The e-Table: Exploring Collaborative Interaction on a Horizontal Display

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Abstract

The e-Table is a table with an embedded LCD display. Research on the e-Table is novel; there remains a lack of published work on two-dimensional horizontal displays. As such, this research has involved investigating the design space of a table display; that is, the unique characteristics and potential utility of a table display. To this end, an observational study was carried out involving participants completing puzzles on a regular table, a table display, and an upright display. An initial analysis of these sessions has been performed, and qualitative observations relating to distinctive qualities of a table display have been made.

Keywords

Human-computer interaction, information visualization, single display groupware, roomware, ubiquitous computing, desk display, horizontal display.

1. Introduction

The research, design, construction and evaluation of the e-Table fall under the sub-disciplines of computer science known as human-computer interaction and information visualization. Human-computer interaction is the study of how people interact with computers and the extent to which computers are developed for successful interaction with human beings. Information visualization is concerned with the various ways computers can assist in enhancing people's understanding of complex and abstract information.

A significant issue related to information visualization is the screen real estate problem. Today's society is experiencing information explosion. There are vast amounts of information available and capable of being generated. Moreover, there have been rapid advances in CPU processing power, computer memory and graphics capabilities; gains which have not been matched with proportional gains in display size. The end result is that the size of display screens is a significant limitation in the research of complex visual information spaces; there is simply too much information to represent in too small an area.

Large-scale displays have been examined as a possible solution to this problem. Although display size has not increased at a rate that has matched the performance of computer hardware, there have been some moderate advances in this area. Additionally, there has been an increasing move to incorporate displays into the surrounding environment, a concept referred to as ubiquitous computing. Associated with this is the idea of roomware, or the combining of information devices and physical objects (such as walls, chairs, and tables) in a room. A natural extension of these ideas is the incorporation of a display into a table.

As well, a table seems to be a natural medium for group collaboration. This type of collaboration involves groups of people exploring and examining the same visual field. A model for supporting such collaborative group work is single display groupware. Single display groupware typically refers to computer programs that enable co-present users to collaborate via a shared computer with a single shared display and simultaneous use of multiple input devices.

Currently, there are no high-resolution large-scale displays available (the highest resolution currently available on these displays is 1280 x 960). Due to the close proximity required for interacting with a table display, sacrificing resolution is not a desirable option. As such, the e-Table incorporates a smaller (20”) high-resolution display (1600 x 1200), and serves as a useful prototype for a future, larger table.

2. Previous Work

While unique, the e-Table has a broad heritage of related work published in the associated areas of single display groupware, ubiquitous computing, and desk displays.

2.1 Single Display Groupware

Recently, single display groupware has been an active area of research. Stewart et al’s paper [15] provides a good introduction to and overview of single display groupware. The CoLab project [13] and the shared room built by Krueger [8] allowed for shared control of a large-scale display. The Liveboard digital whiteboard and the Tivoli application [13] enabled shared use of an electronic whiteboard. Work by Inkpen has shown that significant learning improvements were realized when multiple input devices were provided to children [7]. Further, Inkpen has investigated the effects of turn-taking protocols on children’s collaborative activities [6]. She has shown that computer support for co-located collaboration is important, and that adapting the computer environment to more effectively support collaborative interaction can bring about positive changes in motivation and productivity [2]. McGrath and Hollingshead have produced a list of variables to be evaluated when examining the effect technology has on group processes [11].

2.2 Ubiquitous Computing & Roomware

Work on ubiquitous computing has focused primarily on what are currently termed electronic rooms, which consist of a number of roomware items. The most pertinent work here is i-Land, which involves a full-sized wall display (DynaWall), an electronic table (InteracTable), and electronic chairs (CommChairs) [16]. The InteracTable is a rear-projected table display, similar to the e-Table. The i-Land paper includes only a brief discussion of the InteracTable that highlights a few of the important issues involved in horizontal displays. These include interaction concerns such as gesture recognition and orientation issues relating to the inherent lack of predefined orientation in horizontal displays. However, the discussions on this display are minimal, as the focus of the paper is on the environment created by the roomware devices as it relates to work practices. Research by Moran et al has investigated collaborative use of a large-scale display [12]; however, the display examined here is a wall display and the focus of the paper is on the technological framework of the display.

2.3 Desk Displays

The work by Wellner on the Digital Desk [20] was the first major research published concerning a horizontal display. However, this paper is concerned with augmented reality, which involves superimposition of virtual objects onto an existing real-life surface. There have been numerous other papers written on computer-assisted manipulation of actual physical objects; for instance Augmented Surfaces [14] and the metaDesk [18]. The work on the Virtual Round Table is an example of collaborative group work in a computer-augmented environment [3]. Additionally, there has been significant work done on three-dimensional immersive desks. Examples include the CAVE [19], the Virtual Workbench [19] and the Perceptive Workbench [9]. The Responsive Workbench is an example of a virtual reality desk supporting two-user collaboration [1]. The ImmersaDesk is an immersive reality desk that can be rotated to a 45-degree angle [4], while the ErgoDesk is an angled display that can be used for both two and three-dimensional interaction [5].

3. Research Directions

Although there exists material published concerning the general areas associated with the e-Table, there has been no work published concerning the design space of a table display; that is, the unique characteristics and potential application domains of a table display. An appropriate understanding of these foundational issues is required before an investigation into more particular aspects of table displays can be carried out. Indeed, without such understanding, it is difficult to even know the correct questions to ask. This paper endeavors to serve as a framework to guide and inform future, more specific research by empirically discovering issues of importance for table displays.

To this end, two differing and complimentary approaches were employed. The first involved endeavoring to understand the nature of a regular table via discussion and brainstorming. This approach stemmed from the recognition that in our culture individuals have had years of experiences with tables of differing sorts. Upon close examination of these experiences, it became evident that unique characteristics of tables could be described. This was a logical starting point for investigating the design space of a table display, as the discussion served to inform decisions relating to the design and construction of the e-Table. The second approach involved carrying out an observational study involving the newly constructed table display. This approach was based on the recognition of the need to observe the use of a table, a table display, and an upright display in an effort to more completely understand the e-Table's unique characteristics. In regards to this approach Tang states [17]: "The approach is especially appropriate in a field … where the issues are not already clearly established, but need to be identified and formulated for further investigation … Inappropriate or premature application of quantitative methods can result in misguided conclusions or can miss crucial aspects of the activity that do not lend themselves to quantification."

4. The Basics: the Nature of a Table

As mentioned, the first approach to understanding the design space of a table display and a logical starting point for the discussion of the e-Table involved discussion of the nature of a table itself. What follows is a summary of informal knowledge gleaned from the experiences of computer science professionals casually observing individuals interacting around various information mediums. These points served as a starting point for the design of the e-Table, and were more formally investigated with the observational study that followed.

- A table allows individuals to engage in face-to-face communication. When compared to other mediums that individuals often use collaboratively (such as traditional vertical displays, whiteboards, SMART boards, and distributed groupware applications), a table allows people to engage each other more directly. In this sense, a table allows individuals to link themselves to other individuals, and thereby create a connected sense of distance.
- Reachability on a table is different than for traditional mediums. Depending on the general size of the table, it is often the case that objects of discussion can be reached for and manipulated by each individual at the table with relatively little effort. In contrast, when using whiteboards or other large vertical displays, it is often necessary to physically extend or relocate one's self to point to information.
- In part due to the reachability and face-to-face advantages of a table, a table seems to promote more simultaneous interaction than traditional vertical displays.
- A table denotes a more informal level of interaction compared to traditional mediums. It is often the case that individuals sit at a table for impromptu gatherings as well as for recreational purposes (such as eating lunch or playing cards). In this sense, a table is often viewed as a multipurpose device.
- Since a table is flat, it can be used to support the gathering of actual physical objects. Oftentimes this is the primary reason a table is used by individuals: to hold plates of food, paper documents, physical models and cups of coffee.
- An obvious but important feature of a table is that it allows people to sit down while using it. This has significant implications in terms of comfort: people are

generally more able to spend longer periods of time sitting at a table than standing at a whiteboard.

- The shape of a table can influence how people interact at the table. Positions around circular and square tables are more or less identical; one particular position is generally not viewed as being more advantageous, prestigious or powerful than another (although, depending on the table's positioning in a room relative to other objects, this may not be the case). The same is not necessarily true of a rectangular table, since the distance from each seat to the center of the table (and perhaps various objects of discussion) is not the same.
- Individuals sitting at different parts of a table do not share the same orientation. For instance, if one person is reading a document at one position, it has to be rotated in order for an individual sitting across the table to read it.
- A table introduces the notion of personal space: often the area directly in front of each individual is interpreted informally as belonging to them.

5. The Nature of the e-Table

In order to empirically investigate the nature of a table display, it was necessary to construct a working prototype. Taking into account the unique characteristics of a table just discussed, a relatively inexpensive table display was designed and the design given to a professional finishing carpenter to construct. The result of this work was the e-Table: a wooden, rectangular table that incorporates a 20" LCD flat-panel display (see Figure 1).

Initially, it was thought that a larger plasma display would be used, but due to concerns with resolution and price, the decision was made to go with a smaller, higher-resolution (1600 x 1200) display as discussed earlier. Using a flat-panel display rather than a rear-projected display involving a mirror system enables people to sit at the table and put their legs under it. The table is approximately 31 inches wide, 27 inches long, and 30 inches tall. This means that the display itself is surrounded by 6-inch margins on all sides. Four corner legs as opposed to a central table leg support the table in order to allow individuals legroom under the table. The decision was made to construct a rectangular table instead of a round one for ease of construction. As well, the intended benefits of a round table (namely that such a table would not be as strongly oriented as a square or rectangular one) may not have been realized due to the rectangular nature of the embedded display, and the need for four corner legs (which strongly implies four distinct seating positions).

Figure 1: The e-Table

The decision was made to use multiple mice as input devices instead of making the e-Table touch sensitive. Currently, touch sensitive overlays do not support multiple users interacting at the same time. Support for simultaneous interaction was required in order to adequately investigate the nature of collaborative group work around the e-Table. Further, a touch sensitive screen would have been adversely affected by the Midas Effect, which is the idea that people tend to rest their hands and other objects on horizontal surfaces. Parallax (that is, distance between the touch sensitive overlay and the actual display) would also have been problematic, as would eventual sagging of the overlay due to the effects of gravity. Hence, the decision was made to employ multiple-mice as input devices.

6. Application of the Design: The Puzzle

In order to allow for empirical investigation of the research questions given above, it was required that an appropriate test application be developed. Ideally, one would have liked to observe relatively unstructured and uncontrolled activity in order to not impose specific and perhaps unnatural modes of interacting with the table display. However, in order to carry out an observational study it was required to observe an activity of some kind, and as such a suitable test application was developed. Suitable in this sense means that the application could be run on a “real” table, a “virtual” one, and an upright display, as well as allow for simultaneous user interaction. A puzzle legitimately satisfies all these criteria: it is often completed by groups of individuals and is typically done on a horizontal surface.

The puzzle application (also known as the e-Puzzle) consists of rectangular puzzle pieces (the number of which can be varied), which are pieced side-by-side to form a completed image (see Figure 2).

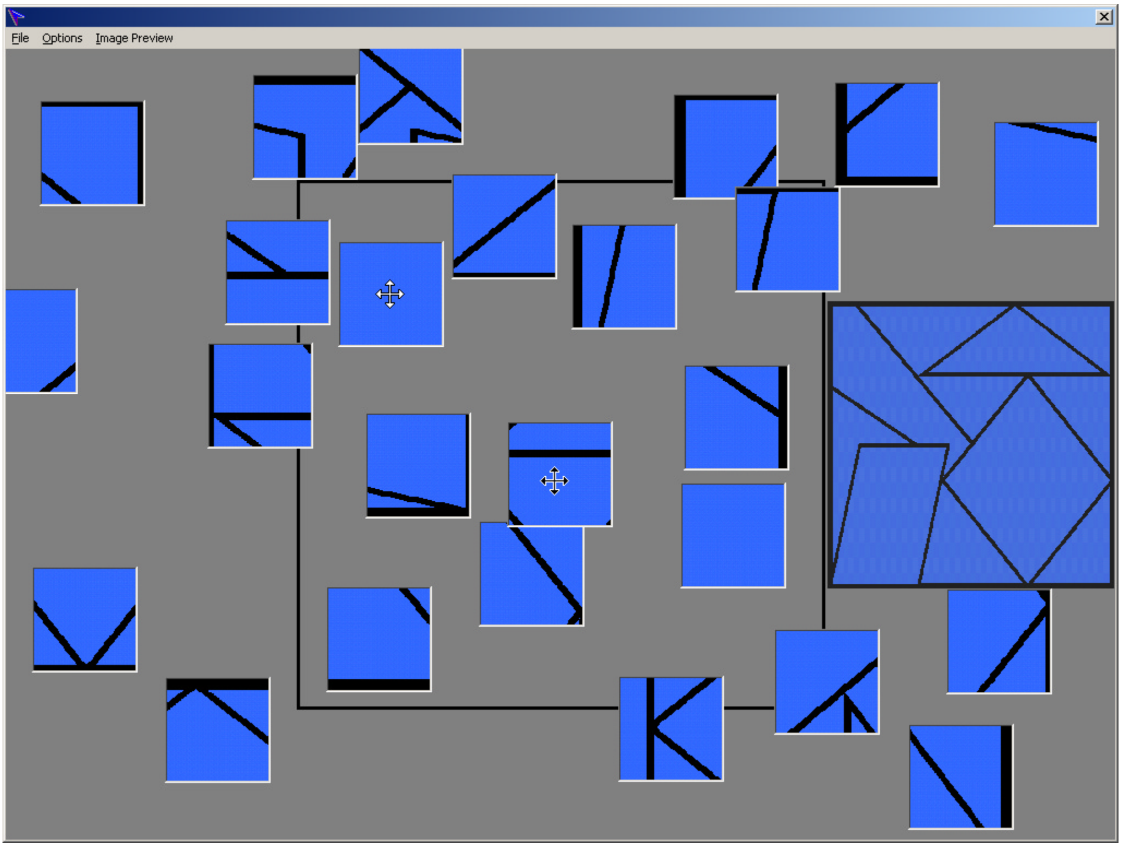

Figure 2: The e-Puzzle

The completed puzzle rests inside the inner black rectangle pictured above, and a preview image of the completed puzzle appears to the right of the black rectangle. The picture used can be varied; any image file can be divided amongst the pieces. Each puzzle piece is capable of being rotated 90 degrees by right-clicking on the piece.

In order to allow for simultaneous user interaction, the puzzle was modified to incorporate support for marmots. Marmots are mice that have been configured so that an operating system does not recognize them as mice; however, a programmer is still able to detect the events they generate. Support for two marmots was included in the e-Puzzle thereby allowing two users to simultaneously work on the puzzle.

There are important issues that require consideration when designing and implementing a single display groupware application such as the e-Puzzle, including [15]:

- Shared user interface: the user interface elements that are used to communicate with the computer must handle multiple simultaneous users.
- Shared feedback: the user interface elements must be capable of conveying information to all users at the same time.
- Coupled navigation: the navigation of one user affects the others.

Further, there are also possible negative side effects to allowing simultaneous user interaction. These include [15]:

- Frustration resulting from incompatible navigation decisions made by the different users.
- Slower applications due to increased processing requirements.
- Portability problems due to lack of widespread operating system support for the single display groupware architecture.
- Increased time to complete tasks due to necessity of cooperative group work.

However, it was felt that allowing multiple users to interact at the same time would also produce some or all of the following benefits [15]:

- Enriching group productivity by reaping the benefits of shoulder-to-shoulder collaboration.
- Reducing conflict arising from different users sharing a single input channel.
- Motivating peer learning by reducing competition for access to input channels.
- Supporting the development of effective communication skills by forcing users to communicate more amongst themselves to settle conflicts.

These issues pertaining to single display groupware had important implications for the e-Puzzle. Design of the e-Puzzle attempted to maximize the advantages of single display groupware while minimizing its ill effects. For instance, the e-Puzzle was designed to be a single application that involves no navigation. Further, design decisions regarding piece ownership were made to reduce conflict over puzzle pieces: when an individual has "picked up" a piece, another user is not able to manipulate that piece until the individual has released it. Simultaneous picking up of pieces is not allowed. These decisions mirror what typically happens in real-world puzzle completion. In regards to performance concerns, even after incorporation of the marmots the e-Puzzle responds in real time to user actions. However, portability remains a problem; support for marmots is limited to the Windows 2000 and Windows XP operating systems.

7. The Observational Study

7.1 Purpose

After implementing the e-Puzzle, an observational study was carried out involving participants completing puzzles on a regular table, the e-Table, and an upright display.

The intended purpose of the study was fivefold:

- To observe how participants interact with a table display in order to assist in formulation of appropriate research questions, and hence future research directions.
- To provide initial directions or hypothesis in regards to some of these issues if possible.
- To empirically evaluate the brainstormed characteristics of a real table and their applicability to the e-Table.
- To evaluate the design of the e-Table in an effort to help inform the future design of a larger digital table.
- To evaluate the design and implementation of the e-Puzzle in an effort to help inform the design of future table display software.

7.2 Design

As mentioned, horizontal display research is an emerging field in which research issues have not yet been identified. As such, an observational approach was deemed necessary; this approach typically involves careful observation of activity that leads to a description and thereby often an understanding of the actions that were performed. Use of an experimental approach instead of an observational one to investigate the e-Table would not have been appropriate: Tang states [17] "An experimental methodology is effective when studying an activity that is consistent and the variables to control and how to manipulate them are well-known. Under these conditions, an experimental methodology can convincingly demonstrate cause and effect relationships between a limited number of clearly defined variables." Since these conditions do not exist for table displays, this method was not employed.

7.3 Methodology

The observational study consisted of seven pairs of participants from the university population. The pairs were composed of peers who were not part of a formal hierarchical relationship, such as supervisor and student. Each pair of individuals was asked to participate in six different puzzle completion exercises. There were three workspace conditions: a real table with physical puzzles, an e-Table with e-Puzzles and a traditional vertical display with e-Puzzles. There were two types of puzzles used for each condition: a non-oriented puzzle (a puzzle whose completed image was not oriented in a particular direction, such as one involving geometric shapes), and an oriented puzzle (a puzzle whose completed image was oriented in a particular direction, such as one involving text). Hence, the six different puzzle completion exercises were composed of one of each type of puzzle for all three of the workspace conditions. The puzzles used on the real table were identical to the e-Puzzles in terms of number and shape of pieces. The within group comparison design was chosen to allow for efficient comparison of the experimental conditions. Prior to the commencement of the study, an ethics package was completed and submitted to the ethics approval board at the University of Calgary (see Appendix I for a copy of this package).

Each session proceeded as follows: an initial pre-session questionnaire was completed by the participants which included questions relating to the participant's experience with computers, their experience with table displays, their experience with completing both regular and electronic puzzles, their view of working in pairs, and their level of familiarity with their partner. Then, the first of the three conditions (regular table, e-Table, or upright display) was randomly chosen by having the participants shake a die. The order in which they completed the puzzles for this condition was then determined by shaking the die again, as were their seating positions. Each session was videoed to include an image of the participant's hands and actions (no faces were recorded), as well as an audio recording of their dialogue. Participants were encouraged to employ the "think aloud" approach, which involved speaking out loud as often as possible to indicate what they were thinking. After the two puzzles were completed on the first condition, the participants filled out a questionnaire providing comments on the exercises. The above process was repeated for the remaining two conditions. After the third and final condition was completed, the users filled out a questionnaire involving comparison between the different conditions. At this point they were prompted for comments relating to the differences between the various information mediums, their opinions on the e-Table, the e-Puzzle, their opinions on the study itself and various other issues that will be discussed later on. The participants were then debriefed and thanked for their time. Each session took approximately 1 hour to complete.

The sessions were run in a recently constructed usability room at the University (see Figure 3 for a picture of this room and the experimental setup). A separate room was deemed necessary in order to provide participants with a quiet and controlled environment in which to complete the exercises. Participants completed both the regular table and e-Table conditions while sitting on opposite sides of the table. For the upright display, participants sat side-by-side in front of the display. In order to make a fair comparison between the different conditions, it was necessary to use a regular table the same width as the e-Table. As well, the upright display used, although not exactly the same as the display used in the e-Table, was a 20" flat screen CRT, and hence was comparable to the e-Table in terms of size of display. The video camera was positioned at the end of the e-Table for both the regular table and e-Table conditions, and was moved to the other end of the room for the exercises on the upright display. The videoing was meant to be unobtrusive and passive, and as such as little adjustment as possible with the camera was done during the session. Screen capture software was considered for the upright display and e-Table conditions instead of videoing, but since the regular table still required videoing this was not done. Additionally, such software may have interfered with the performance of the e-Puzzle in terms of responding in real time to user actions. As well, it was desired to have a recording of hand movements made by participants during the session.

Figure 3: The Experimental Setup

In regards to the puzzles themselves, pilots run prior to the commencement of the study indicated that a 25 piece puzzle (5 x 5 square) typically took from 3 – 7 minutes to complete. This approximate time per puzzle was appropriate in regards to not detaining participants for more than one hour in total, and hence the decision was made to use this number of pieces for the actual study. The shape of the pieces was the same for all conditions (square), and the regular table condition was supplemented by a large cardboard square on which the completed puzzle fit (similar to the large black square used for the e-Puzzle). Additionally, a significant snap-to effect initially used for the e-Table and upright display (where a piece that was within a certain number of pixels of its correct position "snapped to" place and a brief audio clip was played) was removed to allow for fair comparison between the conditions. The oriented puzzles initially used images that a definite top and bottom, but were later switched to more strongly oriented text puzzles in an effort to make the effects of orientation more pronounced. The non-oriented puzzles consisted of geometric images arranged inside a square. Due to the within-group design, each of the 3 oriented and non-oriented puzzles were required to be different, but were also required to be equivalent in terms of their difficulty level. Careful attention was paid to this. Each of the oriented puzzles was designed and involved pilots being run to ensure a relatively uniform level of difficulty. For instance, this meant that each of the geometric puzzles used had the same number and relative size of shapes inside the square. The text puzzles were created to have the same font, and were similar in terms of language comprehension levels. Also, the images used for each of the conditions were randomly chosen before the session was run.

It should also be noted that the participants and pairs chosen were quite distinct in many respects. There were expert computer users (those who were PhD candidates in computer science) as well as novice computer users (those whose formal computer education consisted of a single introductory computer science course). Some participants came from environmental design and educational backgrounds, and others came from management and computer science backgrounds; even among those with computer science backgrounds there were numerous sub-disciplines represented including graphics, human-computer interaction, information visualization, and distributed systems. There were pairs in which the participants knew each other very well, as well as those who had never met before. Some participants were puzzle experts, and some were puzzle novices. Some had experience with single display groupware and there were also those who had none. This purposed variation was guided by the premise that a rich and varied participant group would be beneficial in terms of gaining unique and differing perspectives.

7.4 Analysis

The method used in this study to record and analyze the video recordings of the sessions can most closely be likened to an interaction analysis method. Interaction analysis refers to participants being videoed while working on a real task, and then later the activity as a whole is analyzed via observation of the video. For an observational study, employing an interaction analysis approach is especially appropriate. Tang states [17]:

> Interaction analysis does not depend on accurate preconceptions of the activity in order to construct experimental studies. It does not attempt to separate specific aspects of an activity and study them in isolation. Rather, the activity as a whole is treated as the subject under investigation, and it is studied under conditions similar to those in which it is naturally experienced. Interaction analysis also does not depend on an artificial means for eliciting cognitive information, such as giving protocols. As a method based on video records of the actual activity as data, it is not susceptible to the incomplete reporting, faulty recollection, or post-rationalization that can occur in case studies or retrospective interviews.
>
> The record of the observed behavior is then analyzed to provide a description of what happened and how it was accomplished. Reviewing the recorded activity helps formulate the research issues to investigate by identifying recurring issues or patterns of activity. A deeper understanding of a particular issue is obtained by collecting multiple examples of these recurring patterns, so that they can be analyzed by comparison and contrast. In this way, the record of the actual activity is used as data to inductively construct and support observations about the activity.

After observing firsthand the experimental sessions and reviewing the questionnaires, a list of different issues and areas of possible interest was compiled. With these items in mind the video was reviewed, and further notes were made. In addition, the questionnaires completed by the participants were re-examined, as were the observational notes made during the sessions themselves.

8. Results of the Study

It was found that significant research issues relating to the e-Table include: the unique physical characteristics of the e-Table, orientation issues, collaboration issues, shared use of space, potential application domains, and design principles for a second-generation table display. It should be remembered that the initial directions observed for these issues are not meant to be conclusive in nature; rather, they are an attempt to inform the course of future, more extensive research.

8.1 Unique Physical Characteristics of the e-Table

Part of the motivation for creating the e-Table was a belief that a digital table would combine the physical characteristics of a table with the digital characteristics of a display. It became clear over the course of the study that the e-Table was in fact very much distinct from a regular display as well distinct from a regular table. The following unique physical characteristics of the e-Table came to bear:

- The e-Table is distinctive in terms of physical space. The top of the e-Table offers a surface for resting of objects. This space is often greater than the area directly in front of a display on a desk. It would seem that the e-Table offers a unique opportunity for the mixing of physical and digital objects. Additionally, as compared to an upright display, physical objects can be placed directly over the screen for various purposes such as comparison.
- The e-Table appears to offer a tactile quality that the upright display does not, in terms of being able to manipulate objects that rest on the table. People seemed more willing to transfer the tactile quality of interacting with physical objects on the regular table to the e-Table than to the upright display.
- The e-Table is more informal than a traditional upright display. People felt that they would be more inclined to use the e-Table for impromptu gatherings, and believed that the e-Table had more of a social focus than the upright display.
- The e-Table can physically support more people around its perimeter than an upright display: with an upright display, people are limited to standing on one side of the display. As such, people felt that the e-Table would be more inviting in terms of congregating several individuals around the table to view something.
- The e-Table offers the opportunity to sit down while working. This is important in terms of comfort as compared to other mediums that require standing (for instance, whiteboards).
- It would seem that using the e-Table would require a bit of an adjustment for people in terms of getting used to the display's horizontal nature. As one person

stated: "it was easier to see the whole screen on the upright display; my body was naturally postured to look at it."

- For prolonged usage, the e-Table may pose problems in terms of neck/shoulder/back strain due to leaning over the table to view the screen. For some people this may pose a barrier to using the e-Table.
- The e-Table's display cannot be viewed from a distance. Hence, sitting back in a chair physically precludes a person from viewing the display. Additionally, this means that other people not using the display cannot view the display contents at a distance.
- The e-Table may be less advantageous than an upright display in terms of being able to get a sense of what is on the whole display with a single glance.

8.2 Orientation

One of the clearest outcomes of this study was the recognition that orientation on the e-Table is a definite issue.

- Because the e-Table can support individuals gathering on its various sides, digital objects on the e-Table may or may not be properly oriented for all individuals. Objects that lack a predefined orientation, such as geometric shapes, may not be particularly affected. However, objects such as text that have a definite orientation are very much problematic in this regard.
- In general, people felt far more comfortable dealing with oriented objects on the upright display. Although it took some people longer than others to notice the effect that orientation had, all people in the study commented on it. Viewing text upside down on the e-Table concerned some people more than others; some people were so disturbed viewing text upside down that they tried to stand up and turn their head in an effort to view the text in its correct orientation. People also thought that viewing text that wasn't upside down but rather sideways was still more difficult than viewing text that was right side up.
- Orientation of objects on the screen can be affected by the physical design of the table. Rectangular tables with four distinct seating positions give rise to four distinct orientations, as do rectangular displays (regardless of the shape of the table itself, such as circular vs. square). People felt that if the e-Table's display was circular or square, then this may have resulted in interaction that was not as strongly affected by orientation. It should also be noted that the casing of the display itself can contribute to orientation: having display adjustment controls visible strongly implies one position as having the "correct" orientation.
- The physical size of the table may affect orientation. For instance, if a table is large enough to support the desired number of collaborators on one side of the table, then orientation is no longer an issue.
- The input devices used may also affect orientation. Displays that require mice or marmot input constrain the number of distinct orientations to four or less. This is because mice and marmots usually require a rectangular region with a definite top and bottom in which to operate, thereby resulting in at most 4 distinct

orientations. An input device such as a stylus or even a finger would not be similarly affected.

- It appears that incorporating a mechanism to allow digital objects to change orientation so that individuals seated at different positions can view them in their correct orientation is something that is necessary to support on a digital table. However, there are numerous issues related to this that require attention. For instance, would rotation of individual objects on the display be more preferable than rotation of entire windows or even the entire screen? What sort of mechanism could be used to allow for quick and intuitive rotation of objects? Would having multiple copies of the same information in different orientations be a feasible solution? If change of orientation was supported, would this result in decreases in productivity or efficiency because of the constant requirement to re-orient objects? Is supporting freehand rotation as opposed to orthogonal rotation desirable?
- Observations gleaned from the study indicate that many individuals rotated objects at various angles on the regular table, and thus it may be desirable to support such rotation capability on the e-Table. People felt that freehand rotation would especially be required for creative endeavors. Also, people felt that having multiple copies of information may be confusing, and that perhaps a mechanism whereby objects could automatically orient to whoever is manipulating them may be beneficial.

8.3 Collaboration

Due to its physical design and use of the single display groupware model, the e-Table affords a unique collaborative environment. Results from the study showed that:

- People in general felt that working together in partners was an enjoyable experience, regardless of the display used. As one person stated: "two people working together on the same display results in getting done faster and is more fun and interactive." Another person stated "it's really neat that you can have two cursors on the same screen, it gives a whole new dimension to the computer experience."
- In terms of potential drawbacks of the single display groupware model, it was found that users were able to resolve incompatible piece navigation decisions without much of a problem, in part due to the piece ownership mechanism described previously.
- Some people found working together in front of an upright display to be a bit awkward in terms of interpersonal space. These people were not used to sitting so close to another individual while working. In general it was found that people were more comfortable sitting across from one another as opposed to sitting side-by-side, in part due to the greater physical distance between them. This is not to be unexpected; according to psychological literature [10], an interpersonal space of 0 – 1.5 feet is characteristic of an intimate relationship, while an interpersonal space of 1.5 – 4 feet is characteristic of a personal relationship (the difference between the two relationships being the level of intimacy). Sitting side-by-side in

front of an upright display places individuals in the intimate relationship category, while sitting opposite a person at a regular table or at the e-Table places individuals in the personal relationship category. Hence, the e-Table may be advantageous for collaboration in which more interpersonal space is desirable; in this regard it addresses the potential drawback of the single display groupware model involving invasion of interpersonal space. However, it should also be noted that not all participants felt uncomfortable sitting side-by-side in front of the upright display; this was especially true for those with previous experience with shoulder-to-shoulder collaboration.

- Most people found communicating while using the e-Table and the regular table to be more natural than communicating in front of the upright display. Some people felt unnatural sitting in front of the upright display and talking while facing the screen. As one person stated: "talking is easier on the table-top conditions because we are face-to-face." Another person stated: "I thought that the e-Table allowed for easier communication and collaboration because you can look at the person you are working with while you talk to them."
- An issue whose importance became clear during the course of the study was awareness. Some people felt that they were more aware of their partner and their partner's actions while collaborating on the e-Table, due to the fact that they were seated facing their partner. However, other people felt more aware of their partner and their partner's actions on the upright display, due in part to the closer seating arrangement on the upright display. One person stated: "I can see how the e-Table may cause tension because I am more concentrated on the screen than my partner so I really can't read their body language to see more in depth why they are doing something." This issue of awareness requires further research.
- Another issue that became apparent during the course of the study was the fact that participants felt certain conditions were more competitive than cooperative. Some people felt that sitting opposite one another implied a competitive stance, due in part to other social situations in which people sitting opposite each other compete (for instance, card games). On the other hand, others felt that the physical setup of the table conditions seemed to promote working together, and that while using the upright display they lost the feeling of how they were doing as a team. This issue requires further research.
- It was found that gesturing was another variable that varied between conditions. People gestured the most on the regular table, making full use of their hands for pointing and explaining. This could have stemmed in part from the fact that since people were using their hands to directly manipulate puzzle pieces, they were more aware of their hands and hence were more likely to move them at other times. People gestured less on the e-Table and upright display. However, it was found that for these conditions people sometimes gestured using their cursor; although, they found this in general to be less effective than hand movements in terms of attracting the other person's attention.

8.4 Shared Use of Space

An interesting observation made during the course of the study was the difference between conditions in terms of personal/public space. For instance:

- People felt as if the area directly in front of them on the regular table was their personal space, and that the area in the middle was shared public space. However, on the e-Table and upright display, no such distinctions were made.
- On the e-Table people did not generally view the screen area in front of them to be their personal space, and likewise for the upright display they did not feel that one side of the screen belonged to them. As one person stated: "on the regular table there are clear notions of 'my', 'yours', and 'ours' when it comes to space … on the e-Table and on the upright display, there is so little space that to cut any portion of it and make it 'my' space would be unfair to my partner … I don't want to be selfish in that way, so I think by virtue of lack of space all space is 'our' space and so I don't mind reaching across to my partner's side because it's still 'our' space."
- In accordance with this view, participants by and large felt more comfortable reaching across the e-Table using their marmots than reaching across the regular table with their hands. Part of the concern people had with physically reaching across the regular table had to do with not wanting to invade the other person's personal space, as well as not wanting to touch or bump the other person's arm. With the e-Table, people felt that it was physically easier to navigate to the other person's side of the display, and that using marmots to grab pieces did not have the same territorial or ownership claim.
- It should be noted that some people did feel that the physical wooden margin in front of them on the e-Table was in fact their personal space.
- Although people did generally view the screen area on the e-Table as public space, some people still felt that there were certain areas that were in a sense theirs. For instance, if they were working on a particular section of the puzzle that was physically located in a certain area, they felt as if this area informally belonged to them.
- On the e-Table more than the upright display, it appeared that people worked on areas of the puzzle that were physically located closer to their seating position. As such, the effect of navigating to the other person's side may be more pronounced on the upright display.
- This issue of shared use of space requires further research; a possible approach could involve programmatically tracking marmot movements as well as counting specific instances of hand movements using video analysis.

8.5 Applications

As previously mentioned, the e-Table possesses a number of unique characteristics. As a result, the e-Table may be more suited for certain application domains than others. Results from the study show that:

- Since most people do not have previous experience with horizontal displays, they may be more willing to use the e-Table for novel application purposes.
- Some participants were concerned about the extent to which the e-Table could be used for "real work"; that is, work involving text. Part of this concern seemed to stem from the orientation issue discussed above, but people were also concerned about the ease with which text could be viewed on the screen.
- Most people appreciated the e-Table for its novelty: it was something that they had never seen before, and as such were keen on interacting with it. This aesthetic appeal can be termed the "video game effect." As stated by one participant: "the table top display is just fun – it has a very video game feel."
- People felt that the e-Table would be particularly suited to casual work due to the more informal feeling of a table. For instance, it was suggested that board games might be particularly enjoyable to play on the e-Table, especially if the table was situated in a casual environment such as a lunchroom or a coffee shop. Since board games are normally intended to be played on a horizontal surface, and the digital nature of the e-Table may reduce set-up time and prevent missing pieces, board games may work particularly well on the e-Table. The possibility of distributed gaming may further enhance the desirability of this possibility. As well, the unique physical design of the e-Table would allow for other people to congregate around the game, which would perhaps give it a different feel than traditional computer gaming.
- Applications where orientation is not a strong consideration may be particularly suited for use on the e-Table. Potential domains here include: geography (e.g. examining or creating maps), architecture, environmental design, video games (especially those that involve a bird's eye view), astronomy, chemistry and biochemistry (e.g. dealing with molecular formations), and geology and geophysics (e.g. viewing seismic sections). As well, visual layout and design may work well on a table display, as the display would allow a unique perspective from which to view objects.
- For a particular application domain, minimizing divergent navigational choices if using a single display groupware architecture is a good idea. As well, if marmots are used, cursors should be clearly distinguishable.

8.6 Design of a Future Table Display

The study was very beneficial in terms of informing the design of a future larger table display. For instance:

- It was found that both size and resolution are important to individuals. A large surface is desirable, as is high resolution. Currently, there are no large high-resolution displays available. To achieve both a large size and high resolution for a future table display, one could use multiple projectors in a roof or floor projection system. If a roof projection system were used, users would have to deal with the effects of shadows created by their arms and hands. Future research would be required to see if this would be overly problematic. If a floor projection system were used, users would be unable to place their legs under the table.

- A table whose height is adjustable so that it could support both standing and sitting is desirable, as is a table whose surface angle could be adjusted similar to a drafting table. However, this adjustability would probably preclude the use of a roof or floor projection system.
- When a display lies flat, it appears smaller than it does when it stands upright. This means that it may be necessary to use a larger display surface for a table than what would be required if one were to use an upright display.
- A completely flat tabletop surface is desirable. Such a surface would allow users to take full advantage of the surface of the table for various tasks.
- In terms of interacting with the e-Table, a number of participants felt that supporting traditional tactile methods of interacting on a table while still supporting multiple user interaction would be desirable. Possibilities here include using a stylus for digital input, making the screen touch sensitive, or using a camera system that could detect user gestures. As well, support for two-handed interaction would also be desirable, as regular tables support this mode of interacting.

9. Future Directions

Since the e-Table is an initial foray into horizontal displays, there remain many research directions to be pursued. In many ways, this section is the major contribution of the work done to date on the e-Table. Research possibilities concerning horizontal displays include:

- More formally investigating comfort in terms of physical fatigue on the e-Table.
- Investigating further comfort in terms of interpersonal space between users of the e-Table.
- More formally investigating the accuracy of visual perception on the e-Table.
- Investigating further the orientation issue, and developing a mechanism whereby users seated at various orientations could easily view and exchange information.
- Investigating further communication on the e-Table.
- Investigating further awareness on the e-Table.
- Investigating more formally collaboration in terms of competitive vs. cooperative modes of thinking on the e-Table.
- Investigating further gesturing on the e-Table.
- Investigating further the issue of shared use of space on the e-Table.
- Creating software applications for various application domains.
- Making the e-Table larger while retaining its high resolution.
- Supporting more tactile forms of input, perhaps even two-handed interaction, while still allowing simultaneous user input.

10. Conclusion

The e-Table is a table with an embedded high-resolution LCD display. The movement towards large-scale displays and ubiquitous computing has motivated the creation of the e-Table. Research on the e-Table has involved investigating the design space of a table display; that is, the unique characteristics and potential utility of a table display. In an effort to determine the research issues of importance concerning table displays, an observational study was carried out. Analysis of video footage and questionnaires showed that significant research issues relating to the e-Table include the unique physical characteristics of the e-Table, orientation issues, collaboration issues, shared use of space, potential application domains, and design principles for a second-generation table display. There remain many research directions to be pursued concerning table displays.

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