling, 2008). At gapminder.org, visitors can access a repository of data on the health and wealth of every nation in the world over several years (the data includes over 400 socio-economic indicators, such as GDP per capita, life expectancy, unemployment rates, energy consumption, and education.) Visitors can either download the data or view it using Gapminder World, Gapminder's proprietary online visualization software. Gapminder World is an animated visualization allowing users to interactively explore relationships between two or three different measures, by country and by year. This tool has been successfully used in public health education initiatives (Rosling, Zhang, 2011). Gapminder World has also been used as a classroom tool to teach students geography (Keller, 2012) and statistics (Le, 2013).

While Gapminder World is a useful visualization tool for two-dimensional computer screen interaction, we are curious about exploring other modalities for interacting with data. In particular, we believe cognition and analysis may be strengthened through embodied interaction with data. Embodied interaction with data also fosters collaboration, which contributes to pleasurable user experiences and augments problem-solving abilities; fostering collaboration can strengthen democratic discourse. In this paper we present work conducted in the Visual Analytics Lab at OCAD University where we have developed a tool for interrogating data sets using graspable 3-dimensional objects (tangibles). There is an extensive body of research, reviewed here, suggesting that tangibles foreground opportunities for collaboration and engagement. The rationale for our design work is based on the premise that the physical manifestation of data, and the manipulation of data through interaction with graspable objects, supports collaborative behavior and may lead to an improved understanding of a particular data set.

2. Three-dimensional affordances: Why 3D?

A well-designed tool is one that optimizes human performance by leveraging innate human abilities. For example, a pair of scissors is designed to fit into a human hand and to make optimal use of its natural motion. Humans have evolved sophisticated skills for sensing and manipulating their environment, and therefore, to optimize our digital tools, it is expected that we should start designing them to engage our sense of touch and three-dimensional space (Sharlin *et al.*, 2004). Currently, most of our digital technology is confined to screens, pointers, and keyboards, but the standard interface is rapidly moving towards the touch screens, which take advantage of our intuitive gestures and allow us to apply our sense of touch to the task (Wigdor, Wixon, 2011; Weiyuan Liu, 2010). The current phase of development is in ubiquitous computing and the internet of things (Olson, Nolin, Nelhans, 2015), using everyday objects to interact with data and using natural gestures to formulate operations.

The idea of using physical objects to enhance learning dates back to Friedrich W. Fröbel's (1782-1852) pedagogic «gifts» – objects presented to the children to illustrate mathematical concepts (Huron *et al.*, 2014). Jean Piaget (1896-1980), who believed that children learn naturally by manipulating and experimenting with physical objects, later reinforced this notion. More recent studies have shown that handling and interacting with physical objects may also benefit adult learning (Chapman, 1988).

In the following sections, we present a review of systems that engage three-dimensionality and tangible affordances and discuss how they affect cognition, learning, engagement, and collaboration. Then we present our work within this context and discuss its affordances as a tool for collaborative data analysis. Our vision is to create a tool that supports citizen education by facilitating data exploration, and that supports informed citizen engagement by providing a learning platform for group discussions.

3. Physical representations

We start the literature review with a look at physical data representation. Physical data representation (also known as physical visualization) is the materialization of data into physical artifacts («Data Sculpture | List of Physical Visualizations», 2015). Rather than representing the data visually as a graphic display, the data is manifested as a material, a 3D physical object. Mesopotamian clay tokens, dated to 5500 BC, may have been the first data visualizations, whereby people represented information by grouping and

arranging the tokens (Schmandt-Besserat, 1999). While physical representations are not as ubiquitous as their two-dimensional graphical counterparts for expert use, physical visualizations have played an important role in education and in communicating information to the general public. Hans Rosling, for example, founder of Gapminder, uses physical objects in some of his public lectures to convey important public health information about population growth (Hans Rosling, 2010); watching the objects accumulate on the stage clearly conveys the meaning of the numbers and their impact.

One way in which physical representations help us better grasp abstract notions is by using a concrete or metaphoric scale, whereby abstract ideas are mapped onto everyday relatable objects (Chevalier, Vuillemot, Gali, 2013). One simple example of using a concrete scale in a physical visualization is to use sugar cubes to represent the amount of sugar contained in soft drinks and other foods (Chevalier, Vuillemot, Gali, 2013). Seeing the numbers of sugar cubes contained in a CocaCola may have a stronger cognitive impact than reading the grams of sugar contained on the label. Use of a concrete scale is also an effective means to convey large numbers, which are abstract notions until we can see their physical manifestation. One striking example is the art work «All the people in the world» by artist collective «Stan's Café», in which they represent the world human population with grains of rice – one grain of rice represents one person (Stan's Café, 2013). They use the grains of rice to discuss the effects of climate change: to show how many people will be impacted by rising sea levels for example. Depending on the exhibition, they discuss various social issues, and use the grains of rice to illustrate a wide variety of demographical information, such as the populations of various towns and cities, the number of doctors, the number of soldiers, the number of people born each day, the number who die, or the deaths in the holocaust. Physical representations have also been used to inform the public about political and sociological issues. In October 2015, the New York Times ran a story about the extent of influence that only 158 families have in the United States; only 158 families donated more than half of the total election campaign money. The authors use pieces from the classic board game Monopoly to represent 158 families amid the total 120 million families in the United States to illustrate the extent of the oligarchy (Cohen, Yourish, 2015). The Brookings Institute has launched public outreach videos using lego blocks to represent data; for example, one video illustrates the income inequality in the United States and shows the limited extent to which taxes help in reducing it («How Much Does the Tax Code Reduce Inequality?», 2015).

In a second category of physical representation, spatial dimensions are used to represent data. Loren Madsen's 1995 sculpture CPI, for example, is a sculptural 3 dimensional graph of housing prices, food prices, and fuel prices over a 2 decade

period (Loren Madsen, 1995). In another example, Andreas Fischer's Fundament sculpture is a three dimensional topographical map of the world financial market («Fundament – Financial Data Sculpture / Andreas Nicolas Fischer», 2015).

Some physical representations of data fall into a branch of information visualization entitled «casual visualization» (Pousman, Stasko, Mateas, 2007), in which the information is not directed at an expert user for a specific task, but at the general public for education and contemplation. Casual visualizations may be a misleading term because such works are actually quite interactive. They include any kind of public display of information with which a user is free to engage, including art works and ambient representations. Ambient representations of data are interventions that are embedded into the environment in a way that is not distracting and aesthetically pleasing (Zachary, Pousman, Stasko, 2006). An example of an ambient data representation is the weather beacon on top of the Canada Life building in Toronto, Canada. It blends unobtrusively into the cityscape while also conveying information. Lights moving upward means the temperature is going up, lights moving downward means the temperature is decreasing. There has been a move recently to use ambient visualizations in interior design of homes or workspaces to help people be more mindful of their energy consumption habits (Rodgers, Bartram, 2011). Similarly, physical representations of energy consumption was identified as a means to inform users of their own use of energy and to potentially influence behavior (Szigeti, Davila, 2013).

Some have argued that physical data representations, by existing in the same dimensional space as the viewer, encourages people to reflect on the data's meaning and provides a more enjoyable and engaging experience compared to their 2d graphical counterparts (Zhao, Moere, 2008). The aesthetic engagement afforded by physical representations has made it a fruitful subject of many art works. Perhaps one of the earliest and simplest examples of data art is Hans Haake's MOMA Poll at the Museum of Modern Art in New York in 1970, in which he let viewers enter ballots into transparent containers; as ballots accumulated, the results of the poll were clearly visible (Hans Haacke, 1970). In more conceptual social works, physical representations can viscerally convey a social message with the use of metaphor. For example, in May 2015, a pop up art exhibition in Los Angeles entitled 'Manifest Justice' featured an installation of 22 prison uniforms juxtaposed against one university graduation gown, with a sign above it reading: «Since 1980, California has built 22 prisons, and one university» (Posted by Eye Candy on May 12 and Blog 2015) The image of the metaphoric objects and their quantities gives the viewer a visceral understanding of the government's spending priorities.

With the advent of 3D printing, the creation of physical visualizations is becoming more accessible to the general public. Recent progresses in physical data representation finds ways of adapting their use to everyday life, such as the data sculptures by Stusak *et al.* that are designed to track running activity (Stusak *et al.*, 2014); their three-week field study found that participants engaging with their data sculptures not only encouraged their running activity but generated curiosity and experimentation.

Physical representations of data, in addition to being aesthetically engaging, may offer more intuitive approaches to data analysis and lead to insights into data sets (Vande Moere, 2008). Empirical evaluations have found that in some circumstances they outperform on-screen equivalents when retrieving information and that the component of touch appears to be a key cognitive aid (Jansen, Dragicevic, Fekete, 2013). Jansen *et al.* compared sculptures of 3-dimensional bar graphs with their onscreen equivalent, and found that people were able to retrieve data more rapidly from the sculptural forms. Other recent studies have found that engaging students with the production of physical representations enhances their understanding of statistics (Gwilt, Yoxall, Sano, 2012).

4. Tangible interfaces

Tactility is an important part of the engagement that physical representations of data offer when the data sculptures are scaled for personal use, as seen in the examples of (Jansen, Dragicevic, Fekete, 2013; Gwilt, Yoxall, Sano, 2012; Stusak *et al.*, 2014) discussed above. While in those examples, users were able to touch the data sculptures, the data itself was manipulated digitally before it was manifested physically. In this section, we look at exploring ways to physically manipulate data.

One ancient and well-known example of physical data manipulation is the abacus, an instrument in which beads are manipulated to carry out arithmetic calculations. Another example of tactile data manipulation is described by Huron *et al.*, who presented a paradigm they call «constructive visualization» (Huron *et al.*, 2014), in which users build physical representations of data from the bottom up, using tokens (such as Lego blocks) to represent individual units of data. While this paradigm is a useful formulation for understanding taxonomies of data representations and interactions, their system does not bridge into the digital world, which limits the volume and variety of data that can be represented.

In 1997, Ishii and Ullmer proposed the concept of «tangible bits» (Ishii, Ullmer, 1997), in which computational bits are coupled with graspable physical objects. Since then, many have stepped up to the design challenge of creating

system that extends the affordances of physical objects into the digital domain (Ishii, 2008). For example, at MIT's media lab, the tangible media group has created inForm, an interactive shape-changing system that users can interact with through touch, which also changes form in response to the users' interactions (Follmer *et al.*, 2013).

It is interesting to note from these examples, from the abacus to constructive visualizations, to inForm, that as the user manipulates data, there is not always clear distinction between input and output: the answer to the query does not appear all at once, but rather the system transforms over time to represent the answer. This is actually a typical feature of analog tangible systems; it is only in the digital world where there is a clear distinction, a dichotomy, between input and output *(Sharlin et al.*, 2004). Tangible user interfaces aim to use tactility to engage the user, but they can also aid cognition by introducing some fluidity between user input and data output (Szigeti *et al.*, 2014).

Tangible User Interfaces (TUI) are broadly defined as graspable 3D physical objects with which to interact with data, often digital data. Currently, there is no standard protocol for using the manipulation of physical objects to interact with digital data. Shaer *et al.* (Shaer *et al.*, 2004) made an effort to conceptually define a paradigm for standardizing TUI inputs with what they called a Token and Constraint system (Ullmer, Ishii and Jacob 2005). Tokens are physical objects that are handled to access or manipulate the digital data, and constraints limit the way in which the user interacts with the token. Constraints set the framework of how the user manipulates the tokens, and ideally, they should be designed to express the set of operations that can be performed on the digital data (Jacob *et al.*, 2008).

Many proponents for TUI in the learning environment assume a Piagetian model of children's development in which there is a concrete operational stage that will benefit from manipulating physical materials. These claims, however, have not been extensively tested (Marshall, 2007). Research in TUI for learning applications seeks to clarify which specific elements of tangible interface design support learning. For example, tangible interfaces may augment student engagement with learning tasks (Shaer and Hornecker, 2010). In one study for example engagement was significantly increased in digital learning tools when children are allowed to use their everyday physical play objects to interact with the digital information. In these cases, learning outcomes improve from the increased engagement with the lessons.

While TUI have been shown to enhance learning, it is important to note the importance of the context in which the tool is used. TUI are excellent to support hand-on learning and constructivist knowledge discovery, but one recent study

shows that the way in which they are used makes a significant impact on the learning outcomes (Bertrand Schneider, Bumbacher, Blikstein, 2015). In this study, observations are made on students learning about the anatomical structure of the inner ear canal by manipulating and connecting parts of the auditory system to rebuild a functional structure. The students are separated into two groups. In one group, they are guided with instructions on how to assemble the structure, and in another group, they assemble the structure independently through self-discovery. The latter group significantly outperformed the former (Schneider, Bumbacher, Blikstein, 2015), showing that a poor lesson plan will have an impact on learning outcomes independent of the learning tools used.

As learning tools, tangible interfaces have been shown to encourage activities and behaviors that augment learning and problem solving. Schneider found that outcomes in solving logic puzzles are improved when interacting with a tangible interface compared to a working on a touch-screen (Schneider *et al.*, 2011). These studies, however, also noted that the participants using the tangible interface worked on the puzzles much more collaboratively than those using the multi-touchscreen, which suggests that the collaboration was the key factor that improved outcomes, and that using the tangible interface fostered the collaboration.

5. Tangibles and Collaboration

We are particularly interested in the role of collaboration, which many studies suggest may be a key differentiator between tangible and screen-based interfaces (Hornecker, Buur, 2006; *Lee et al.*, 2012). Collaboration interests us for two reasons. One, the ability to work collaboratively and organize is essential for meaningful public participation in a democracy. Two, there is an empirical correlation between collaborative problem solving and improved learning outcomes (Schneider *et al.*, 2011). Many of the physical representations of data discussed earlier respond to individual and group and interaction, creating highly collaborative experiences.

Tangible interfaces measurably increase collaborative behavior. A recent study using eye-tracking devices found that participants working in small groups on a problem-solving task experienced more moments of joint visual attention when working with graspable movable objects on a tabletop than when working with a screen-based interface (Schneider *et al.*, 2015).

It should be noted that the amenability of tangible interfaces for collaborative work has made them promising tools for facilitating collaboration over long distances by augmenting teleconferencing (see for example Bouabid *et al.*, 2014; Gonzalez-Franco *et al.*, 2015), and for strengthening communications in co-

located meetings by means of smart boards and digital Post-It notes (see for example Haller *et al.*, 2010). MIT Media Lab's inFORM is a dynamic shape display that can render 3D content physically, so users can interact with the physical world around it, for example moving objects on the table's surface (Leithinger *et al.*, 2014). Remote participants in video conferencing can be physically displayed, allowing a strong sense of presence.

Interestingly, the eye-tracking study by Schneder *et al.* (2015) that measured increased joint visual attention with the use of tangibles also suggested that there was a correlation between joint visual attention and learning outcomes. Previous empirical studies have shown that using tangible interfaces usually results in better task performance of the group, but using them did not always affect the learning outcomes of the individuals (Do-Lenh *et al.*, 2010). Other studies have shown that the collaboration fostered by TUI may improve creative outcomes. Kim and Maher, for example, compared Graphical User Interfaces (GUI) with TUI in study participants that were assigned a collaborative design task, and they found that the groups using TUI performed multiple cognitive actions in a shorter time, made more unexpected discoveries of spatial design features, and exhibited more problem-finding behaviours (Kim, Maher, 2008).

## 6. Our tool – a tangible interface for interactive data query

The body of literature reviewed above suggests that TUIs ability to engage people, to help process abstract concepts, and to foster collaboration could make them useful for citizen data exploration. Interestingly, while the use of tangible interfaces has been extensively explored in gaming applications (not discussed here), in pedagogical applications (discussed above), and in communications (mentioned above), there has been comparatively little work done in using tangible interfaces for data query. TUIs share characteristics with other physical representations in their use of metaphor or concrete representations of data content, aesthetics and bodily engagement. In our project we take advantage of the benefits that tangible data representations bring and combine these with graphical representations in a highly interactive environment.

One of the first tangible data query systems was designed to interactively convey historical information at a tourist site, using blocks that can be positioned to form a query (Camarata *et al.*, 2002). The idea of rearranging objects to create data queries was later used in Stackables (Klum *et al.*, 2012), and later in Cubequery (Langner, Augsburg, Dachselt, 2014), whose cubes include a small display screen for the output.

In contrast to these systems, our system does not require any specialized hardware, a feature we believe to support the idea of data democratization. Our system only requires standard equipment: a computer, a webcam, and a projector. The figure below shows a schematic of the interaction.

In our system, users create queries by placing and arranging clearly demarcated objects (that are handheld in size) onto a common tabletop, and the results of the query are displayed onto an overhead screen placed at one end of the table. The visualizations that appear on the screen respond to the configuration of the objects on the table. In our current prototype, there are 4 different types of objects the user can manipulate to discover the data. 1) The category objects let the user decide the subject of the data. For example, each category object could represent a country. 2) The measurement objects let the users determine what data about the category they want to see visualized. For example, one may want to look at the population of a country, or the income per capita. To illustrate this example, if a user places two category objects on the table: one representing Canada and the other representing the United States, along with a measurement object representing population, or income per capita, then the screen will display a bar chart of the populations, or income per capita, of Canada and the United States. Reordering the category objects on the table will reorder them on the screen. The other two types of objects allow the users to probe the data in more detail. 3) The subdivision objects divide the data into subcategories. For example, the users might want to view the population, or the income per capita, broken down by gender, by age group, or by regions. 4) The detail objects provide a close up view of the data in any subcategory when these objects are placed in close proximity to a subdivision objects. So, for example, the detail object is applied if a user wants to know with precision what the income per capita is of women between the ages of 25 and 35 for each country.

The objects are tracked by means of a camera placed discretely beneath the transparent tabletop. The bottom of each object is marked with a fiducial marker, and the camera placed below the table captures the image of the fiducial markers in real time. The fiducial markers are read using open-source reacTIVision software (Kaltenbrunner, Bencina, 2007). The reacTIVision software outputs the position of the markers, if they are in the field of view of the camera, and this information is input into our software, which constructs the visualizations from a (user-provided) database, filtered by the user's query.

Figure 1: Sketch of TUI prototype (Jofre *et al.*, 2015)
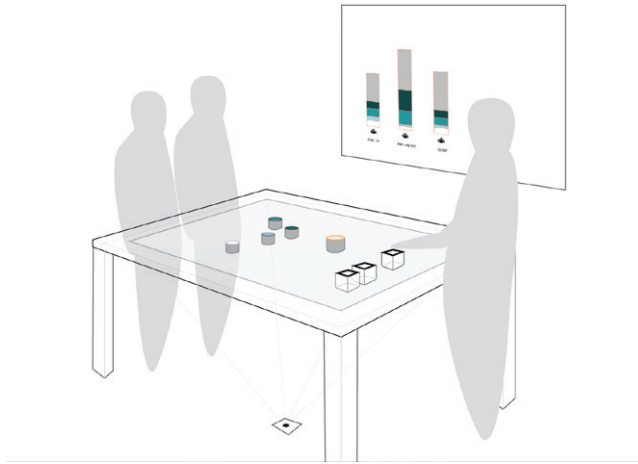
In our first prototype application (see Figure 1), we use demographic data on radio listeners and their consumption habits, which was collected on April 1, 2013 for the Toronto area in Canada, and compiled by nLogic Canada, our industry research partner. In this prototype application, each category object represents a radio station, and we have two measurement objects, which allow users to determine whether they view data on the radio stations' number of listeners, or on the number of minutes listened. Each of these data sets can be broken down into age and gender demographics by placing the subdivision objects on the table. The detail objects are used to get the precise number of listeners or minutes listened within any subdivision. For example, the user can determine the exact number of female listeners between the ages of 18 and 25 for each radio station by placing the detail object in proximity to the corresponding subdivision objects. This particular application of the tool will be used as a part of a market research package for advertisers targeting radio air time (Jofre *et al.*, 2015).

While our first prototype is specific to this radio-station data set, we note that it can be adapted to any dataset, as the system allows users to provide their own formatted data. The fiducial markers can be printed and glued onto the bottom of any object the user wishes to use to explore their data set.

Our system has two levels of users, providing two levels of affordances; expert users that provide the data set, and that choose or create the physical objects used to interact with it, and non-expert users that use the tabletop objects to explore the data. This type of system can be directly translated to the classroom, where the teacher provides data for the students to explore collaboratively in constructivist learning exercises.

Democratization of data not only requires the ability for active citizens to create and share their own visualization, but it also requires a venue for discussion. While data analytics is typically performed individually, this tool encourages data exploration to be a group/team activity with the tabletop interface.

Results from our first pilot study of test users support our assertion that our tangible interactive tool for data query encourages communication and collaborative data exploration, which is consistent with the literature on tangible interfaces and observations about interactive data sculpture above. We organized participants into small groups of two to four, and gave them problems to solve using the data. Participants exhibited collaborative behavior, and in subsequent surveys, they reported positive feelings towards their teammates and about their interaction as a group.

In addition to encouraging collaboration, the playful nature of the tangible interaction could lead to a greater degree of engagement. Preliminary observations of users are promising – test subjects seem eager to handle the objects, and they take on a playful disposition when interacting with the system. Turning data query into a pleasurable experience can encourage people to spend more time exploring data, which, in the information age, is essential to being an educated and engaged citizen.

7. Conclusion

Making use of open data (and learning from it) is an important aspect of citizen education and civic participation. We offer here a tool with which users can visualize and investigate their data collaboratively using a graspable tangible interface. We designed our tool to create a pleasurable data exploration experience, and to help users gain insight into their data. The intuitive nature of manipulating blocks to form a query may help bridge any data literacy gap for non-expert users, and a playful collaborative situation may encourage non-expert users to make contributions of their insights into the data (which in the context of civic participation are equally valuable as expert user contributions). We believe that a big part of citizenship engagement should be spent in dialogue, and to this end, we designed this tool to be used by teams of two to four people to collaboratively examine the data. Our design rationale was based on a wealth of literature, reviewed here, which suggests that using tangibles has cognitive benefits, and encourages collaboration, making them a promising technology for better engaging people with data.

8. References

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