Design and Evaluation of Ambient Displays: The Bus Mobile and Daylight Display

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Abstract

An ambient display is a device that provides information via a user’s peripheral perception channel, differentiating it from standard output devices by not requiring a user’s full attention. In order to determine if an ambient display will influence the behavior of users of computer labs, two displays were designed and deployed. The first display, the Bus Mobile, is a mobile that hangs from the ceiling and has six bus numbers extended from it, which adjust according to the bus schedule for various lines. The second display, the Daylight Display, is a floor lamp programmed to adjust its brightness according to the sunset and sunset times. We hypothesized that the peripheral display of the time left until the next bus arrives would help bus-riding subjects optimize their logout times. Similarly, subjects preferring to depart the windowless lab before sunset might optimize their logout times based on the ambient display of sunset times. To test the prediction, the two displays were set up in computer labs without windows. The behavior of the users was determined by making surveys available before the displays were deployed, while the displays were installed, then after the displays were taken down. The login and logout times of the users were obtained from a system log will be evaluated to see how long people were actually staying in the lab. Using the data from the surveys and the analysis of the login times, it was determined that the Bus Mobile was very effective at providing information to users, and using the results of the surveys only, the Daylight Display was found to be somewhat effective.

Introduction

Imagine working in a room without a window for an extended period of time. Many things can go on in the world outside without your knowledge. The weather could change from sunny to rainy, day could turn to night, or hundreds of people could pass you by without your knowledge. Many people work in this kind of environment every day, since buildings are typically designed to maximize space rather than provide offices with windows for all its employees. However, technology in the field of computer science has been evolving innovative ways for people to gain knowledge of their surroundings. One of these ways is to create what are termed ambient displays, which are devices that do not demand full attention from the user but convey information through the user’s peripheral perception channel.

In order to provide information pertinent to people working in an area without a window, we have designed two ambient displays, the Bus Mobile and the Daylight Display. The Bus Mobile is a mobile that hangs from the ceiling and has six bus numbers hanging from it, each representing a distinct route, which adjust their height according to the closeness of a bus. The Daylight Display consists of a floor lamp that adjusts its brightness according to the sunrise and sunset times, indicating the amount of outdoor light. The two displays were deployed in different labs in the computer science building at the University of California at Berkeley, and then the users of the lab were surveyed to determine if the displays affected their behavior. The results of those surveys were evaluated to determine if these displays were effective in influencing a user’s decision about when to leave the lab.
Background Information

The concept of ambient displays is just a small part of the computer science research area of Human-Computer Interaction, or HCI. The definition of HCI is “a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them” [1]. The field of HCI is broad, and can be multidisciplinary. Many experts in fields such as cognitive science and psychology are interested in HCI because of its influences on people’s behavior. HCI covers areas such as user interfaces, context-aware computing, assistive technology, and ubiquitous computing.

As the field of computing has taken shape in the past fifty years, major trends have evolved in how humans and computers interact. The first of these trends is the Mainframe era, in which many users shared one computer. As technology advanced and became more affordable, the second trend in computing, the Personal Computer phase, began to take shape. This means that there is one computer per person. Through the Internet, the next trend of computing is advancing, which has been named the Ubiquitous Computing phase. In this phase, many computers will share each person. [6]

In the era of Ubiquitous Computing, humans will use many computers at the same time. Because the human is only capable of perceiving so much at once, many of these computers will be almost invisible to the users. They will break the mold of the conventional Graphical User Interface using a keyboard, monitor and mouse [7]. The computers can be anything from servers accessed via the Internet, to computers embedded in buildings, furniture, vehicles, clothing, and anywhere possible.

Ambient displays are being researched as a suitable means of system output in the age of Ubiquitous Computing. An ambient display allows a user to perceive information in the periphery of the user’s attention, and does not require or expect the user to be giving it its full attention. [5] This contrasts typical personal computers, which demand a user’s full attention by only presenting information via a screen and requiring the user to actively seek the data they need. Ambient displays typically show data abstractly and sometimes take on the form of art, and the user may not even be able to distinguish one from other objects in the background.

A study in the field of cognitive science [3] has shown that subjects can still accurately perceive data through the periphery while their main attention focuses on a different task, which means that ambient displays have the potential to be valuable sources of information. This way, instead of having many programs providing information on the user’s desktop and creating a sense of information overload, displays showing data in the periphery may have more of a calming effect.

There have been various ambient displays developed throughout the computing and design field, and have covered many of the basic senses. Some of these displays include the visual Dangling String [6], the auditory Audio Aura [2], and the scent-based Meeting Pot [4]. The Dangling String was one of the first ambient displays, and it consists of simply a string hanging from a motor, and the motor adjusts its speed according to the network traffic. The busier the network, the faster the string will spin. Audio Aura uses a headset and audio cues to convey information to a user regarding things such as new email or activity around them. The Meeting Pot is a
display that detects whether people are in a break room and then produces the smell of coffee at someone’s desk, to alert them that there are others taking a break if the user wishes to socialize with them.

Motivation

There are three purposes behind designing the Bus Mobile and the Daylight Display. The first is to provide a service to the users of the two computer labs that do not have windows. In order to determine what kinds of information would be useful to users, a preliminary survey was conducted, asking participants to rank in order information they would like to see in an ambient display. Some of the choices included how dark it is outside, the weather, the population of the computer labs, the network load on the login servers, when a bus was next scheduled to arrive, and sports statistics. The survey also queried the lab users with questions such as which bus lines they used frequently and which sports teams they followed. Both the bus schedule and the amount of daylight ranked highly after the results of the survey were evaluated. There were some types of information that ranked even higher, such as how full the labs were and which servers had the most traffic. However, it was decided that these data sources would not make effective ambient displays, since it is data that only needs to be obtained once before entering the lab, and not while one is working.

There are two more purposes behind the project. In addition to providing a service for the users of the labs, the motivation from the research perspective is to determine if ambient displays showing information not easily obtained otherwise will predictably influence people’s behavior. The third purpose and a desirable result would be to increase the users’ awareness of the bus schedules and the daylight schedule.

Hypothesis

It was expected that having the displays in the two computer labs would be a benefit to the users of those labs. The benefit would be that the knowledge that a bus is about to arrive or knowledge that it is starting to get dark will allow the subjects to make an informed decision to leave the lab within a specific time frame based on that information. For the effect of the Bus Mobile, it was predicted that there would be an increase in the number of students who leave the lab within an optimal time frame before a given bus arrival, because students would like being able to catch a bus immediately instead of waiting at the stop for one to arrive. For the Daylight Display, it is predicted that there will be an increase in the number of students leaving the lab in the time leading up to sunset. It is for safety reasons that we believe users of the lab would be interested in leaving before dark.

Method

Building and Programming the Displays

The Bus Mobile
Once the types of information to display were decided upon, the next step was to decide what the displays were going to look like and how they would work. It was decided that the display showing the bus schedules would use a display already built for another purpose. This display was known as the Weathermobile, which was a mobile designed to show the current weather downloaded from a weather website. The bus display was to replace the weather mobile because since this display was to be implemented in Berkeley during the summer months, the weather would not be very dynamic and would not provide information as interesting as desired.

A graduate student constructed the mobile using six motors attached to aluminum rods, which are computer controlled through the parallel ports. Around the base of the display hangs a curtain that is approximately six inches long, behind which the icons, attached to each of the motors with a wire, can be hidden from view. Bus numbers painted on wooden plaques for the six most popular bus lines mentioned on the pre-survey replaced the icons from the Weathermobile. A picture of the display is shown below as Figure 1.

![Figure 1: The Bus Mobile](image)

The display was designed so that the six bus numbers will be at various heights according to how many minutes are left before the next bus is scheduled to arrive at the stop closest to the building where the labs are located. Each inch the number hangs below the bottom edge of the skirt represents one minute remaining, for a maximum of twenty-five minutes. If no bus is scheduled
to arrive within twenty-five minutes, the bus number will move to its minimum depth and will be hidden from view behind the curtain. The display is updated every minute, and the icons will move up one inch per minute. After the bus has passed, the bus number will then be lowered the amount of inches that are remaining until the next bus is scheduled.

An application programming interface (API) was previously written for the mobile so that a program written in Java could easily control the mobile. The program written for this project parses the bus schedule data from text files and stores in arrays. The current time is determined using the local system clock and then compared to the bus schedules. Next, the minutes remaining until each bus arrives are calculated, and the program communicates to the Bus Mobile which bus numbers to move and the specific height to which they should move. This process is iterated every minute for an indefinite amount of time.

The Daylight Display

Construction of the Daylight Display was not nearly as complicated. The display consists of a regular floor lamp, which is controlled by ActiveHome, a device produced by a company named X10. The device includes a display for controlling the brightness of a lamp by adjusting how much power is supplied to the lamp. A picture showing the X10 devices is shown below as Figure 2.

![Figure 2: The X10 interface module and lamp module.](image)

The Daylight Display was designed to have the lamp adjust its brightness according to the recorded sunrise and sunset times. A number of sunrises and sunsets were observed to determine when it actually begins to get light and dark, so that the display could accurately show the light level outside. It was determined that, for this time of year in Berkeley, the sun begins to set
about forty-five minutes before the listed sunset time, and it is completely dark about thirty minutes after. For the sunrise, it begins to get light thirty minutes before the listed sunrise time, and it is completely light about forty-five minutes after. The display was designed to alert a user of the lab that it is beginning to get dark or light outside by flickering the lamp a few times, then beginning the cycle of brightening or dimming the lamp, depending on the time of day. A picture of the Daylight Display is shown below as Figure 3.

![Figure 3: The Daylight Display](image.png)

To get the lamp to adjust its brightness using the X10 controller, another Java program needed to be written. Fortunately, a Java API for the controller already existed, so the program could be written similarly to the Bus Mobile’s program. This program parsed and stored to arrays the sunrise and sunset times from a text file, which contained estimates on the times obtained from an almanac. It then determined if the time was before sunrise, during sunrise, after sunrise but before sunset, during sunset, or after sunset and then told the lamp how much to adjust its brightness according to the phase. The X10 controller allowed for 22 brightness levels from off to on, which meant that the light adjusted brightness approximately every three minutes.

**Data Collection**

The study was conducted in three phases. The first phase occurred in the week before the displays were to be deployed in the labs, when a questionnaire was distributed to the users of three labs, which they could fill out at their own leisure. Two of the labs were the ones where the displays would be located, and then the third lab was one that would have no display and would be used as a control. The questions on the survey covered various topics that could give us an indication of whether or not the information about bus arrivals and outdoor light levels affected a subject’s behavior.
Phase 2 of the project started about a week and a half after the surveys were first made available. It began with the installation of the two displays in two different labs. The Bus Mobile was suspended from the ceiling on one side of the room in a location where most users in the lab could see it when they look up. The notebook computer controlling the display was placed in the ceiling above the display. The Daylight Display was set up in a corner of the other lab where it would be the most noticeable. A metal tray with a locking mechanism was used to secure the notebook computer that was controlling the display to a nearby table. We hung a sign by each of the displays, explaining how to use them and where they could go for more information. As soon as the displays were deployed, we removed the surveys from Phase 1.

The planned length for Phase 2 was three weeks, but ended up being two and a half weeks. The first week was just to get the users of the lab used to the ambient displays, so that when the next survey became available, the novelty of the displays would have worn off. Surveys with different questions were made available to the users of the labs, this time with questions pertaining to how they use the display and whether or not it is useful to them. Users had the opportunity to complete surveys posted on the door, using an online form with the web address advertised in the labs, or completing the survey after being recruited in the hallway after leaving.

After the displays had been running for three weeks, the third phase began. Phase 3 started when the Bus Mobile and Daylight Display were removed, along with the surveys from the second phase. A third round of surveys were distributed to the labs in the same manner as the surveys from the second round. The objective of this questionnaire was to find data on the impact of the removal of the displays and whether or not the users of the labs missed having them.

In addition to the data collected from the surveys, monitoring of the labs was done for ten minutes a day for approximately two weeks. The observations made during the monitoring sessions consisted of how many people were in the lab initially, how many people entered or left the lab during the time period, how many users were there in the end, and then any observations that could be made about people using the displays, discussing them, or filling out the surveys.

Another source of data was a list of all the login and logout times from the system log were retrieved from each of the phases, which were compared to the sunrise and sunset times, along with the bus schedules, then compared from phase to phase.

**Results**

**Survey Data**

Seventeen users of the instructional labs responded to the Phase 1 survey, forty-three to the Phase 2 surveys, and twenty-two to the Phase 3 survey. It is assumed that the subjects are from a random sampling of users in the lab. To recruit the subjects of the study, surveys were posted at the door, the web addresses for the online surveys were written on the board, and people were solicited as they left the lab on several days.
There were several questions that appeared on all of the surveys. The first of these questions was the subject’s reason for leaving the lab at the time they completed the survey. In an analysis of the responses to this question, it showed that the most popular reason for leaving before the displays were installed was because the subject was finished with their work, which was the case for 40.9% of the subjects. The second most popular response for this phase was because the subject was leaving to get something to eat, which accounted for 31.9%. Other responses included needing to catch a bus, heading to a class, being forced to leave the class because of a lab starting, and needing to get home before dark. These results were for all three phases in all of the labs.

For the phase where the displays were deployed in the labs, the results were slightly different. The subjects stating they were leaving because they were finished with their work was still the most popular response, accounting for 34.8%, and leaving for meal was the third most popular response at 17.4%. The second most popular response from this phase included 26.1% of the subjects, who indicated they were leaving for other reasons not listed on the questionnaire. These subjects wrote in their own reasons for leaving, which were varied. After the displays had been removed from the lab, the results more closely matched the results of the first phase, with 54.5% of subjects leaving because they were finished with work and 27.3% leaving to get something to eat.

One question that appeared on all the surveys in all three phases of the experiment was whether the bus schedule or daylight schedule was important to the users. Out 61 total respondents from all three phases, 16 subjects, or 26.2%, found the bus schedule information useful. For the daylight schedule, 18 out of 61 (29.5%) were interested in the data. This indicated that the schedules were important to fewer than half of the subjects. This information is best analyzed when combined with the responses to the questions on how useful the subjects found the displays. The questions include whether the user felt that the display was useful in finding out either the bus or daylight schedules, how many times per lab visit the display was used, and whether the users missed the display after it was removed. To find this information, the responses of “Strongly Agree” or “Agree”, on a Likert scale were considered to be positive responses.

Overall, the Bus Mobile was effective for a large percentage of interested users, while the Daylight Display was effective for a smaller percentage of users. Table 1 shows a comparison between the subjects who answered that a bus or the darkness did influence their decision to leave the lab during Phase 2, and whether the display was helpful in gaining that information. All of these results come from Phase 2.

<table>
<thead>
<tr>
<th></th>
<th>Interested in data</th>
<th>Found display useful</th>
<th>Did not find display useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Mobile</td>
<td>6</td>
<td>5 (83.3%)</td>
<td>1 (16.7%)</td>
</tr>
<tr>
<td>Daylight Display</td>
<td>10</td>
<td>3 (30.0%)</td>
<td>7 (70.0%)</td>
</tr>
</tbody>
</table>

*Table 1: Effectiveness of the Bus Mobile and Daylight Display for subjects interested in data.*
Most of the users (80%) from Phase 2 who were interested in the bus schedule used or looked at the Bus Mobile, while only half of the users who were interested in the daylight information used or looked at the Daylight Display. Similar results were found from the Phase 3 responses. Of the users interested in the bus schedule information, 80% of the subjects stated they missed the Bus Mobile after it was removed, while only 50% of the subjects interested in the daylight schedule indicated they missed the Daylight Display after its removal. It should be noted that although the percentages ended up being the same in Phase 2 and Phase 3, the subjects were not necessarily the same set of respondents.

To give a more solid verification of the results, Bivariate Spearman correlations were calculated for all pairs of ordinal variables using statistical software. Table 4 shows a summary of the Spearman correlation values for the ordinal variables of interest with strong, positive correlations with high significance. Strong, negative correlations with high significance are found in Table 5, and Table 6 shows ordinal variables where a strong correlation was expected, but one was not found.

<table>
<thead>
<tr>
<th>Correlation between interest in bus schedules and …</th>
<th>Phase</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest in the daylight schedule</td>
<td>1</td>
<td>0.561 (p &lt; .05)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.598 (p &lt; .01)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.783 (p &lt; .01)</td>
</tr>
<tr>
<td>Usefulness of the Bus Mobile</td>
<td>2</td>
<td>0.808 (p &lt; .01)</td>
</tr>
<tr>
<td>Missing the Bus Mobile after it was removed</td>
<td>3</td>
<td>0.595 (p &lt; .01)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Correlation between interest in the daylight schedule and …</th>
<th>Phase</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usefulness of the Daylight Display</td>
<td>2</td>
<td>0.618 (p &lt; .01)</td>
</tr>
</tbody>
</table>

*Table 2: Strong, positive Spearman correlations with high significance*

<table>
<thead>
<tr>
<th>Correlation between the number of hours spent in the computer lab and …</th>
<th>Phase</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest in the daylight schedule</td>
<td>2</td>
<td>-0.731 (p &lt; .01)</td>
</tr>
<tr>
<td>Missing the Daylight Display after it was removed</td>
<td>3</td>
<td>-0.715 (p &lt; .01)</td>
</tr>
</tbody>
</table>

*Table 3: Strong, negative Spearman correlations with high significance*
Use of the Daylight Display several times per lab visit  |  2  |  0.220 (p > .05)  
Missing the Daylight Display after it was removed  |  3  |  0.323 (p > .05)  

<table>
<thead>
<tr>
<th>Correlation between interest in bus schedules and …</th>
<th>Phase</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of the Bus Mobile several times per lab visit</td>
<td>2</td>
<td>0.064 (p &gt; .05)</td>
</tr>
</tbody>
</table>

**Table 4:** Spearman correlations with low significance where a high significance was expected.

**User Logout Times Data and Lab Monitoring**

Because self-evaluations through surveys do not always give a complete picture of how users spend their time in the computer labs, a second set of data that would cover every person in the lab was necessary to make evaluations on the effectiveness of the displays. The type of data used for this project was the logout times for all of the users in the labs during the times of interest, as reported from the system logs on the servers used in the three instructional labs. Additionally, the data from monitoring of the lab was collected, which served the purpose of verifying that the times reported by the system log were indeed accurate. Due to the fact that the users of the labs were working during the times the labs were monitored, we were unable to make observations other than how many students were entering and leaving the labs. We would have liked to have been able to tell if users were giving their attention to the displays, or having discussions with other users about the displays, but we unfortunately did not observe these things.

We removed certain data to make our results resemble the typical use of the lab. This included removing the entry of any user who had a total login time of 5 minutes or less. This is to reduce the amount of data that may skew the results due to a user merely logging in to check mail or logging into a machine, then immediately deciding to use another one. Another set of confounding factors that would alter the results were the times that lab sessions were scheduled to meet in the rooms with the displays. All logout times just before, during, and after all lab sessions were not considered.

To analyze the logout data for the Bus Mobile, a script was written to calculate the time each bus would next arrive following the logout time. There are six bus lines the mobile tracks, but each subject is only going to take, at most, one bus. We came up with a heuristic to determine the bus each subject was most likely to take, which is as follows. For each bus, we calculated a minimum and maximum length of time it would take someone to walk from the lab to the bus stop at a reasonable pace. If a logout time was within this range, then there was a significant probability that the subject left to catch that bus. If the logout time was in the range of several buses, the bus with the closest time was chosen as the most likely bus. Note that this assumes every subject left to catch a bus, which we know from our survey data is not the case. Nonetheless, we did control for a number of confounding variables when analyzing this dataset and we believe this heuristic serves as a reasonable estimate of bus-influenced logout behavior.
Once the most likely bus was determined, the logout time was subtracted from the arrival time for that bus. The resulting time we call the logout-bus delta.

To find the statistical significance of the logout times, we ran a t-test across the three phases of the project. The phases were before the deployment of the Bus Mobile, during the deployment, and after the removal of the Mobile. The t-test found a significant difference between mean logout-bus deltas across Phase 2 and Phase 3 in the lab containing the Bus Mobile (t = 1.992, df = 1485, p < .05). There were no significant differences across means in the other labs, or across Phases 1 and 2 in the lab with the Bus Mobile.

There is one problem, however, with our heuristic as described above. Two of the bus lines ran quite frequently at certain times of the day and were therefore showing up many more times than the other four bus lines. To fix this problem, we repeated the heuristic, but this time ignoring those two bus lines. Running an Analysis of Variance (ANOVA) on the newly calculated logout-bus delta means showed a significant difference from Phase 1 to 2 and from Phase 2 to 3 in the computer lab where the Bus Mobile was located (F = 2.763, df = 4, p < .05). As with the results of the t-test, no significant difference was noted in the other two labs.

Due to time constraints, the analysis of the logout data for the Daylight Display and daylight schedule could not be included in this report. The analysis and discussion of the Daylight Display system log data will be included in the study as future work.

**Discussion**

The reasons people reported for leaving the lab indicated that there were not as many people who were interested in the displays as previously predicted. The interpretation for this is that since filling out the survey takes time, people who were leaving for other reasons, such as being in a hurry to catch a bus, or to make it to class, might not have had time to take the survey. This was reaffirmed by the answers to the question about whether or not the subjects were interested in the data indicating an overall negative trend. Another reason for this observation could be that there is a percentage of students do not use the bus at all, or are not concerned with leaving the lab after dark. Fortunately, there were enough users who indicated they were interested in the bus and light schedules to do some analysis on the displays.

The next set of data in Table 1 and the other two survey questions is perhaps the most significant analysis of the survey data. This focuses the survey responses on the users who indicated they were interested in the bus schedules or the light schedules, and then compares it to whether or not they found the displays useful, how often they used the displays, and whether or not they missed the displays after they were removed. Table 1 shows the number of users who found the Bus Mobile or the Daylight Display useful, who were also interested in the data. A large majority, 83.3% of users found the Bus Mobile to be helpful in determining the schedule of the busses. However, only 30% of the subjects indicated that the Daylight Display was useful in determining the daylight schedule.

This trend continues in for the other two survey comparisons. Of the users interested in the bus schedules, 80% stated that they used or looked at the display several times per lab visit. Another
80% who were interested state that they missed the Bus Mobile after it was removed. For the Daylight Display, the results showed that the display was not as useful for the occupants of the lab, with only 50% stating they used or looked at the display during their time in the lab, and 50% missed the display after it was removed. This set of data indicates that the Bus Mobile was highly effective in providing data valuable to the users of the lab, and the Daylight Display was not quite as effective.

To strengthen the previously evaluated data, the correlation tables were calculated to see if, by using all the data, trends existed between ordinal variables. In all three phases, a fairly significant positive correlation was found between people who indicated they were interested in the bus schedule and the daylight schedule. A possible explanation for this could be that some people who are concerned about their safety after it gets dark would be interested in taking the bus home instead of walking.

In the survey data of Table 2 for the phase during which the displays were up, very strong, positive correlations with high significance were shown to exist between people that were interested in the bus schedule and people who found the Bus Mobile useful and who missed it when it was removed. This reinforces the analysis that the Bus Mobile was effective for the subjects who were interested in the data. Another positive correlation, although not as strong, was found between the students interested in the data and how useful they found the Daylight Display.

Table 3 shows two strong, negative correlations that are significant. The main point of interest for these negative values is that they both relate to the Daylight Display. It seems that the longer the students spent in the labs, the less interested they were in the daylight schedule. Perhaps the subjects who were in labs the longest were working so hard that they didn’t want to be know what time of day it was. As an anecdotal verification of this theory, it should be noted that one subject pointed out this idea in the comment section of the survey.

Correlation values in Table 4 were for the categories were positive correlations were expected but were not found. For example, it was expected to find a correlation between the students who indicated they were interested in the data and the number of times they used or looked at the display while in class, but there were low values for these in both the case of the Bus Mobile and they Daylight Display. The rationalization for this could be due to the fact that even though people were not interested in the data, they still looked at the displays, either because they were facing that direction, or because they found them interesting, if not useful. Also, it could be that the subjects who were interested in the data did not use the display because they did not understand how it worked, or they never saw a change since it was only actively changing during three hours in a given day. The other correlation that was expected but was not observed to be significant was the comparison between the subjects interested in the daylight schedules who missed the display after it was removed. This could be for the same reason as previously offered. Why would a user of the lab miss the display if they never understood how it worked to begin with?

The above results, even without the additional login time data factored in, give some insight into whether or not the hypotheses were correct. For the prediction that the Bus Mobile and Daylight
Display would impact people’s decisions to leave the lab at a certain time, it can be said that the Bus Mobile was definitely effective for the people interested in the data, although not for as many people as originally expected. Some subjects had very positive comments about the Bus Mobile, saying they chose to work in the lab where it was displayed because they found it so convenient.

For the Daylight Display, the survey results show the display was only effective for a maximum of half of the subjects interested in the daylight schedule, which does not meet the expectation. There are several possible explanations for why this might be the case, using the comments from the surveys as an indication. For one, the design of the Daylight Display might not have been appealing. Many people saw it as just a lamp in the corner of the room and may not have noticed there was anything special about it unless they got closer to it and read the sign. Also, some subjects mentioned they never noticed the display working, which could mean a display that changes more frequently is more useful. One subject complained that the lamp was too bright and painful to the eyes, which would also make it less appealing. These are all things to take into consideration for future work that could be done on the Daylight Display.

The analysis of the logout time data involving the Bus Mobile was supportive of the evidence found in the results of the surveys. The significant difference in logout-bus delta means across the three phases, as shown by the t-test and ANOVA analyses of the empirical logout data, shows a significant likelihood that our first hypothesis is correct: the presence of the Bus Mobile, which presents dynamic, peripheral information, affects the behavior of those exposed to it.

As far as the lack of a significant difference in logout-bus delta means between Phases 1 and 2 in the Bus Mobile lab, we are not sure why there was no significance. A number of factors could have contributed to this, including the fact that the Independence Day holiday weekend occurred during Phase 1, which means the labs were not filled to their normal capacity on those days. It is important to note the fact that this analysis was not significant does not disprove the hypothesis. It simply means that the data does not give evidence to support the hypothesis.

Without the analysis of the logout time data for the Daylight Display, we can only draw tentative conclusions about the hypothesis that the Daylight Display would influence a subject’s behavior. Judging from the survey results, the Daylight Display is somewhat effective at providing information useful to the subjects.

**Conclusions and Future Work**

The ambient displays in this project were designed to provide information through users’ peripheral perception, as opposed to standard output devices which require a user’s full attention. The Bus Mobile provided the users of a computer lab with information regarding bus schedules, and the Daylight Display conveyed information to users in a windowless lab how light or dark the conditions were outside. For the Bus Mobile, we hypothesized that the peripheral display of the time left until the next bus arrivals would help subjects interested in riding the bus optimize their logout times. The results from both surveys of the lab users and analysis of student logout times indicate that the Bus Mobile was indeed influential in helping subjects interested in the bus schedules. For the Daylight Display, a similar hypothesis was made for subjects preferring to
depart the windowless lab before sunset. It was expected that these subjects might optimize their logout times based on the ambient display of sunset times. With just the results from the surveys analyzed, we conclude that the Daylight Display was somewhat effective at achieving its motive.

The next step with this project is to complete the analysis of the system log times with respect to the daylight schedule, and use this information to strengthen the conclusion about the Daylight Display. The analysis of this will be similar to the heuristic used in the analysis of the Bus Mobile. Additionally, if the rest of this data proves that the Daylight Display is not as effective of an ambient display as desired, a redesign of the display may occur in the future. If the resources are available, there may also be some work done to find a permanent location for the displays so they can be useful to people in a real life setting.

The purpose of ambient displays is to provide information in the periphery of the users, and the ambient displays designed and evaluated in this study accomplished that purpose. Some important considerations for designing ambient displays are to make sure that the information is important to the users. A display that conveys information users do not wish to know will not be beneficial. Also, the evaluation techniques of ambient displays are currently very complex, and some work could be done to simplify the process of evaluation.

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