DEVELOPMENT AND USABILITY EVALUATION OF AN

E-LEARNING APPLICATION USING EYE-TRACKING

A Thesis

by

PUNIT ASHOK DEOTALE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Visualization

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Approved by:

Chair of Committee,   Ann McNamara
Committee Members,   Carol LaFayette
                       Sheng-Jen Hsieh
Head of Department,   Tim McLaughlin

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ABSTRACT

Development and Usability Evaluation of an E-learning Application Using Eye-tracking.

(May 2011)

Punit Ashok Deotale, B.E., University of Mumbai, India

Chair of Advisory Committee: Dr. Ann McNamara

The primary goal of this research is to use eye-tracking in the development and usability evaluation of an e-learning tool called "Problem Solving Environment for Continuous Process Design" (PSE). The PSE is meant to aid engineering students in learning the design processes of automated manufacturing systems. PSE is a user-interactive Flash application which gives the user an opportunity to virtually design an automated industrial process by manipulating the parameters associated with it. PSE is evaluated using eye-tracking experiments in which users' eye movements are tracked using camera and sensors to determine users' gaze direction and fixations. The data collected from the experiment is used to determine if use of visual cues improved the usability of the PSE. Results show that use of visual cues for gaze direction improved the usability of the PSE application, based on faster task completion times and improved navigability.

DEDICATION

To my family

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Ann McNamara for her continued support and guidance throughout the course of this research. Her expertise in the field of eye tracking, writing skills and high standards have been instrumental in successful completion of this thesis. I would also like to thank my committee member Dr Tony Hsieh for giving me the opportunity to work on the PSE which formed the basis of this thesis. His innumerable inputs and ideas over the last one and a half year helped me immensely while working on this thesis. Special thanks to Professor Carol LaFayette who apart from being an invaluable committee member has also played a very important role in my academic life as my first academic adviser when I first joined the Vizlab.

Thanks also go to my friends and fellow Vizzers, faculty and staff at the Department of Visualization for making my time at Texas A&M University a great experience. I also want to extend my gratitude to all the people who were willing to participate in the study.

Very special thanks to Rabab for being patient and supportive as well as helping me with programming, statistics and experiments.

Finally, thanks to my parents for their encouragement, love and everything.

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CHAPTER I

INTRODUCTION

E-learning

The use of e-learning or virtual learning environments has steadily increased with the advent of technology. Educational institutions at all levels are developing systems for e-learning. E-learning can be broadly defined as the *use of electronic tools or processes for learning or teaching*. It encompasses all forms of electronically supported learning and teaching. Software applications and media that are used to implement or aid the learning process are known as e-learning tools [1]. These tools can be as simple as e-books, which replace print books, or as complex as elaborately programmed software applications, which incorporate varying combinations of images, videos, text and user interaction. It can even take the form of an educational game at the highest level of user interaction. In addition to these technologies, today's social networks are also used as an important tool towards e-learning [2]. To improve the usability of the e-learning solutions, it is necessary to perform usability evaluation. Eye-tracking offers a platform for evaluating the usability of the e-learning applications.

This thesis follows the style of *IEEE Transactions on Visualization and Computer Graphics*.

Eye-tracking

Eye-tracking is the process of tracking the movements of users' eyes to determine point of gaze. Eye movements consist of saccades and fixations. Saccades are very rapid eye movements that reposition the eye to a new point of interest in the visual field [3]. Saccades typically last for 10 ms to 100 ms. Focusing of the eye on an object is termed fixation. A fixation typically lasts 300 ms [4]. The path that the eye follows during successive saccades and fixations is known as a scanpath. An eye-tracking device records these movements. Software tools are used to render the scanpath into a visual representation. Generally, fixations are represented as dark spots or dots and saccades as thin lines depicting a path. The darker the spot, the longer is the fixation time.

Eye-tracking can be a very effective tool in the field of e-learning as it gives the developers an opportunity to learn how to better present the learning material based on user's visual attention span, gaze direction and other visual data. Eye-tracking was used in this thesis as a usability evaluation tool.

Gaze Direction

Baily et al. presented a technique where visual modulations are used in a digital image to direct gaze around the image [5]. This technique capitalizes on the fact that our eyes are sensitive to movements in the peripheral region of the field of view, but the acuity is poor. Subtle visual modulations are introduced in the peripheral region of the field of view to attract the user's attention. These modulations are then terminated before the

eyes fixate on them. This means that the user's gaze is directed towards the intended area without him knowing what caused it. The research in this thesis also used gaze direction but took a less subtle approach in case of the visual cues directing the users' gaze.

Problem Statement

E-learning applications are difficult to use. It becomes difficult for a novice user to use them effectively to achieve the desired goal due to ambiguous user interface or too much data to process.

Significance

Most of the e-Learning solutions, though effective, cannot or do not try to mimic a real teacher in a physical environment. A teacher has the capacity to adapt his teaching techniques according to the interest levels and behavior of his students. He also has the ability to draw the students' attention to particularly important information that might otherwise have gone unnoticed in the vast pool of information available.

In an e-learning environment, the amount of information presented can be overwhelming for the student, often because there is more data than a user can grasp effectively. Moreover, data can be haphazardly scattered all over the page creating ambiguous flow of information [6].

It is not easy for the user to grasp a great amount of information while simultaneously figuring out the flow and importance of the information [6]. For example, when the user is presented with a page having multiple videos that are meant to be watched in a particular order in order to facilitate correct learning, it can be difficult for the user to correctly follow that particular order if proper instructions are not given. Furthermore, it is not in the best interest of the user if he is given explicit instructions, as there will be no impetus for the user to cerebrate. Consequently, it will make the whole learning process a one way operation [7]. There is a need to examine the usability of the e-learning solutions as well as user responses to such solutions so that the e-learning process becomes an intuitive and effective process for the student.

Solution

Use of visual cues to direct users gaze towards the important regions on screen (Significant areas of interest).

Hypothesis

"An e-learning application which has visual cues to direct the user's gaze is easier to navigate, and is a more intuitive e-learning tool than the one without visual cues."

CHAPTER II

BACKGROUND

E-Learning Applications and Problem Solving Environments (PSEs)

E-learning tools are being used in many fields including mathematics, science and engineering. ActiveMeth [8] is a web based PSE whose goal is to teach mathematical courses. It is interactive. Students choose from the scenarios and courses they want to study. Shin et al. [9] developed a PSE to teach students concepts in process systems engineering. Their goal was to recreate a virtual laboratory where students perform virtual experiments in the form of simulations and read about various process system engineering concepts. iVSiCE (Interactive Visualizations in Civil Engineering) [10] is a PSE which makes use of animations and visualizations of simple engineering concepts or processes and "Interactive Learning Objects (ILO)". ILO's are simple interactive applications developed in Flash that can be deployed on the web. Holzinger and Ebner [11] research the role of Flash programming in the development of web interactive PSEs and conclude that Flash is a useful tool for the creation of simple web applications with very simple graphics and visualization that can be effectively deployed on the web. It minimizes several issues like operating system dependency, large file sizes and low quality graphics. Goodyer et al. [12] take the complexity of the PSE to the next level by implementing it on a network and remotely performing parallel modeling and experiments that involve visualizations and simulations that facilitate experimentation.

Cheng and Fen [13] developed a web based distributed PSE, which aims to facilitate computer aided engineering technologies. It has three-tier architecture. One of the components is a web based client presentation interface that uses scientific visualizations, simulations and data analysis. It is a java applet that can be deployed on the web. Echem++ [14] is an object-oriented PSE for electrochemistry. It uses adaptive algorithms that provide problem solving tools and dynamic electrochemical simulation models. Kim et al. [15] introduced a PSE for Multidisciplinary Design Optimization (MDO). MDO is a technology which is used in the design of ships and automobiles. The problem solving environment also provides a platform for global collaboration where designers and researchers can share their designs through a web portal. GasTurbnLab [16] is a multidisciplinary PSE for gas turbine engine design. It provides designers with tools to design, model and run simulations of gas turbine engines which would otherwise be a very complex and demanding procedure. Hyper-TVT [17] is an interactive learning environment which encourages students of chemical and process engineering to use multimedia technology in their learning. It uses pictures, animations, modeling, simulation environments, videos and self-test tools. Hyper-TVT contains textual and visual information on topics in chemical engineering that include separation processes, absorption, evaporation, distillations and liquid-liquid interactions. Undreiu et al. [18] developed a PSE using LabVIEW visual programming. Their problem solving environment has interactive tutorials on concepts in physics. It is web accessible and involves graphical symbols, modular structures and ability to create templates. PDE.Mart [19] is a PSE that deals with solving partial differential equations by using

numerical simulations. It has three different modules to communicate with the user through a graphical user interface, a server which builds solutions for the partial differential equations and a library containing building blocks for the problems and solutions respectively. Ebner and Holzinger [20] try to make learning more fun and interactive by using Game Based Learning (GBL). Games are similar to problem solving environments but with more interactivity and entertainment. They developed an online game that tries to impart complex theoretical knowledge in civil engineering. Ryan et al. [21] developed a PSE that teaches students concepts in engineering economics. The application also helps students develop their cognitive ability to create designs in industrial engineering as well as their meta-cognitive ability by assessing the solutions they came up with and justifying their actions.

While there are many factors one needs to take into account while designing a PSE, the most important would be creating something that will take into account user behavior or skill level. Atman et al. [22] conducted a study to compare freshman and senior engineering design processes. Although it wasn't a PSE, it gave valuable insights into the design practices of students. The study concluded that seniors produced higher quality designs as compared to freshmen.

Usability Evaluation Using Eye-tracking

E-Learning as a teaching tool has a long history. Only very recently, it has begun to be used extensively as an effective learning tool. Early e-learning tools were plain

documents that could be read on the computers. Over time, e-learning tools have evolved into feature rich interactive applications. With increasing complexity, the role of usability testing of the tools becomes important. "AdELE - Adaptive E-Learning through eye-tracking" was one of the first systems to use eye-tracking extensively in e-learning applications [23]. AdELE is a real time adaptable e-learning solution which uses real time eye-tracking. AdELE employs eye-tracking and other techniques to track users' behavioral characteristics such as objects and areas of focus, time spent on particular areas on screen, frequency of visits etc. It processes the data in real time and based on the data, it gives users visual suggestions in the form of pop-up messages.

"Empathic Tutoring Software Agents Using Real-time Eye Tracking" is a system that uses intelligent software agents which track the users' eye movements and other behavioral patterns and use the data to make useful adaptations in the tutoring software for different users [24]. Researchers performed usability testing on the system using eye-tracking and survey questionnaires that users were asked to answer after performing the experiments. In this system, a software agent tracks users eyes to determine the user interest, and based on the data, the agent directs the user to relevant information the user is interested in by using visual cues. "The e5Learning project" also deals with user aware eye-tracking based e-learning solution [25]. Though all of the above described systems present important research in terms of adaptive real time eye-tracking and intelligent tutoring systems, they do not address the subject of usability evaluation in detail.

There have been some studies that tried to do usability analysis on the e-learning solutions with the help of various techniques. One of the most popular techniques is heuristic evaluation. Ardito et al. discuss some of the heuristics to evaluate e-learning such as: consistency, less user memory load, informative feedback, clearly marked exit, shortcuts, help and documentation, aesthetic appeal of the interface, visual clarity etc.[26]. Another important and widely used technique is think-aloud method [27]. In this method, students are asked to say out loud what they are thinking while using an e-learning solution. Another method is to use eye-tracking technology for usability evaluation of e-learning solutions. Ehmke and Wilson used eye-tracking to identify problems in web usability [28]. They performed a study wherein individuals were asked to use certain websites while their eye movements were tracked. The study was used to establish links between common usability issues and eye-tracking matrix. Goldberg and Kotval conducted a similar study but were interested in studying software with a Graphical User Interface (GUI) [29]. They deliberately used a poorly designed interface to distinguish between user responses to the "good" and "bad" interfaces. In the poorly designed interface, they placed tools haphazardly about the screen while in the good one; tools were grouped in separate categories. Eye-tracking data generated from the experiments helped the researchers conclude that the bad design was difficult to navigate and users' eyes moved a lot during the course of experimentation as compared to the good design where users could easily find the tools they were looking for.

CHAPTER III

GOALS AND OBJECTIVES

Goal

The goal of this research is to test whether the use of visual cues is effective in directing the users gaze to help them navigate through the user interface.

Objectives

The objective of this thesis is to investigate whether eye-tracking and gaze direction techniques can be used to improve the usability of the PSE. Following are the steps necessary to carry out the objectives:

- Develop of e-Learning applications.

- Perform eye-tracking experiments for usability evaluation.

- Data analysis.

- Make necessary changes in the prototype to suggest a final better usable application.

CHAPTER IV

METHODOLOGY

The research plan was divided into four phases:

- Development of e-learning solutions.

- Conduct eye-tracking experiments for the usability evaluation of the tool.

- Analyze the data generated from the experiments.

- Documentation of results.

Development of E-learning Application

The PSE for Continuous Process Design is an e-Learning application developed in Adobe Flash CS4. The goal is to provide users with a learning opportunity by allowing them to design a prototype of a production process according to the parameters they specify. Designing a production process can be a difficult process. The designer has to consider many factors, including cost and time. It is not cost effective to physically assemble the machines together before designing the assembly in terms of parameters like cost, cycle time and production rate. Engineers often face these issues when designing a cost-effective production process. While there are sophisticated solutions that fulfill the needs of an engineer in a professional industrial setting, those are not easily available for an inexperienced user in an academic setting. There is a need for a simple application that handles the design problem at a very basic level focused on

learning so that it becomes easier for students when they progress towards a more detailed and sophisticated solution.

In the PSE, the user chooses the machines or equipment that they want to use in their design. Parameters like cost, time of operation, number of machines, interconnections are user controlled which can be changed to better optimize the design and achieve desired cycle time. Examples of processes would be Soap Production and Cane Sugar Production.

Problem Solving Environment Overview

The PSE is a learning based application. This section gives an overview of the application and detailed explanation of the process flow.
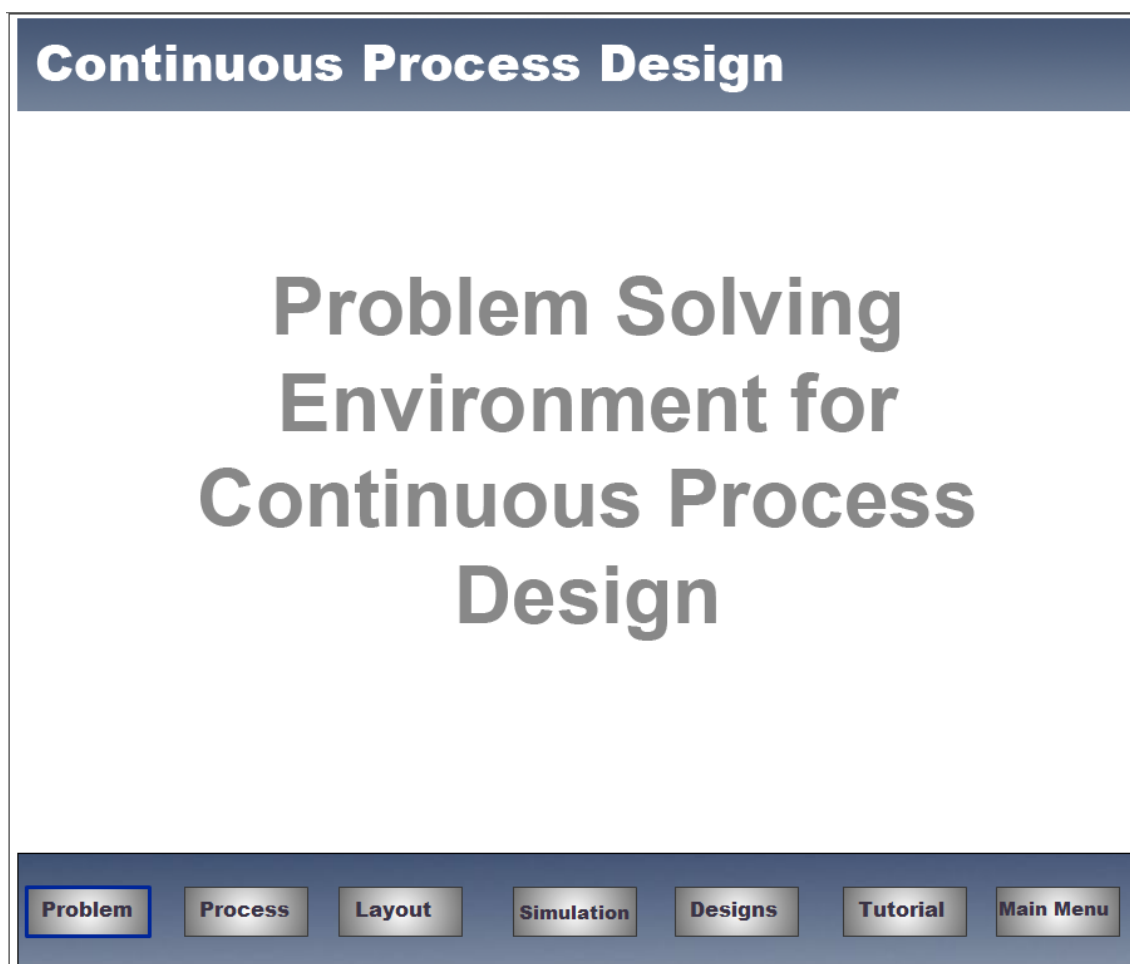
Fig. 1: Title page of the PSE for Continuous Process Design

The application begins with the title page as illustrated in Figure 1. There are seven buttons to choose from. The user can view the tutorial or start with the "Problem" button. When the user clicks on the "Problem" button, several problems appear as shown in Figure 2.

Fig. 2: Problem selection screen of the PSE

The next window (as shown in Figure 3) allows users to choose different machines or equipment for the process they intend to design. There are host of processes to choose from such as fluid handling, cooling and solid transfer. The user can decide which equipment fits the needs of his design in terms of functionality, cost and other parameters. After selecting the machines, the user is expected to enter time and cost into the fields labeled with their respective names.

Fig. 3: Equipment selection screen of the PSE

On the layout page as shown in Figure 4, users arrange the symbols in a particular order

and make interconnections according to the process requirements.
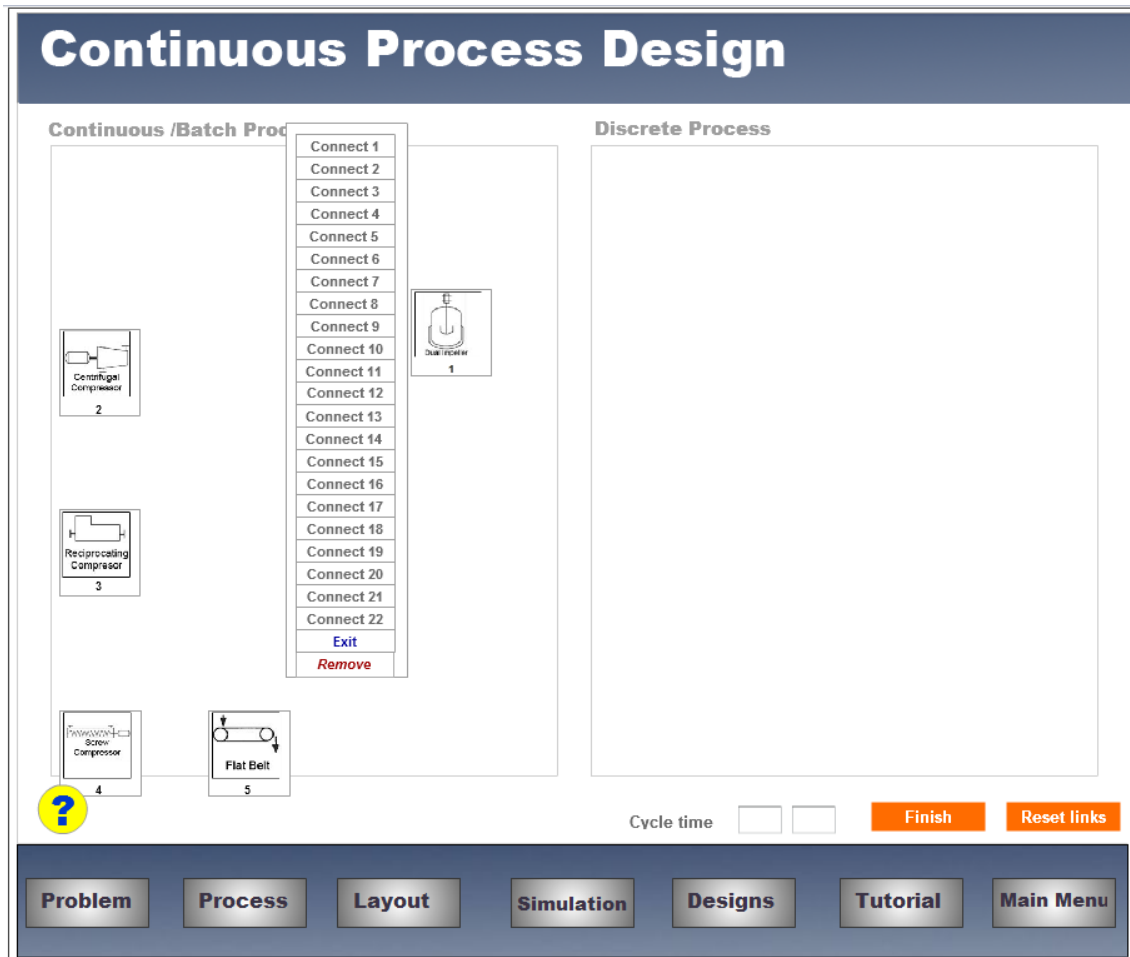
Fig. 4: Layout screen of the PSE

Figure 5 is a screenshot of "Simulation" page which shows users very basic animations for individual machines depicting their functions.
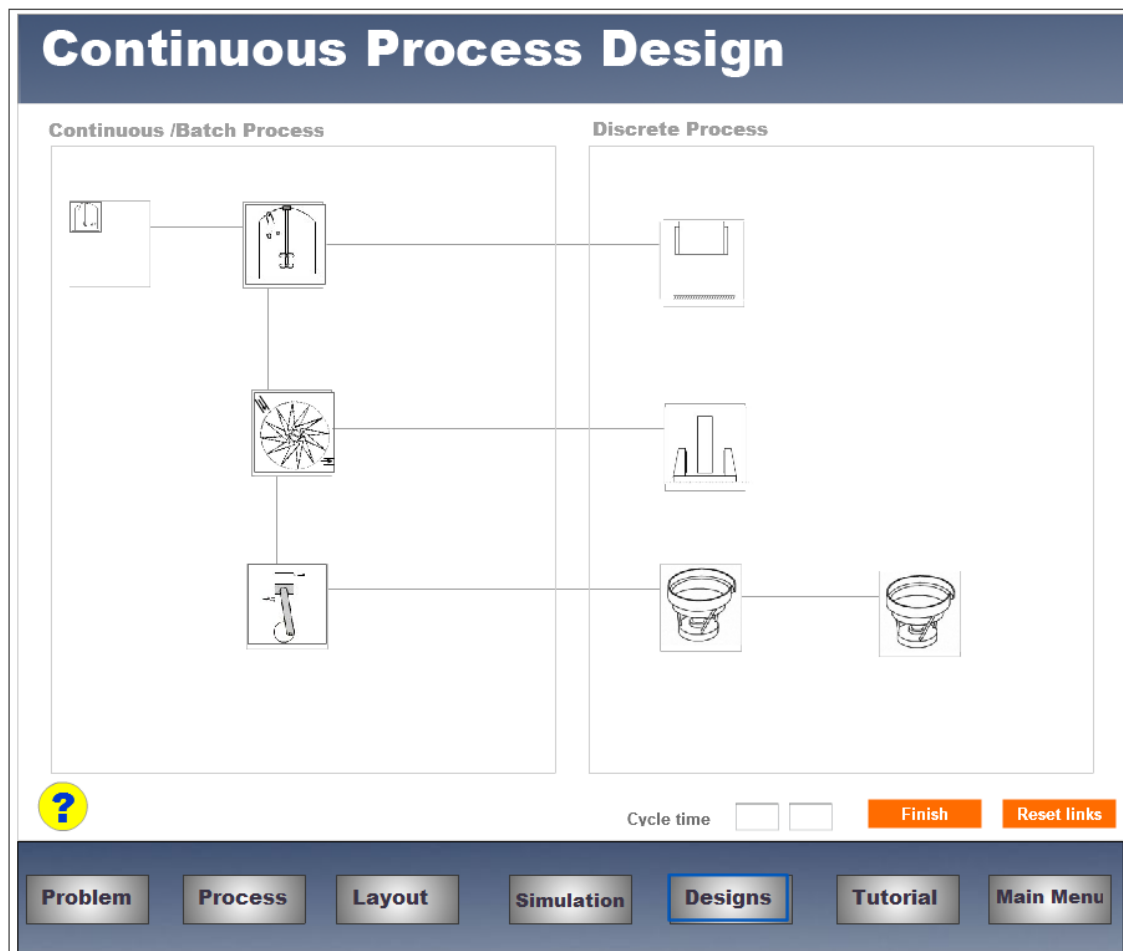
Fig. 5: Simulation screen of the PSE

The Designs tab allows review of all designs created in a single session. The tutorial tab takes users to a tutorial (Figure 6) where the usage of the application is explained with very specific instructions and imagery depicting a typical process flow towards achieving a desired goal.

Fig. 6: Tutorial screen of the PSE

Flow Chart

The flow chart in Figure 7 shows the process flow.
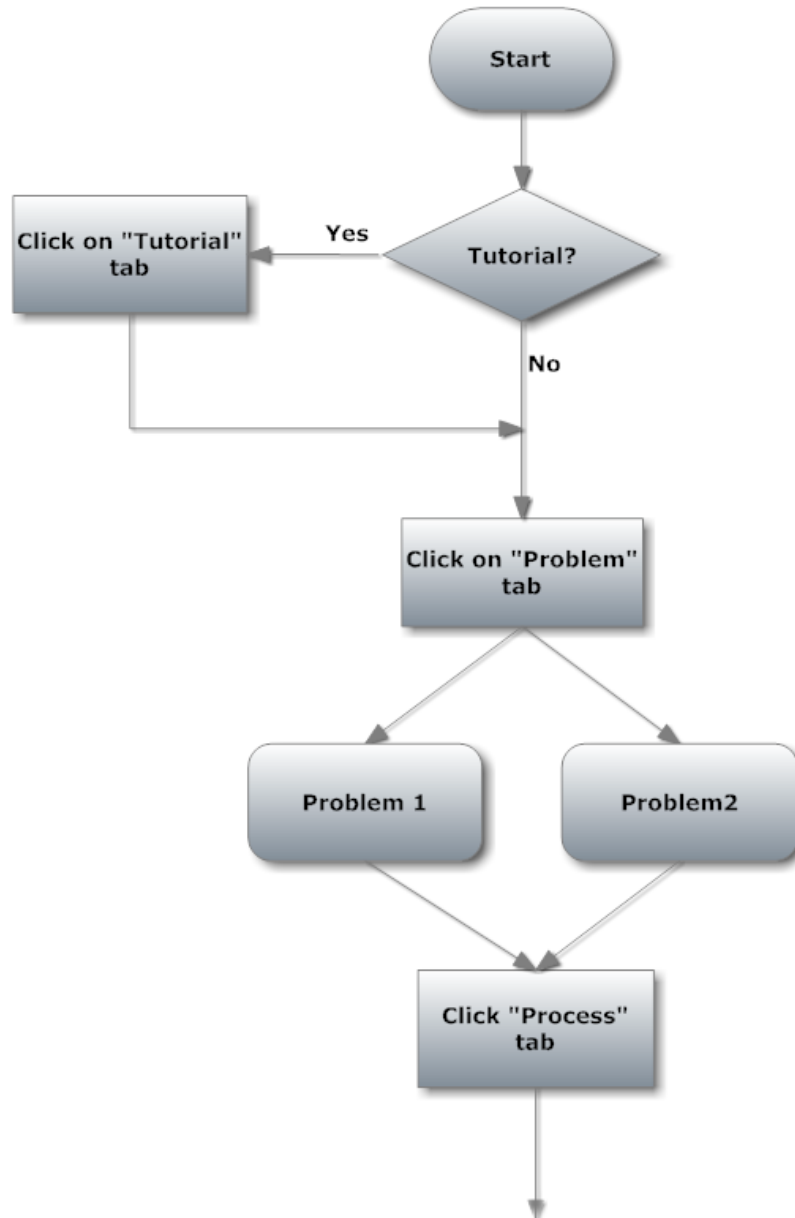
Fig. 7: Flow chart
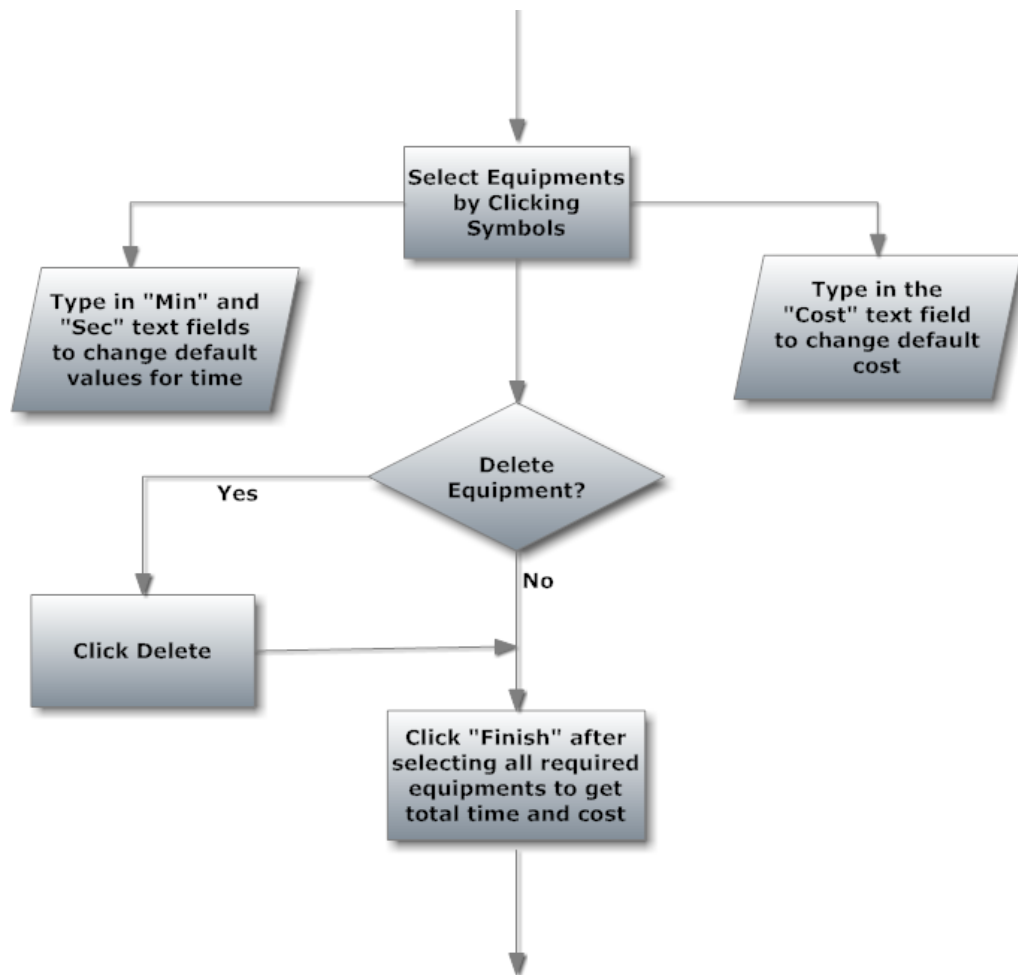
Fig. 7: Continued
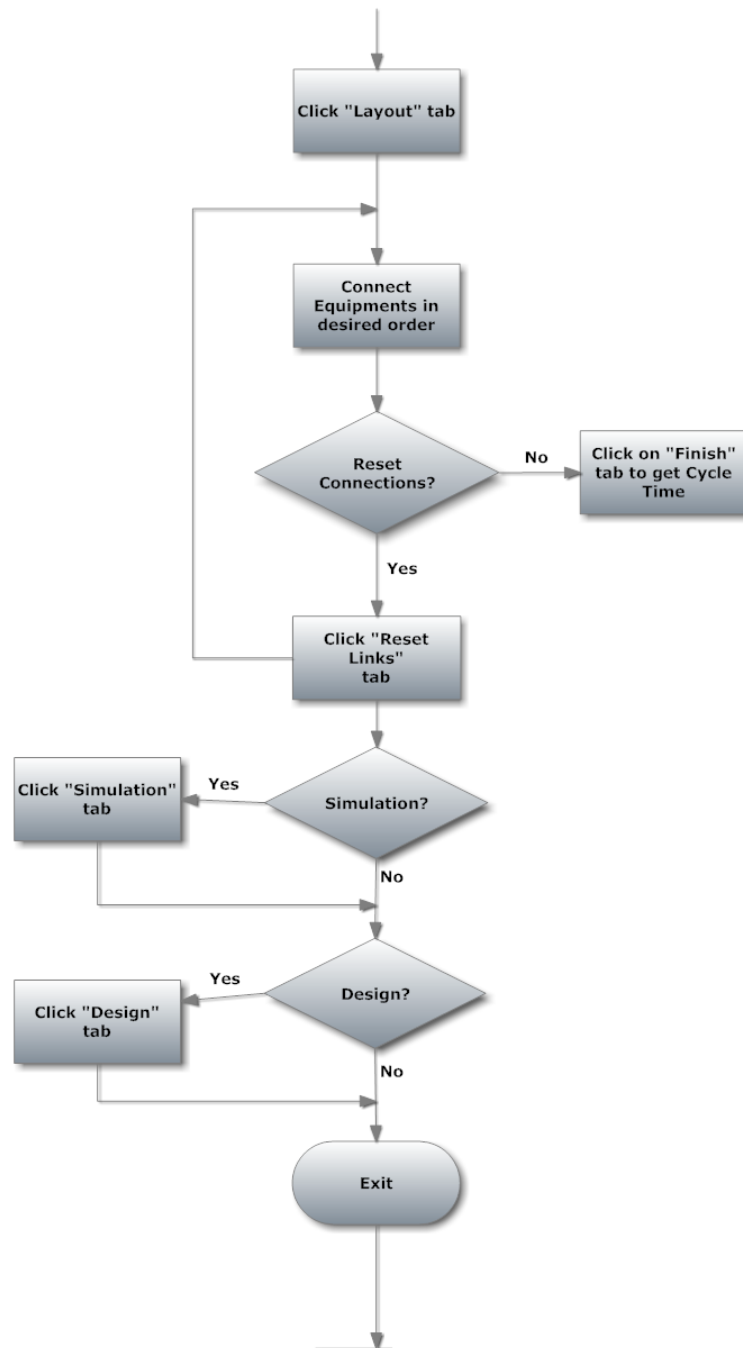
Fig. 7: Continued

Program Development

The PSE application was developed in Adobe Flash CS4 and programmed in the ActionScript 3.0, a programming language - native to the Flash platform. The ActionScript 3.0 language which is also called as AS3 in short is a powerful Object Oriented programming language based on the ECMAScript - the international standardized programming language for scripting. ActionScript 3.0 is compliant with the ECMAScript Language Specification, Third Edition- ECMA-262 [30].

ActionScript 3.0 is used primarily for the development of feature rich websites and software using the Adobe Flash Player platform. It is also used to develop Rich Internet applications (RIAs) which are used as e-learning resources in academia as well as in industry [30].

The source code developed relies heavily on Flash and ActionScript's ability to respond to user input (mouse click or keyboard typing) and execute specific sets of actions driven by the inputs. Flash uses Event listeners, which are functions that Flash Player executes in response to specific events.

For example, when a user clicks on a button, an event is logged. Flash player responds by executing the code associated with that event.

Here is a short example of the Flash Actionscript:

button.addEventListener(MouseEvent.CLICK,doSomething);

function doSomething(event:MouseEvent){

   execute this line of code

}

Apart from using these event listeners, flash uses functions that can repeat the same code again and again. This is helpful for handling a large number of buttons with same functionality like selecting equipment by clicking on the symbols. The symbols may be different, but the code executed each time these symbols are clicked is essentially the same. This code is bundled inside a function which is called with different arguments each time a symbol is clicked.

Visual Cues

Visual cues can direct users gaze attention towards predetermined areas of interest on the screen. In the PSE, these visual cues help the user to follow the correct set of actions to achieve the desired goal. Large amount of data on the screen can prove confusing. It is useful to provide guidance in choosing the correct sequence of actions. A small rectangle or a red dot is presented in the area where the user is supposed to click. The rectangle or red dot changes its location according to actions performed by the user. For example, after clicking the "Process" button and finishing with selecting the equipment, the user is meant to advance to the layout page. The rectangle or red dot appears over the layout button prompting the user to click it. In addition to the visual cues, there are some

textual instructions that appear when the mouse hovers over certain areas. These instructions appear all over the PSE and are intended to give the user more information regarding some of the symbols or buttons and their actions. There are help tabs labeled with a question mark on each page. "Help" provides concise information to guide the user. Each button on the main menu has pop up text associated with it, which gives information the function of that particular button when the user moves the mouse over it.

PSE UI Design

User interface design for the PSE was based on a previous PSE developed at the Department of ETID, Texas A&M University. Main menu buttons were placed on an easily accessible menu bar at the bottom of the page. Design elements were placed in a manner that the users could follow a natural left to right reading order. For example, the first button that the users were supposed to click was placed on the extreme left while the last button in the navigational flow was placed on the extreme right of the screen. The same convention was followed for other significant areas in the PSE. "Process Selection" window which was supposed to be the first step for the creation of a process design was placed on the extreme left. "Time" and "Cost" windows were placed on the extreme right. (These windows were supposed to be accessed last during the work flow.)

Usability Evaluation

Pilot studies were conducted on the PSE which included user testing. A prototype with colored flashing rectangles as visual cues was used. Participants expressed that the flashing rectangles proved to be more of a distraction than help. Some of the participants conveyed that the purpose of the flashing rectangles was not very clear.

Eye-tracking experiments for the usability evaluations were performed with 15 participants. The goal was to determine if the PSE was user friendly and easily navigable via the user interface.

Experimental Design

- Three Prototypes were developed.

- The PSE was tested with three levels of visual cues.

- Participants were given a specific task to complete using the application.

- The task was to select machines, change their "Time" and "Cost" parameters and connect them in a layout according to the guidelines given on the very first page.

- On task completion, they answered questions based on their experience using the PSE.

Participants

Fifteen participants between the ages of twenty to thirty volunteered for the study. All of the participants were students at Texas A&M University.

Apparatus

Seeing Machines Inc's Facelab eye-tracking system was used for all the experiments. Facelab is a desktop mounted eye-tracking system as shown in Figure 8. It consists of two cameras mounted on a stereo head and an Infrared pod. The two cameras are used to record the users' eye movements. The IR pod emits infrared light. This IR light is reflected off users' eyes and the reflection is recorded to track the eye movements. [31]

Fig. 8: FaceLAB Eye-tracking system

The software for recording the eye movements comes bundled with the system. A version of the software called Facelab 5.0 was used to record data. The software has myriad calibration options to configure the system for each individual participant.

A software suite called "Eyeworks" from Eyetracking Inc. was used along with Facelab for data collection and analysis. The Eyeworks suite consists of three different softwares [32]:

- "Eyeworks Design" is used to design custom scripts to be used in the experiments.

- "Eyeworks Record" records the data necessary for analysis.

- "Eyeworks Analyze" is an analysis tool that was used to do visual analysis on the eye-tracking data and export out statistical data out of the software.

Procedure

Fifteen participants were grouped randomly into three groups of five each:

- Prototype I group: Participants in this group were presented with Prototype I which has no visual cues.

- Prototype II group: Participants in this group were presented with Prototype II which has various colored rectangles as visual cues.

- Prototype III group: The participants in this group were presented with Prototype III. Red dots are presented as visual cues in this particular Prototype.

The experiments proceeded as follows:

- Participants were given an information sheet explaining the experiment, significance of the research and potential risks involved with the experiment.

- Participants were seated in front of a computer screen and eye tracker set up as shown in Figure 9.

- Eye tracker was configured for each participant before the experiment. Participants were asked to remain as steady as possible during the calibration.

- Information about the PSE was presented in the first step of the experiment.

- Participants were asked to use the PSE to fulfill a task described on the "Problem" screen.

- Participants were asked to answer some simple questions after the end of the experiment.
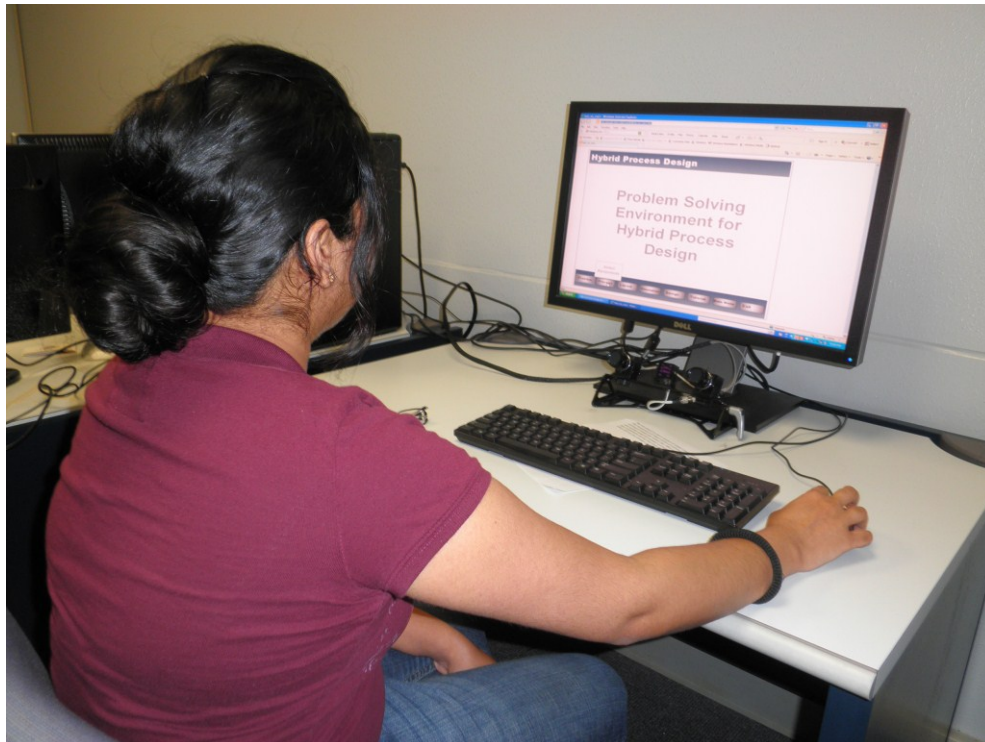
Fig. 9 : Experiment in progress

CHAPTER V

RESULTS

Eye-tracking Data Analysis

Eye-tracking records plethora of data. It is assumed that, a large number of fixations on a particular region indicate a significant area of interest. In this thesis, three factors are important in determining the areas of visual interest:

- Large number of fixations indicates important area of visual interest.

- Frequency of gaze is also an important factor in determining an area of visual interest. The more the frequency of the gaze, the more important are the regions. In other words, if a particular region on the screen attracts the users' attention, the number of gaze hits to that particular region is greater than that of any other region on the screen.

- Scan-paths give information about the users' eye movement pattern. Scan-paths were compared for each of the prototypes on the basis of time and effort taken by the user to find the significant areas of interests. An uncluttered and short scan path is taken to mean that the user was able to easily identify the significant areas on the screen, whereas a lengthy and cluttered scan path is taken to show that the user could not differentiate between the significant and insignificant areas on the screen.

Prototype I

Prototype I does not have any visual cues present. It was essential to test the usability of the application on its own without any visual cues as the Prototype I group served as the control group. The data recorded from the experiments performed with Prototype I is compared to data from experiments performed with Prototype II and Prototype III. Figure 10 shows a screenshot of the application window.
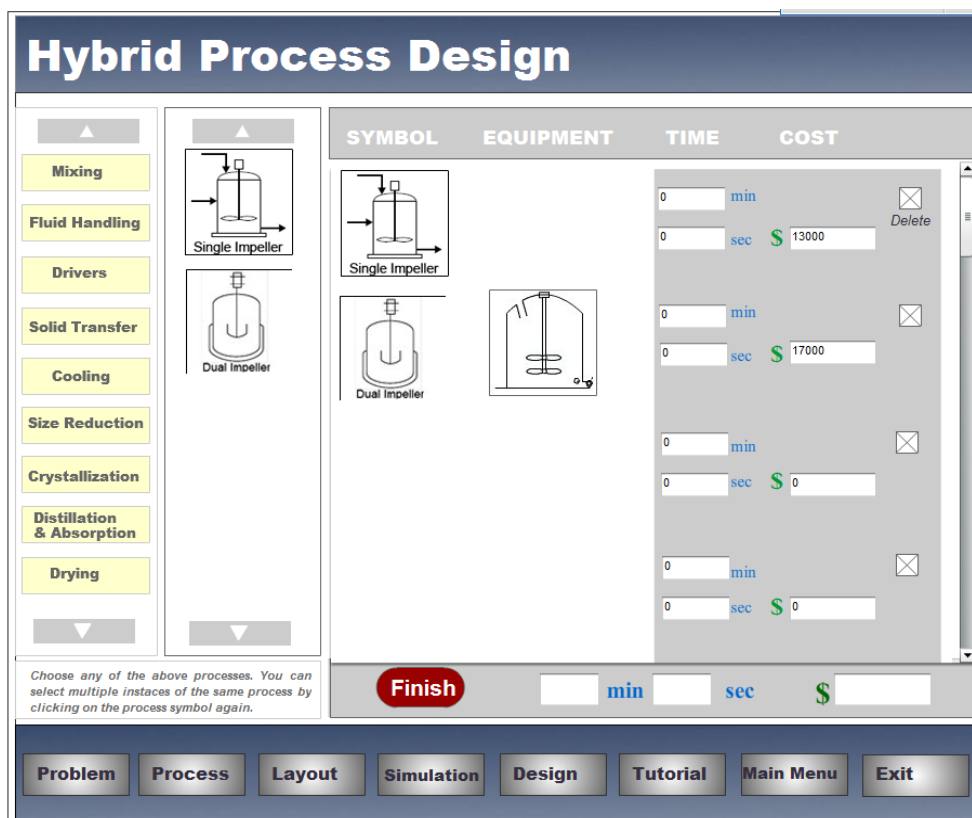
Fig. 10: Prototype I – No visual cues

Five users were presented with this Prototype. The scanpath from one particular experiment, as shown in Figure 11, is an indication of how the users' eyes move about the screen while looking for relevant information. The green circle denotes the starting point and the red circle denotes the point where the users gaze ended. Cluttered scan path shows users low confidence.
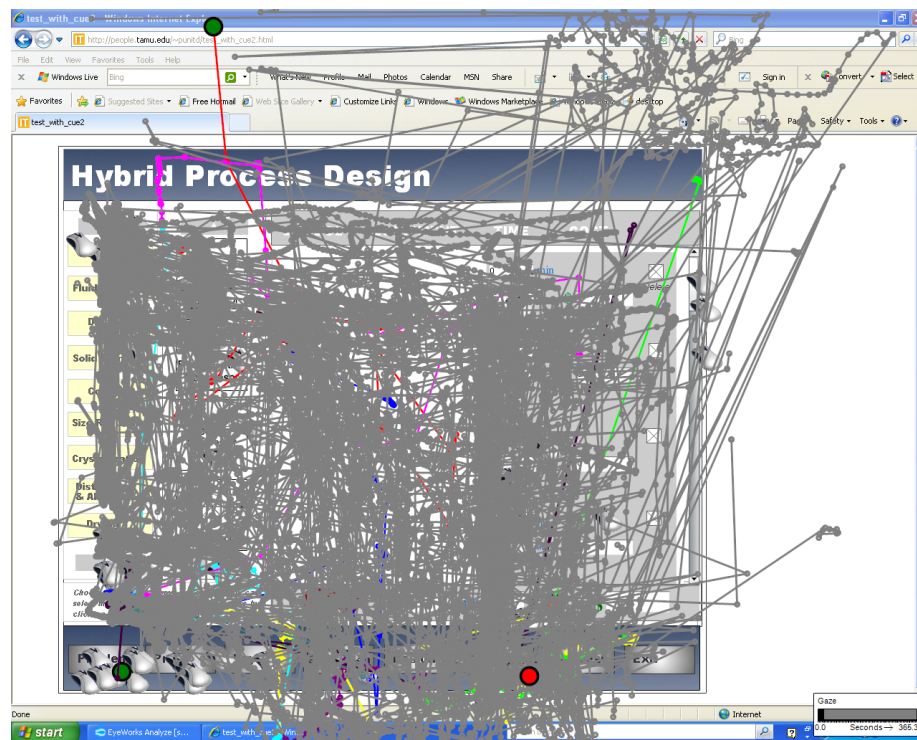
Fig. 11 : Scanpath from an experiment on Prototype I

Figure 12 shows the heat map pattern of the same experiment. Red color denotes the areas that attracted most user gaze and blue denotes moderate gaze activity.
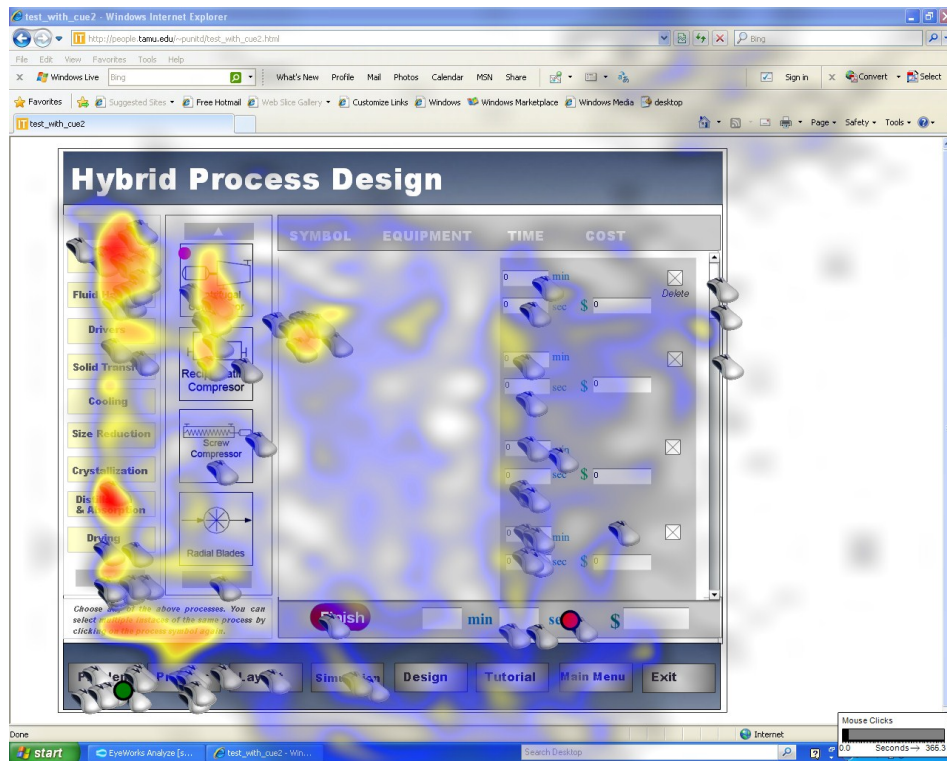
Fig. 12 : Heat map from an experiment on Prototype I

Heat map (Figure 12) shows high concentration of red areas on the left side of the screen indicating that user's eyes are attracted only to one part of the screen. User overlooks or does not notice other areas of interest which are important in the navigational flow. For example, areas labeled "Time" and "Cost" are few of the significant areas of the PSE; but, as seen in the heat map, there are no red areas on the "Time" and "Cost" fields.

Prototype II

Five different participants were presented with this prototype. This prototype has visual cues to help direct the viewer's gaze towards significant areas of interest. Hollow

rectangles appear over the regions where the user is supposed to be looking next. The rectangles also appear around buttons which are important for the next step.
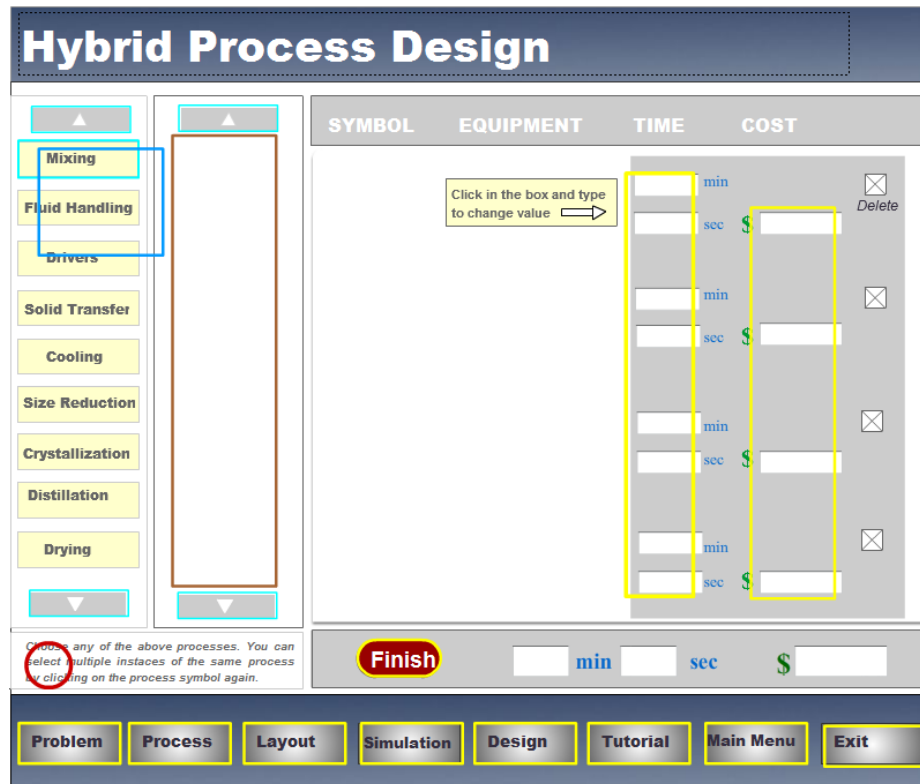
Fig. 13 : Prototype II – Colored rectangles as visual cues

For example, when the user clicks on the "Mixing" button, a rectangle appears over the region where equipment is listed to aid with selection. Saturated colors were used for rectangles to since color scheme used in the PSE consists of less saturated colors. The results were slightly different from the experiment with Prototype I.
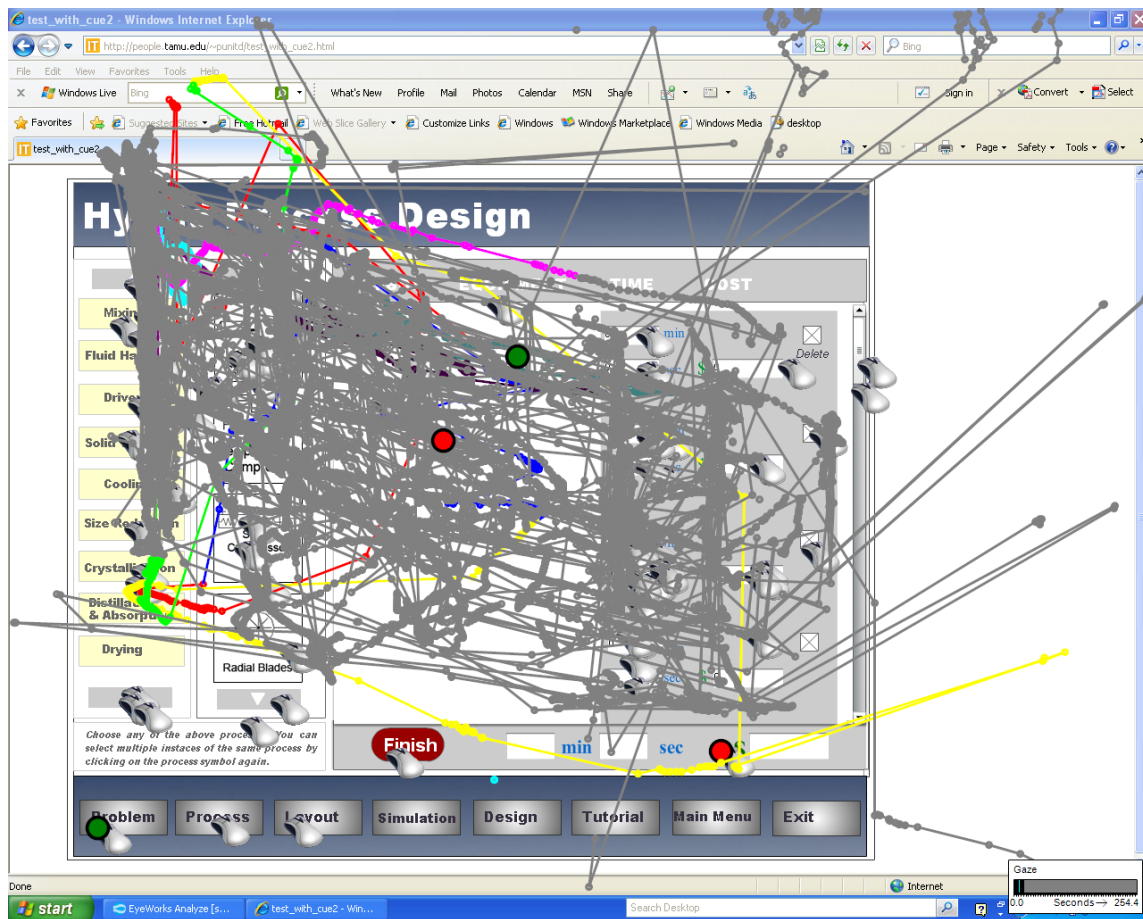
Fig. 14 : Scanpath from experiment on Prototype II

For example, Figure 14 shows the scan path from one of the experiments on Prototype
II. It is less cluttered as compared to the scanpaths from Prototype I as shown in Figure
13. The heat map in Figure 15 shows red areas over the "Time" and "Cost" regions.
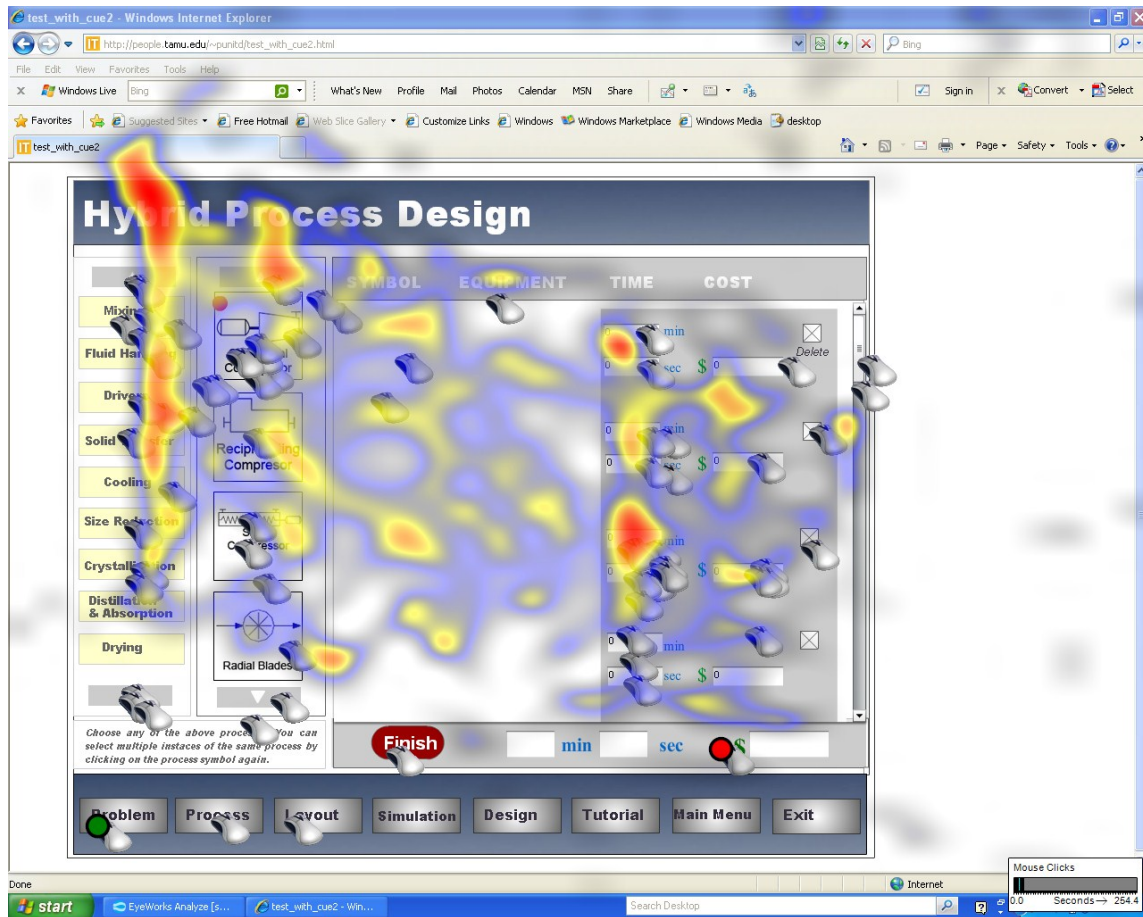
Fig. 15 : Heat map from experiment on Prototype II

Prototype III

This Prototype is a variation of Prototype II. Instead of colored rectangles, red dots serve as visual aids in this prototype. The appearance of the red dots follows the exact same pattern as that of the rectangles. Figure 16 shows an in-development screen shot of the application with red dots on the screen.
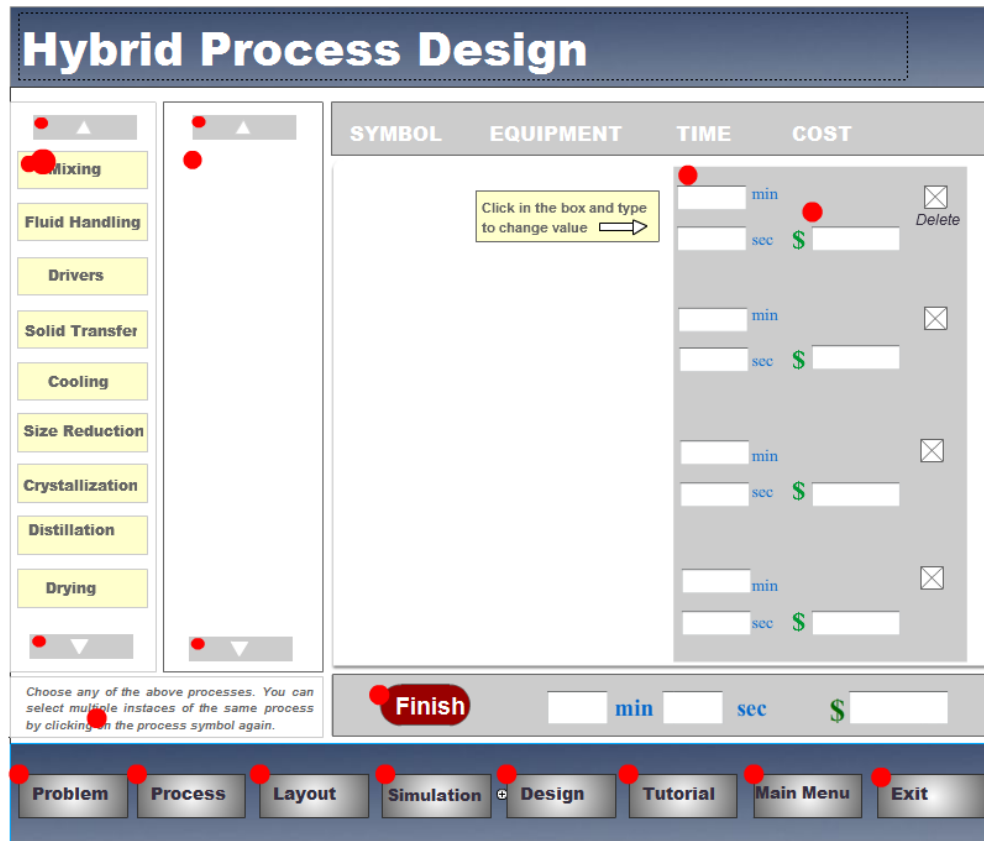
Fig. 16 : Prototype III – Red dots as visual cues

Figure 17 shows scan-paths from the experiment conducted on Prototype III. The scan-path is less cluttered and shorter in length as compared with the scan-paths obtained from the experiments on Prototype I and II. The heat map in Figure 18 shows equal distribution of gaze over the significant regions.
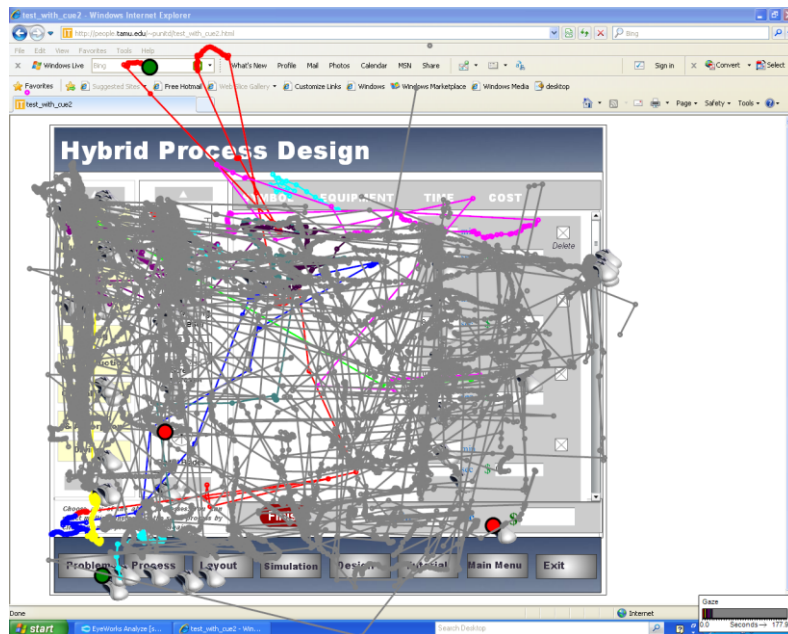
Fig.17 : Scanpath from an experiment on Prototype III
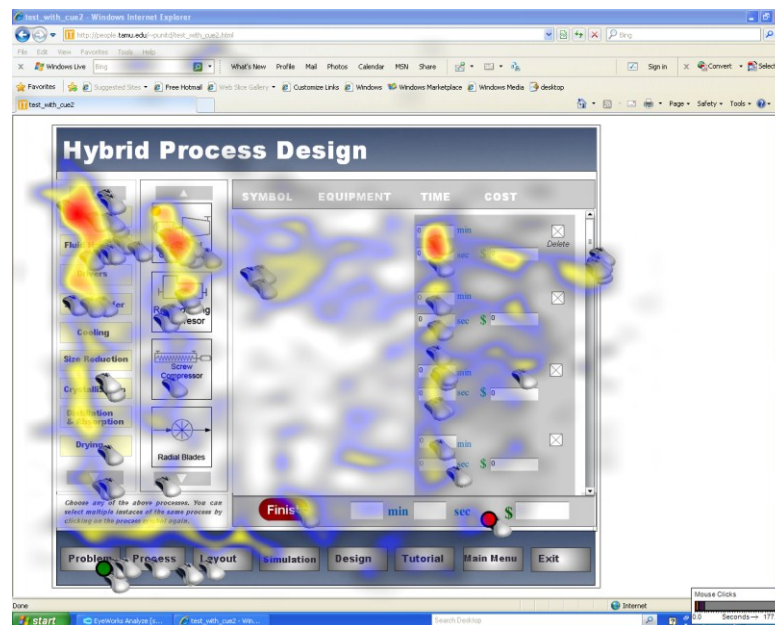
Fig. 18 : Heat map from an experiment on Prototype III

Statistical Analysis

In order to generate statistics, it is necessary to identify the screen areas that need to be analyzed. The screen areas marked with boundaries are termed as regions. Regions can be defined in the software used for analysis. These regions are shown in Figure 19. The areas marked with red rectangles are significant areas of interest. The software used for data analysis exports statistics according to the gaze hits and fixations received per region.
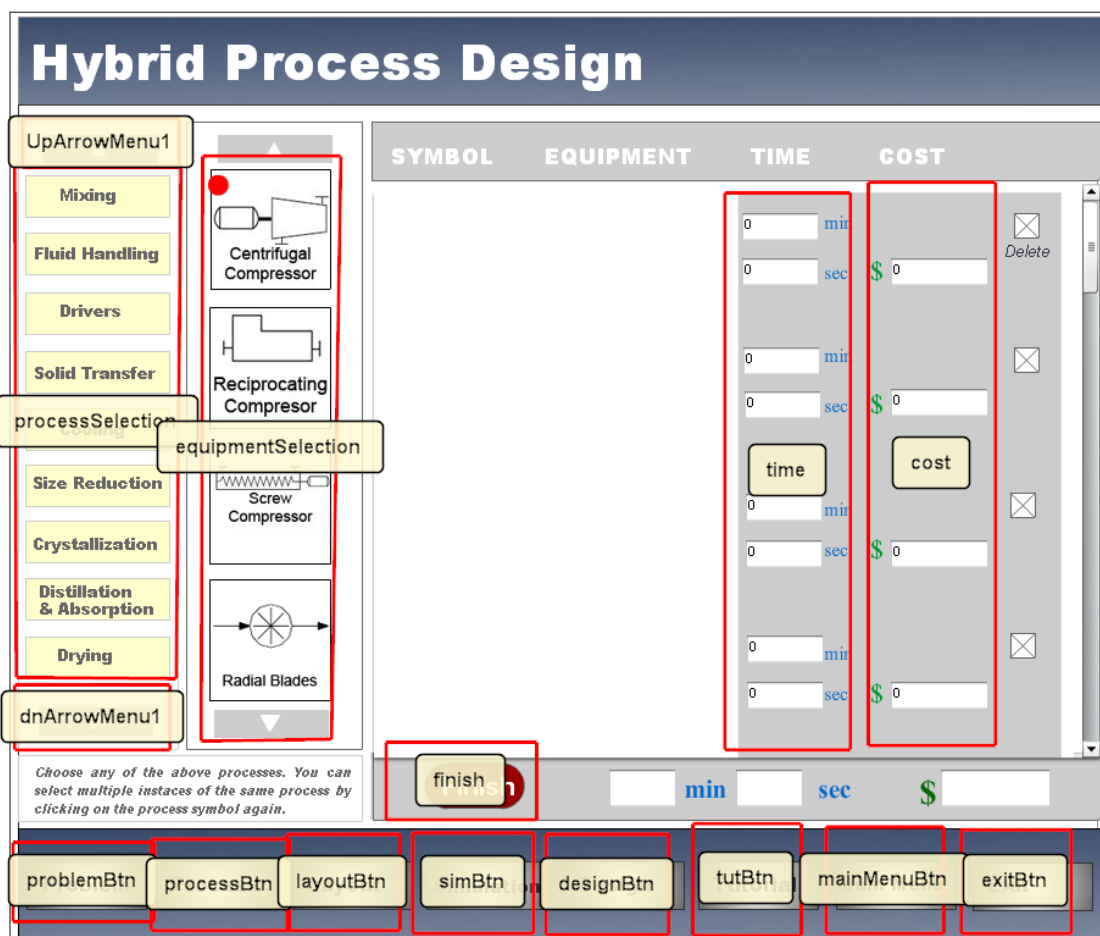
Fig. 19 : Red rectangles represent various regions the image is divided into for data analysis

Regions labeled "Process selection", "Equipment selection", "Time" and "Cost" are the significant areas of interest where users are supposed to be paying more attention.

Gaze Percentage in Each Region

Table 1 shows gaze percentage in each region for Prototype I (No visual cues).

Table 1: Gaze percentage in each region for Prototype I

	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10
Cost	2.3	3.2	1.7	2	3.1
Equipment Selection	9.2	18.7	22.8	20.2	13.9
Process Selection	16.9	14	16	12.7	11.7
Time	6.7	8.6	8.2	7.4	7.7

The gaze percentages over regions "Cost" and "Time" are significantly less as compared with gaze percentages over other regions. This further corroborates the observations made from heat maps in Figure 11 which shows that there are no red areas over these regions. Table 2 shows gaze percentage in each region Prototype II (Rectangles).

Table 2: Gaze percentage in each region for Prototype II

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Cost	3.6	5	5.5	2.3	4
Equipment Selection	16.9	25.9	13	12.5	18.1
Process Selection	12.1	8.7	16.1	18.9	7
Time	6.3	12.4	12	16.7	6.8

Gaze percentages in "Time" and "Cost" regions have slightly improved for most of the participants. This means that the participants in Prototype II group (Rectangles) had their

gaze directed towards the more significant areas more frequently than that in Prototype I (No cues) group.

Table 3 shows gaze percentage in each region Prototype III (Red Dots).

Table 3: Gaze percentage in each region for Prototype III

	Subject 11	Subject 12	Subject 13	Subject 14	Subject 15
Cost	1.2	5.8	6.3	7.6	3.8
Equipment Selection	16.2	16.6	21.9	11.7	16.9
Process Selection	10.2	10.5	14.5	10.9	11.8
Time	10.3	14.5	14.7	13.5	7.1

Gaze percentages for regions "Time" and "Cost" for Prototype III group (red dots) increase significantly over that of Prototype I and Prototype II. This shows that gaze was directed more towards the significant regions in Prototype III as compared to prototypes I and II. From Prototype I to Prototype III, gaze percentages for "Time" and "Cost" regions increase while gaze percentages for other regions decrease progressively. This trend can be clearly seen in Table 4. Table 4 shows averages of gaze percentages for same prototypes compared with each other.

Table 4: Average gaze percentage in each region for all three prototypes

	Prototype I	Prototype II	Prototype III
Cost	2.46	4.08	4.94
Equipment Selection	16.96	17.28	16.66
Process Selection	14.26	12.56	11.58
Time	7.61	10.84	12.02

This decrease in the gaze percentage for regions "Equipment selection" and "Process Selection", coupled with the increase in gaze percentages for "Time" and "Cost" means that participants looked at the "Time" and "Cost" more frequently than "Equipment Selection" and "Process Selection" Figure 20 shows graphical representation of the data presented in Table 4.
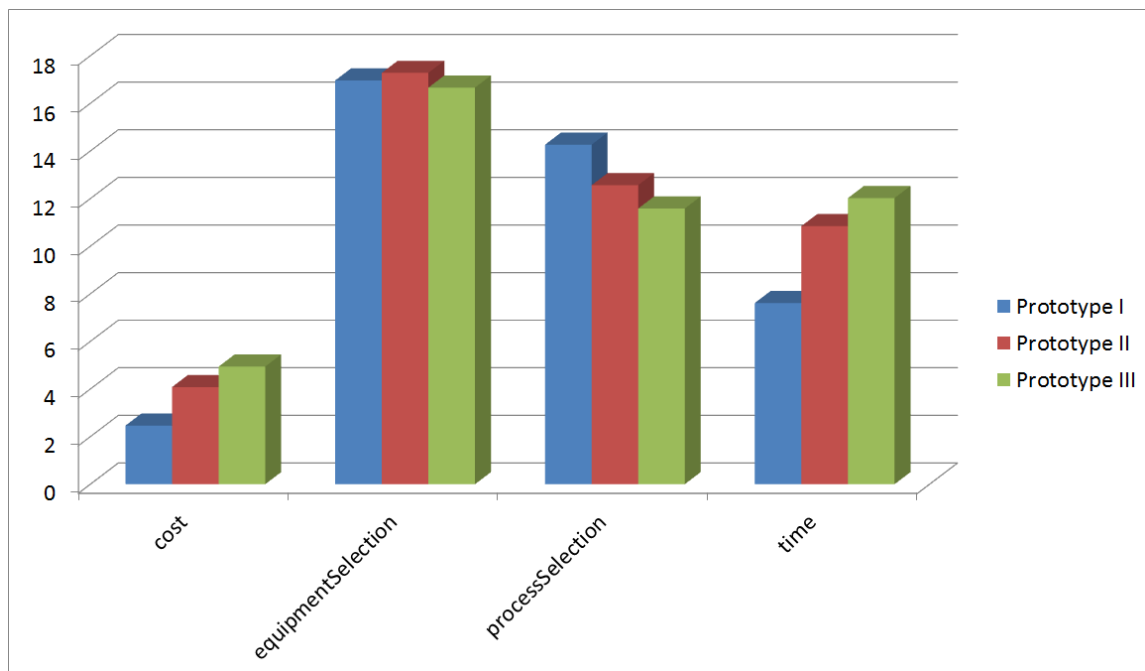
Fig. 20 : Average gaze percentages for regions "Cost", "Equipment Selection", "Process Selection" and " Time" for all the Prototypes

Average gaze percentage for regions "Cost" and "Time" increases from Prototype I (No cues) to Prototype III (Red dots). Visual cues in prototypes II & III were meant to draw users gaze towards previously neglected "Cost" and "Time" regions. Prototype III does an efficient job of directing users gaze towards the significant areas of interest as compared with Prototype II.

Figure 21 gives a visual representation of average gaze percentage in each region for all the prototypes which further corroborates the hypothesis.
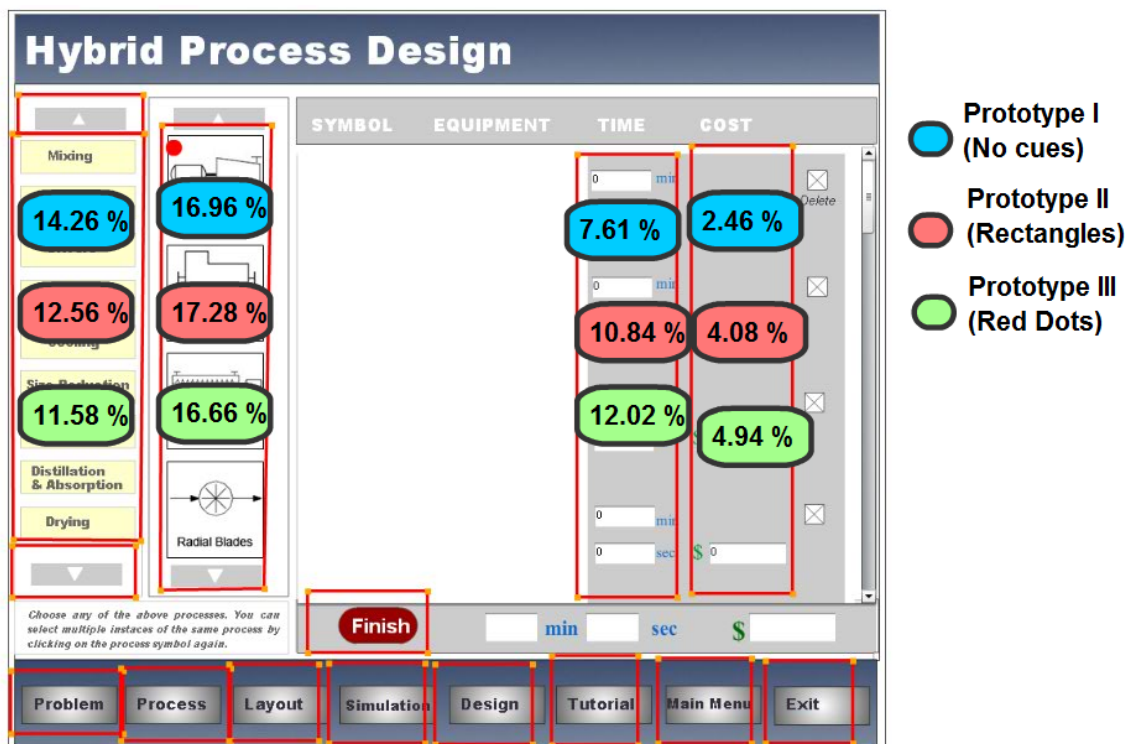
Fig. 21 : Average gaze percentages for regions "Cost", "Equipment Selection", "Process Selection" and " Time" for all the Prototypes – Overlaid on top of PSE background

t-Test and Correlation

It is hypothesized that the gaze percentages are significantly different among prototypes I, II and III. To determine this, an independent samples t-test was done on the data sets. Table 5 shows the probability values associated with students' t-tests for each region.

Table 5: t-Test values

	P1(Between Prototype I and Prototype II)	P2(Between Prototype I and Prototype III)
Cost	0.033906	0.06423
Equipment Selection	0.927688	0.920469
Process Selection	0.503498	0.064065
Time	0.15094	0.020768

P is the probability that there is significant difference between two data sets. P-value for cost is P1 (cost) =0.033. This value is less than 0.05 (P1 (cost) <0.05). This means there is a significant difference between the gaze percentages in region "Cost" for Prototype I (No cues) and Prototype II (rectangles) [33]. The p-value for "Cost" between Prototype I (No cues) and Prototype III (Red dots) is 0.064 which is also near to 0.05. The same is also true for p-value in all the regions of Prototype III except for equipment selection region. All the p-values for Prototype II (rectangles) are higher than 0.05 except for "Cost" region. This implies that there is a significant difference between gaze patterns of Prototype I (No cues) and Prototype III (Red dots) as compared to the difference between gaze patterns of Prototypes I (No cues) and Prototype II (Rectangles). Hence,

the hypothesis that there is a difference between gaze patterns of Prototype I and III holds true while it does not hold true for significant gaze pattern difference between Prototypes I and II.

It is expected that Prototype III (red dots) does a better job of directing users gaze around the significant areas of interest as compared with Prototype II (rectangles). To determine this, gaze percentages for each region from four participants who used Prototype II (Rectangles) were averaged. Coefficient of correlation was calculated between the average values and gaze percentage values of a fifth participant (from the same group). The coefficient of correlation for this particular case came out to be 0.54 ($r1=0.54$). In the same way coefficient of correlation for Prototype III was calculated. ($r2=0.85$). This shows that there is a greater linear correlation between the gaze percentages of participants in Prototype III group than that of Prototype II group. Based on the earlier t-test results and the correlation results, it is deduced that gaze percentages in each region across all the five participants of Prototype III match closely with one another. High degree of correlation among the gaze percentage of participants who used the same prototype shows that most of the users followed the navigational path their eyes were supposed to follow with the help of visual cues; whereas the same cannot be said to be true for Prototype II (rectangles) which has a low coefficient of correlation.

f-Test

An f-Test was performed on the data sets to determine if the variance of the two gaze percentage data sets was equal. Table 6 shows the F-test values.

Table 6 : f-test values

	F1	F2
Cost	0.248628	0.025214
Equipment Selection	0.994064	0.454009
Process Selection	0.140012	0.671259
Time	0.004559	0.013331

F1 and F2 are the probabilities that the variances are equal. F1 is the probability value calculated between gaze percentage for Prototype I and Prototype II while F2 is the probability value calculated between gaze percentage for Prototype I and Prototype III. For the variances to be equal, the probability value should be equal to one. The table shows that F2 is less than F1 except for "Process Selection" and "Time" regions. Both F1 and F2 values for all the regions are significantly less than one. This shows that the variance values for prototypes II and III differ against that of Prototype I.

Mouse Clicks

Number of mouse clicks per region was analyzed to assess if there were differences among mouse click patterns in three different prototypes. Figure 22 shows the number of mouse clicks per region for all three prototypes. Mouse clicks are higher for Prototype

III in "Cost" and "Time" regions as compared to Prototypes I and II. Users clicked in the "Time" and "Cost" regions in greater numbers when assisted with visual cues.
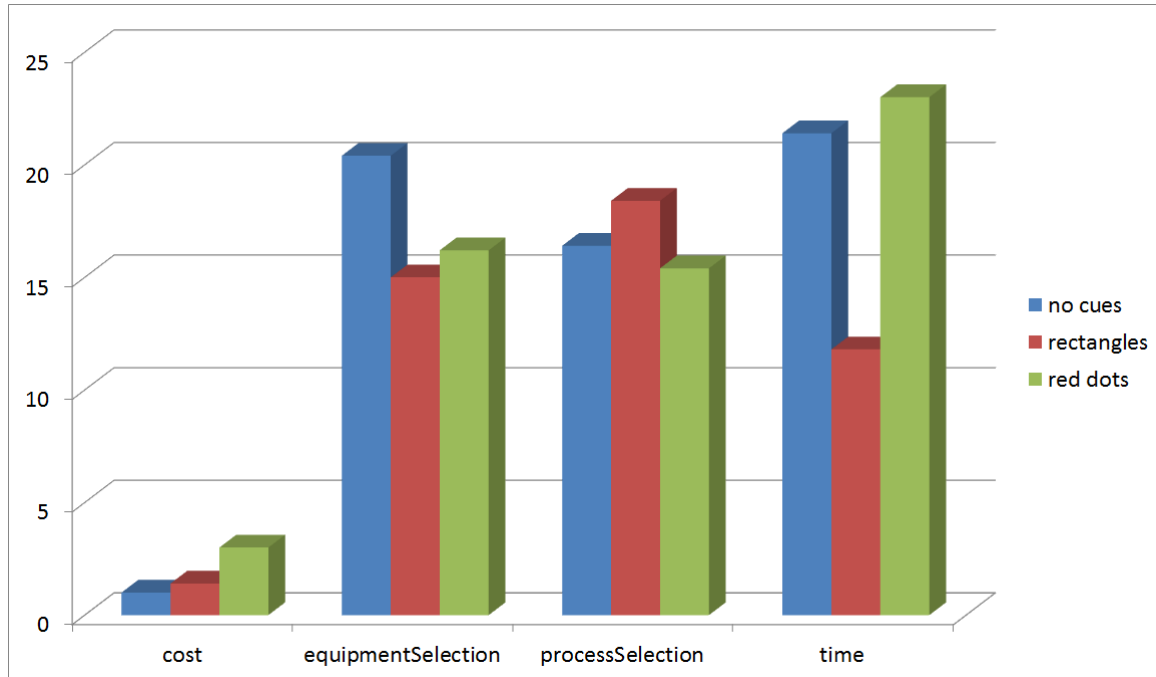
Fig. 22: Number of mouse clicks per region

Coefficient of correlation was also calculated among the users in the same group. The number of mouse clicks in the same region for four participants of a group was averaged. Coefficient of correlation was calculated between the average values and that of a fifth participant. Coefficient of correlation for Prototype II came out to be equal to 0.69, and for Prototype III it came out to be 0.87. For number of mouse clicks, there is a greater correlation among the participants from the same group. This result shows that the participants from the Prototype III (red dots) group clicked consistently in the regions highlighted by the visual cues.

Gaze Observations in Each Region

The following Figures show the number of gaze observations registered by different subjects. This is different from the percentages of gaze in each region as these are numbers of gaze observations recorded per region. Results from different experiments are compared side by side. In Figure 22, each vertical bar denotes number of gaze observations by a single subject while a vertical bar in Figure 23 denotes average of the gaze observations registered by subjects who performed same kind of experiment. The graph in Figure 23 and Figure 24 shows the number of gaze observations is higher in the experiments without cues (Prototype I) as compared with the ones with cues (Prototypes II and III). This shows that the users who viewed Prototype I scanned the screen multiple number of times leading to greater number of gaze hits as compared to the prototypes with visual cues where users gaze was more frequently directed towards the areas of significant importance, and consequently meant less number of gaze observations.
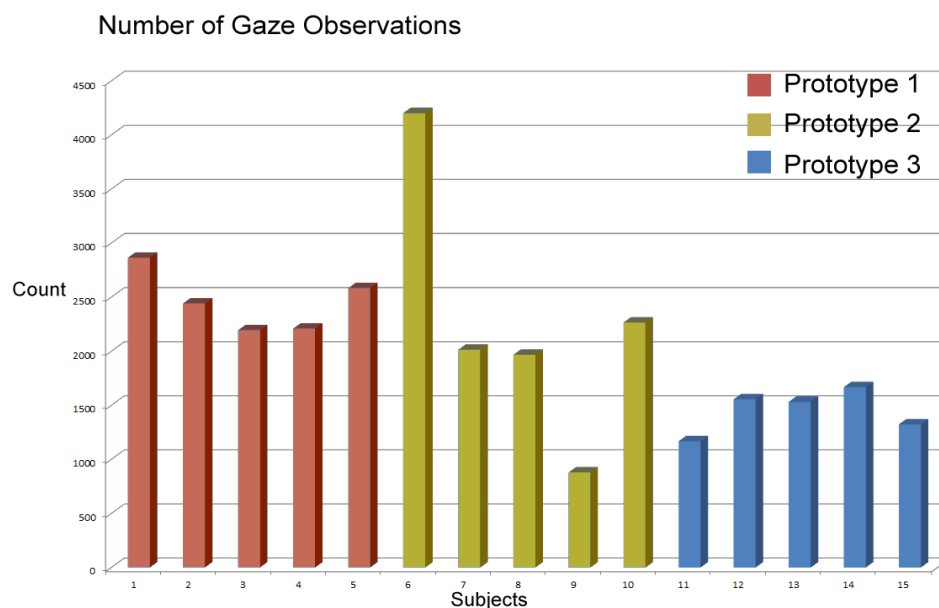
Fig. 23 : Number of Gaze Observations for all the subjects

Prototypes II and III also differ in their number gaze observation values. Participants who used Prototype II (Rectangles) registered more gaze observations as compared to the ones who used Prototype III (Red dots). This means that the participants who used Prototype III found it easier to identify the significant areas on screen as compared with the participants who used Prototype II.
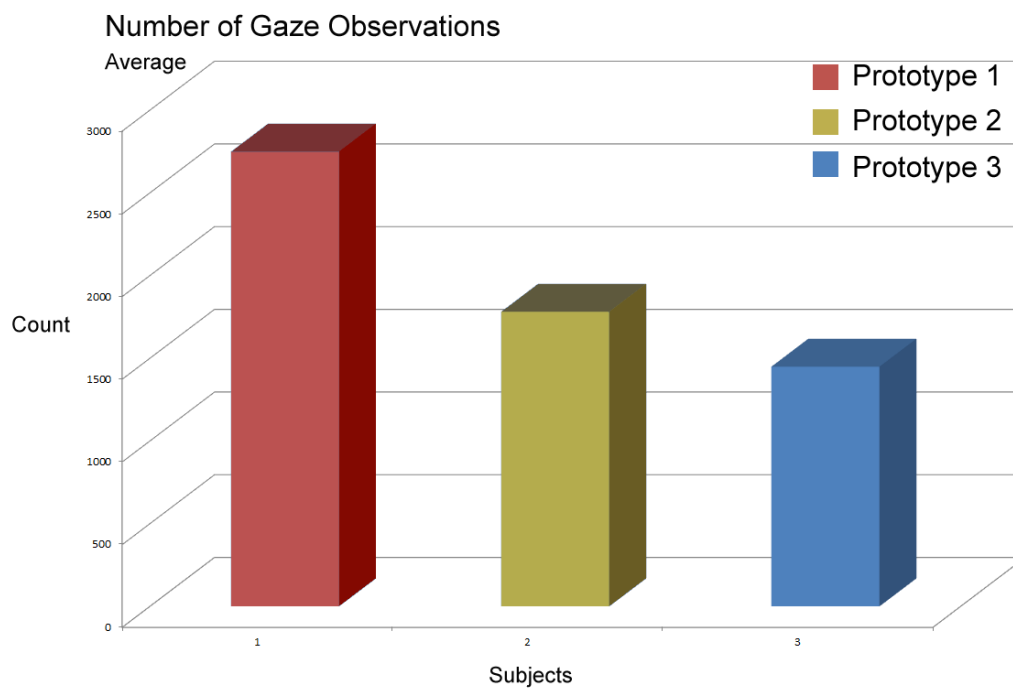
Fig. 24 : Averages of number of gaze observations

Fixations

Figure 25 shows number of fixations for different subjects. Each vertical bar represents the number of fixations by a single participant. Each vertical bar in Figure 26 represents average of the fixation counts of participants who used the same Prototype.
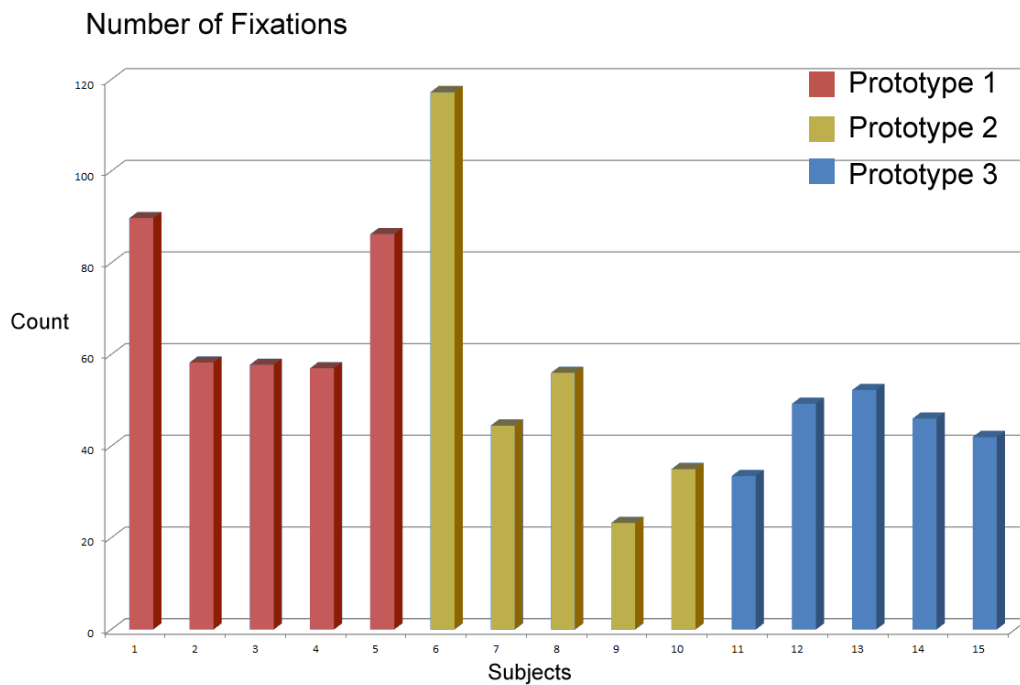
Fig. 25 : Number of fixations for all subjects

The average number of fixations decreases from highest in participants who viewed Prototype I to lowest in participants who viewed Prototype III. Less number of fixations is a measure of efficient visual design where users identify the significant areas of interest easily [34].

Number of Fixations
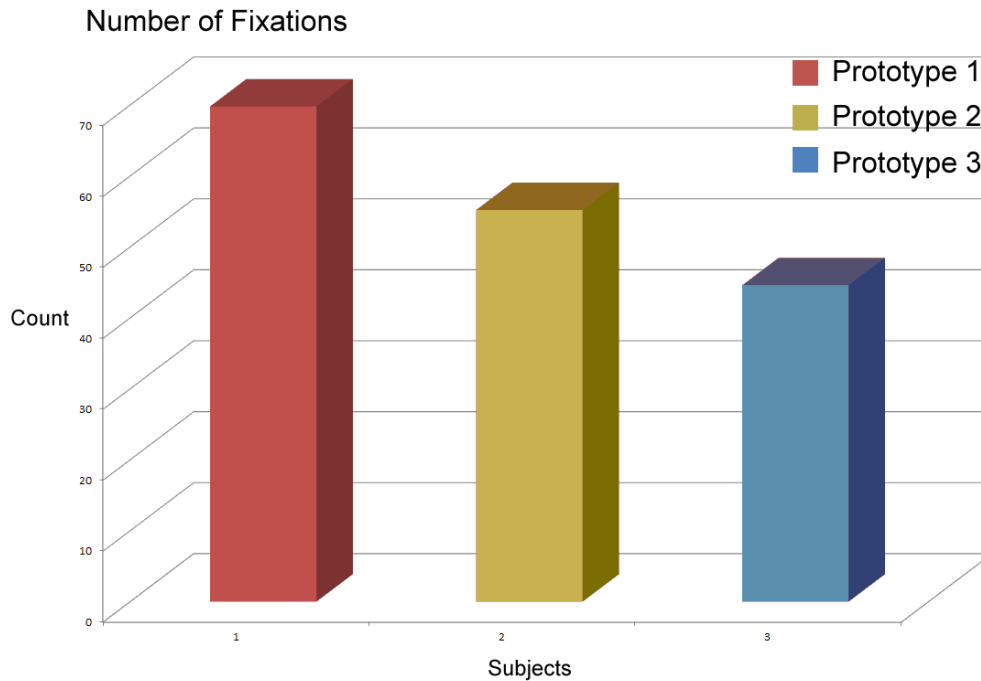
Fig. 26 : Averages of number of fixations

Time to First Fixation in Each Region

Time to first fixation is a time between the start of the task and the time when first fixation occurs in a particular region. Longer time to first fixation in a region means it took longer for the users' gaze to get directed towards that particular region [34]. It is not desirable that it takes longer for the user to notice the significant area of interest. A vertical bar in Figure 27 represents average of the times to first fixation in all the significant regions of a particular experiment. Figure 28 compares the averages of the times to first fixation in all three Prototypes. The time to first fixation is highest in Prototype I (no visual cues) whereas it is lowest in Prototype III (red dots).
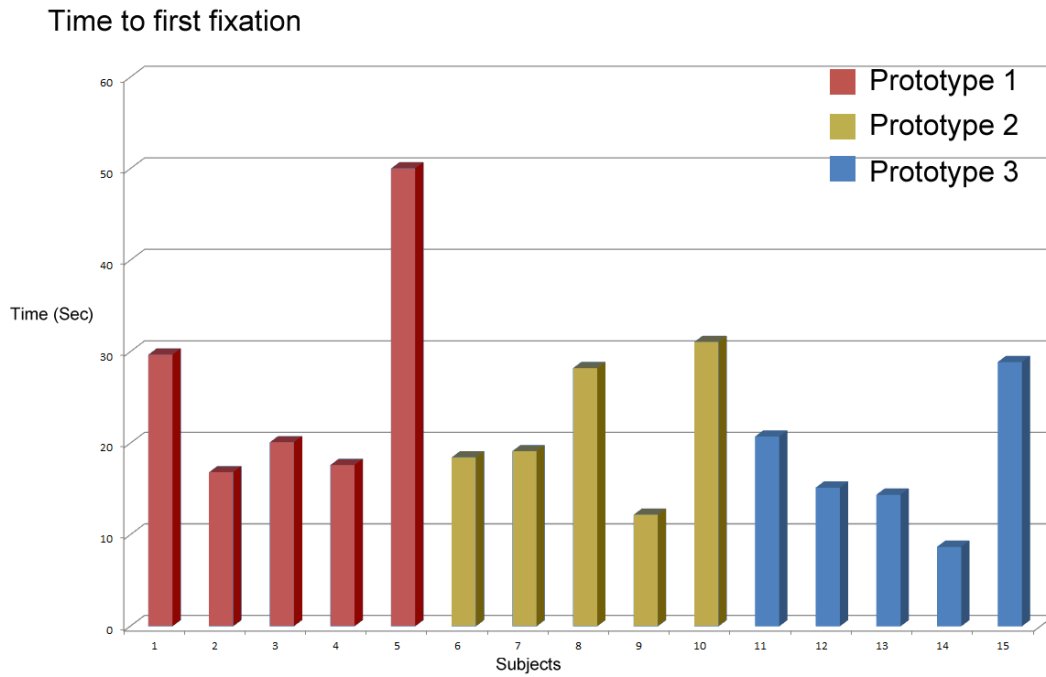
Fig. 27 : Times to first fixation in all the regions for all the subjects
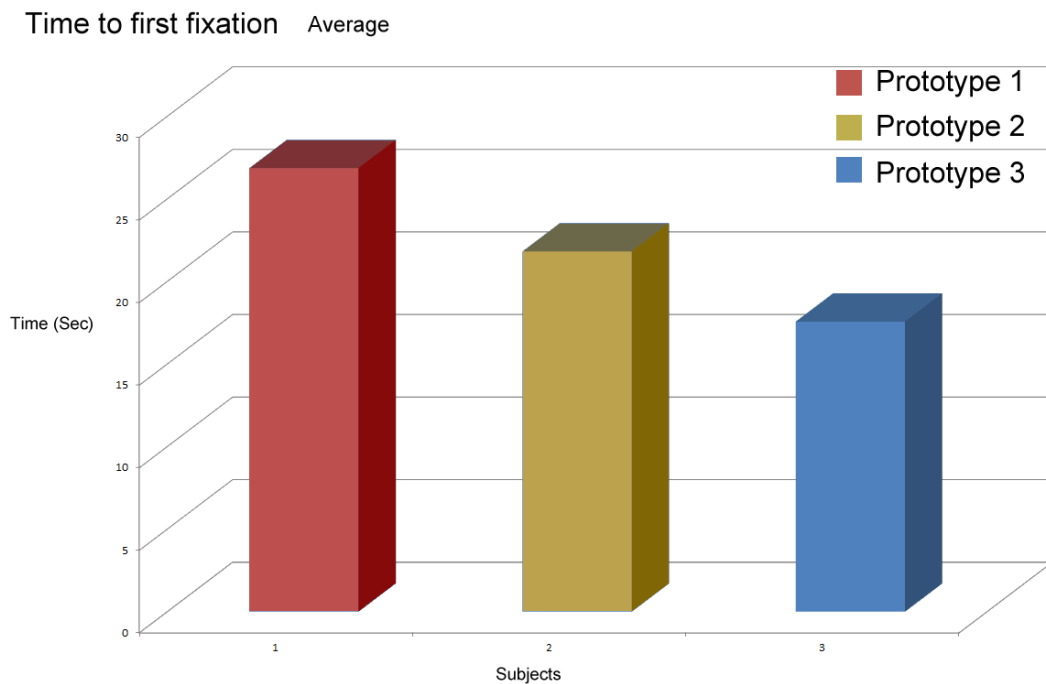
Fig. 28 : Averages of times to first fixation in all the regions for all the subjects

Task Duration

The time taken to finish the tasks in each of the prototypes was also measured. Each experiment had the same tasks. Figure 29 shows time taken by each participant to finish the task. Task duration is highest in Prototype I (No cues) while it is lowest in Prototype III (red dots). Faster time of completion is an indicator of improved usability of the application [34]. Figure 30 shows the average of the task duration for all subjects.
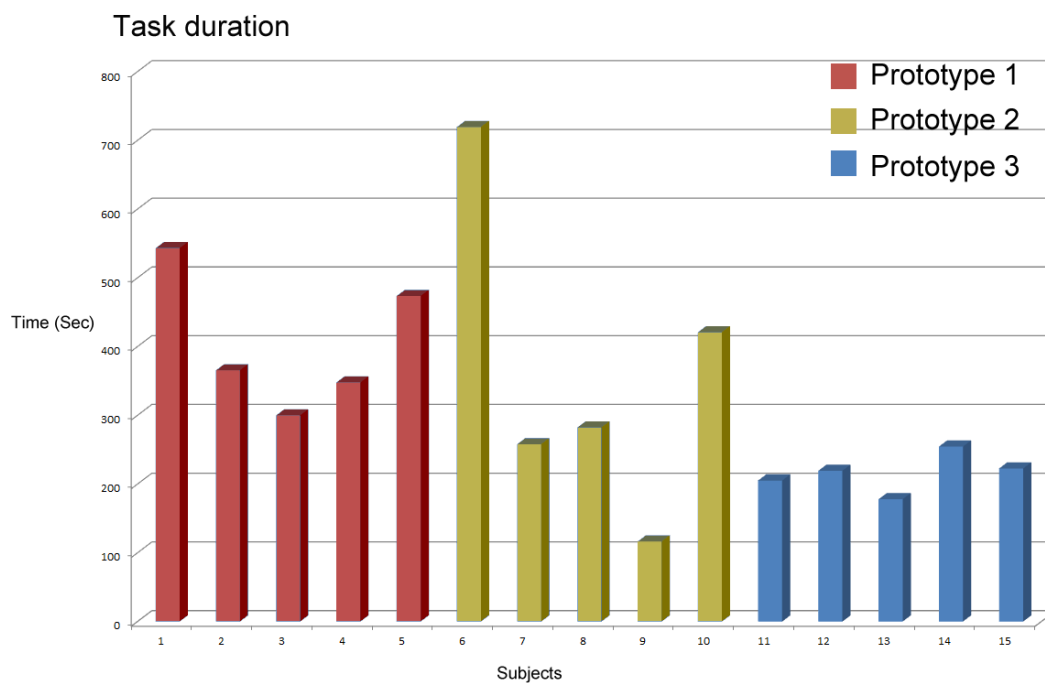
Fig. 29 : Task duration for all subjects
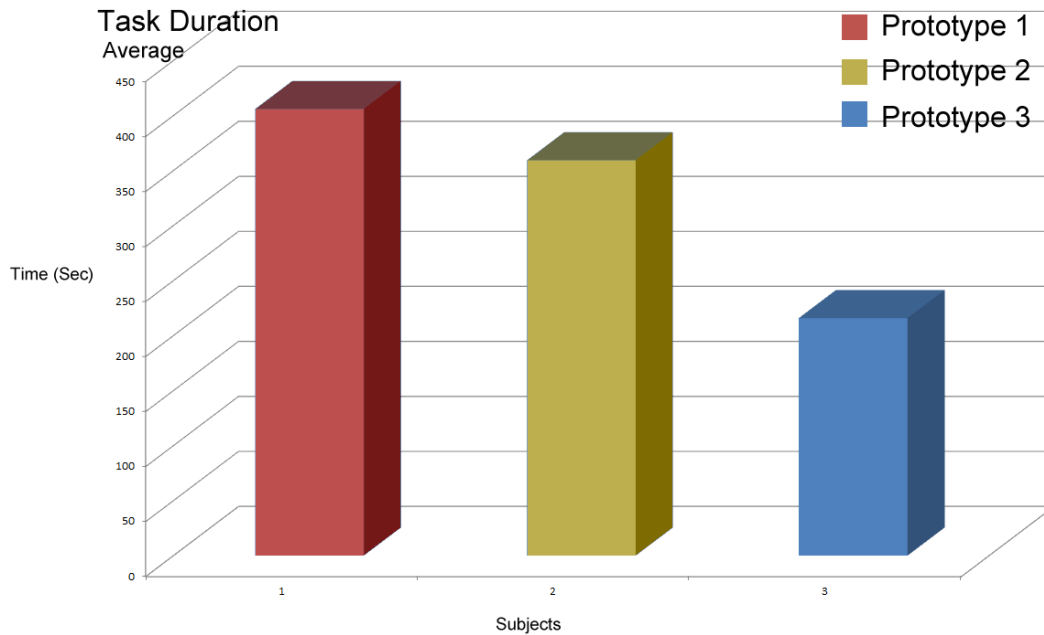
Fig. 30 : Average task duration for all subjects

Questionnaire Analysis

Participants completed a questionnaire after using the PSE. In Question 1, participants had only two choices. They were asked to select either a " Yes" or a "No" answer. Question 1 was "Did you need to watch the tutorial?" Only two participants answered the question as a "Yes". One participant was from the Prototype I group (no cues) while another was from Prototype II (rectangles) group. For the next eight questions, participants were supposed to choose from one of five different choices. The choices were "Strongly agree", "Agree", "Somewhat agree", "Disagree" and "Strongly Disagree".

Questions two to eight are described as follows:

- Question 2: The tutorial was helpful (Hit "Somewhat Agree" if you did not watch it)

- Question 3: It was difficult to identify the next step in terms of interface.

- Question 4: It was difficult to select the equipment.

- Question 5: It was difficult to change the cost and time.

- Question 6: It was difficult to arrange the symbols in order.

- Question 7: It was difficult to make connections.

- Question 8: The visual cues (Colored rectangles/Red dots around buttons and other places) helped me to navigate effectively.

Table 7 shows the number of participants who selected the respective options for each question.

Table 7: Questionnaire answers

Protoype I					
QUESTIONS	Strongly Agree	Agree	Somewhat Agree	Disagree	Strongly Disagree
Q2	1	0	4	0	0
Q3	0	3	2	0	0
Q4	0	1	2	1	1
Q5	0	1	1	1	2
Q6	0	3	2	0	0
Q7	0	1	4	0	0
Q8	NA	NA	NA	NA	NA
Prototype II					
QUESTIONS	Strongly Agree	Agree	Somewhat Agree	Disagree	Strongly Disagree
Q2	1	0	4	0	0
Q3	0	3	2	1	2
Q4	0	0	0	4	1
Q5	0	0	0	3	2
Q6	0	1	2	2	0
Q7	0	0	0	5	0
Q8	2	0	2	1	0
Prototype III					
QUESTIONS	Strongly Agree	Agree	Somewhat Agree	Disagree	Strongly Disagree
Q2	0	0	5	0	0
Q3	2	0	0	1	2
Q4	0	0	0	4	1
Q5	0	0	0	2	3
Q6	0	1	2	2	0
Q7	0	0	2	3	0
Q8	2	3	0	0	0

Responses to Question 8 were the most important ones. In Prototype II (rectangles) group, Forty percent of the participants felt strongly that the use of visual cues helped in the navigation. Twenty percent of the participants in group II did not think that the visual

cues (rectangles in this case) helped in navigation. Hundred percent of the participants of Prototype III (red dots) group agreed that the red dots were useful in terms of navigating through the user interface.

CHAPTER VI

CONCLUSION AND FUTURE WORK

This thesis presented a technique to perform usability evaluation of an e-Learning PSE application while subsequently improving its usability.

Eye-tracking experiments were conducted with fifteen participants to evaluate the usability of the PSE. The following factors led to conclusions:

- Participants who tested Prototype III had smaller and less cluttered scan-paths as compared with that of Prototypes I and II.

- Prototype III had better distribution of gaze percentage over significant areas of interest as compared with Prototypes I & II.

- Prototype III had less number of fixations over each significant area of interest when compared with Prototypes I and II.

- Prototype III had shortest fixation durations in all three variants. Prototype III also had the shortest times to first fixation among the three Prototypes.

- Participants who used Prototype III finished the task fastest among the three groups.

- Participants who used Prototype III found it to be the most easily usable.

Based on these factors it was concluded that Prototype III (red dots) is the most navigable among all three prototypes. Prototype II which has hollow rectangles as visual

cues performed better in terms of usability than Prototype I which has no visual cues. The results recorded for the group that tested Prototype II were not consistent among all the five participants of the group. This means that all of the participants of the group did not find it to be an easily usable application. The hypothesis – "An e-learning application which has visual cues to direct the user's gaze is easier to navigate, and is a more intuitive e-learning tool than the one without visual cues." was tested and determined to be true for both Prototype II (Rectangles) and Prototype III (Red dots).

Though the hypothesis stands true based on the eye-tracking data recorded for the two prototypes used in the thesis, it has certain limitations. The eye-tracking data could differ substantially with a different user pool. A user pool other than the current one in terms of age, culture or technical competence could have significantly different responses to the PSE's user interface. A user who is less technologically competent might take longer to figure out the user interface. The current design scheme assumes that all the users of the PSE read and write from left to right. Reading from left to right is considered normal in English and most European languages. Users who use languages like Hebrew, Arabic or Chinese read from right to left. These users might have a drastically different response to the PSE user interface. These and many other factors could have a profound impact on the usability of the PSE. This thesis does not account for all those possibilities and cannot be considered a comprehensive study on the usability of e-learning problem solving environments.

The gaze direction techniques used in this thesis could be further modified to incorporate various scenarios. Currently, the visual cues used to direct users gaze in the PSE are not subtle in appearance. User is able to see the visual cues. A system could be developed where the visual cues disappear before user fixates on them. Visual cues in which there are intermittently flashing rectangles could also prove to be useful in directing the users gaze. Such a system could be developed to further test its usability to gain some insight into ways of increasing the usability of the PSE. An altogether different scheme for visual cues can be used for the PSE. It will be interesting to test if the scheme of visual cues that is hybrid of rectangles and dots will be more efficient than that of the current schemes used.

Eye-tracking has been used in this thesis as a tool for doing usability analysis on the PSE. Instead, real time eye-tracking could be used to determine users' skill and attention level. Gaze direction technique may be modified to adapt to users' skill or attention levels. Software tools or algorithms could be developed that determine users' knowledge of the subject matter based on their gaze patterns. For example, a user with limited knowledge of the subject matter in the PSE would have a different scan path or gaze pattern in comparison with someone who has expert knowledge.

The field of graphic design is inherently attentive to intuitive readability and usability. The evaluation technique used in this thesis can improve draft designs iteratively to evaluate their effectiveness.

The eye-tracking hardware and software used in this thesis are expensive. Inexpensive and portable eye-tracking hardware could be deployed to increase the reach of the system.

Gaze direction technology could be used in educational games. Educational games present a fun and interactive way of imparting education [35]. Use of eye-tracking and gaze direction in educational games would help in the propagation of technology and innovative ways of its usage.

As e-learning applications become increasingly complex, users become inundated with cluttered user interface. There is a need to use gaze direction techniques so that the users gaze can be guided around the user interface to facilitate learning. Even with its limitations, the technique presented in this thesis is a useful first step towards developing more intuitive e-learning applications.

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