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Comprehensive evaluation of a computer based learning system

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COMPREHENSIVE EVALUATION OF A COMPUTER BASED LEARNING SYSTEM

by

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ABSTRACT

This thesis presents the results of a comprehensive multi-method evaluation that was conducted on the Rapid Development System (RDS), a computer-based learning environment. The development of the project was funded by a National Science Foundation grant. Prior to this evaluation, the RDS had gone through two iterations.

A pre/post evaluation was conducted using questionnaires and eye tracking. Multi-method evaluation was employed to help triangulate the results and to provide additional insights. Data from the eye tracking was used to study the influence of the RDS interface on the attention and the cognitive workload of students with respect to the learning styles (visual/verbal).

From the results, a significant improvement was noticed in users' interest levels toward the subject after using RDS. Students reported a significant increase in knowledge after using the system. Minor usability issues were reported using the qualitative data from the eye tracking. We also found differences between visual learners and verbal learners with respect to attention, cognitive workload, perceived ease of use and perceived learning outcome.

Overall, this study found that RDS was well received by the participants and could be used as an effective learning tool in teaching the concepts of control design. Results from this study can help guide the design of computer based learning systems.

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I would also like to thank my other committee members for their valuable guidance throughout the project, especially Dr. Richard Hall.

I would like to thank Dr. Robert Landers without whom this project would not be possible. Thanks to Dr. Landers' vision, the budding control engineers of the future now have a modern and motivating system to learn control design.

Finally, I would also like to thank my family members and friends, especially my parents including Anusha, for all the sacrifices they have made for me, for putting up with me throughout this project, and for being available when I needed them.

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1. INTRODUCTION

1.1. RATIONALE

E-learning broadly encompasses all forms of electronic teaching (including computer-supported and computer-based) and learning and is becoming more popular every day. In 2007, the American e-learning market was valued at 17.5 billion dollars. This number was expected to more than double to 52.6 billion dollars in 2010 (Kopf, 2007).

One area in e-learning that has seen explosive growth is the use of computer-based learning environments (CBLEs) to aid educators in teaching concepts. The use of CBLEs is becoming more prevalent with the high penetration of computers in the education sector. These environments have become ubiquitous in the classroom to help students learn difficult and challenging topics (Azvedo, 2005; Graesser et al., 2005). Recent advances in computer hardware and software and decreases in the costs of computer hardware have helped to boost the penetration of these learning environments in engineering education to help students understand key engineering concepts (Cheok et al., 1991). In the engineering curriculum, CBLEs help to strengthen course delivery and provide laboratory innovation (Cheok et al., 1991).

The advent of computer-based learning environments coupled with high resolution color graphic capabilities have enabled the development of new technologies such as animation which, when used as part of the learning environment, help to improve conceptual understanding and the appeal of the system. These items enhance the quality of a student's learning process by accommodating the unique learning styles of students (Carlson & Sullivan, 1998).

Recent research in learning styles calls for more testing to understand how learning styles affect the learning outcome and to shed more light on understanding if learning styles cause the software to be perceived differently (Mayer, 2009). This testing can be accomplished by means of a thorough usability test in which the end user interacts with a system to provide valuable indicators on the performance of the interface.

Usability testing plays a central role in the development of interactive educational software. A user-centered design is quintessential for promoting the usage of such software. Usability problems in educational software programs can cause disturbance within the learning process by distracting the learner's attention from the learning task and, consequently, increasing the cognitive workload on the learner (Domagk et al., 2004).

Research in the area of e-learning has shown that progress in this area has been slow due to problems related to the poor interface designs of the learning systems (Zaharias, 2005). Furthermore, despite the importance of including usability evaluations in the design of learning systems, research in this area has indicated that usability evaluations are not frequently used (Sigchi, 2001).

1.2. RESEARCH OBJECTIVES

In this thesis, we build on the previous research done in this area where a comprehensive usability framework (Jain et al., 2009) was developed to evaluate educational technologies. We utilized this framework in evaluating a computer-based learning system called the Rapid Development System (RDS), which was designed for teaching control design concepts. The main objective of the evaluation was to test if users would accept the system as a learning tool. The second objective was to understand how an interface that included animation as a significant part of the system influenced the learning outcome between two groups: (a) visual learners and (b) verbal learners.

1.3. THESIS OVERVIEW

Section I covered the motive of our research, the research objective and the gap in the literature that we need to address. Section II, the literature review, examines the previous literature on the concepts used in our research.

Section III describes the research model with constructs adapted from previous literature. Section IV describes the overview of the project.

Section V discusses our approach and the procedures that were followed in conducting the study, the approach taken and materials used in this research. Section VI presents and explains the findings of the questionnaire data. Section VII presents and explains findings from the eye tracking data.

Finally, Section VIII summarizes the findings and uses both qualitative and quantitative results to determine the conclusions in section IX.

2. LITERATURE REVIEW

2.1. THE COMPUTER BASED LEARNING ENVIRONMENT (CBLE)

"Learning environments are comprehensive, integrated systems that promote engagement through student-centered activities, including guided presentations, manipulation, and explorations among interrelated learning themes" (Hannafin, 1992). Learning environments that use computer aided information delivery are called computer-based learning environments (CBLEs). These environments are increasingly used to supplement traditional forms of education (Carlson & Sullivan, 1998).

Computer-based learning environments enable individuals with different learning needs and unique learning requirements to obtain a deepener understanding of a subject and to study multiple hierarchies of complexity in an interactive and complementary manner (Hannafin & Land, 1997). CBLEs can boost both the speed and the level of student learning (Horton, 2000; Najjar, 1998). These environments also help to improve the students' confidence and motivation (Klassen et al., 2001). Using an interactive web-based learning program can increase the learning enjoyment level, which, in turn, may increase a student's understanding and his or her information retention (Street & Goodman, 1998).Thus, computer-based learning environments provide a fertile ground that help to enrich thinking and learning.

Understanding complex systems to help solve real world problems is an important part of engineering education. In the recent decade, universities have rapidly embraced CBLEs for providing in-depth real-world laboratory education for engineering disciplines.

Engineering is also a practical discipline and a hands-on profession where the "doing" is key (Feisel & Rosa, 2005). The use of hands-on experimentation using either the equipment or tools that simulate this equipment is a key aspect of engineering education (Carlson & Sullivan, 1998). Previous research has shown that hands-on experimentation in laboratories are an essential supplement to the relatively passive experiences of learning via listening to lectures and reading textbooks (Edelson et al., 1999; Bransford et al.,1990; Lave &Wenger, 1991). Knight et al. (2007) found that courses that were designed to include active hands-on pedagogy improved the retention of students in engineering education.

Currently, computer-based learning environments are being used as an integral part of teaching in the engineering curriculum. These learning environments enable students to emulate many physical and technical processes for the experimental studies of systems that would otherwise be expensive, large, or dangerous to test physically (Feisel & Rosa, 2005). Previous studies have shown that students who learn using computer-based animation environments have a higher understanding of complex concepts and systems compared to students who learn in a traditional learning environment that focuses on verbal explanation (Park, 1994; Reiber, 1991; Tversky et al., 2002). Computer-aided engineering tools make it possible to increase the personal efficiency of problem solving. These tools also allow students to work on realistic problems which contribute to making teaching more realistic and more interesting (Kheir, 1996).

An overview of the design of various computer-based learning systems (Evans & Edwards, 1999; Evans et al., 2004) shows that most of these systems resemble traditional textbooks and lack interactivity (Markwell & Brooks, 2002). This results in learning through observing as opposed to hands-on learning (Moos & Azevedo, 2009). This also results in students using strategies such as memorizing the paths and completing the tasks on the computer-based learning systems without gaining knowledge. In view of this, Mayer (2009) recommended the use of a learner-centered approach (similar to a user-centered approach) in developing these systems where the goal is to design the system in such a way that it aids the processing of information.

One method of designing CBLEs that aid the processing of information is by building features that support different learning styles. Learners attend differentially to selected stimuli and invest their effort accordingly (Hannafin, 1992). New technologies have made new presentation formats available (e.g. animation, narration, and cueing) (Bannert, 2002), which can be built into the learning systems to support the unique learning styles of students. Building these features into an interface allows a student's attention and effort to be selectively directed. These methods allow learners to be engaged towards the content and to learn in ways that are uniquely suited to the individual's perception.

2.1.1. Animation. Animation is defined as a visual representation that "generates a series of frames, so that each frame appears as an alternation of the previous one" (Betrantcourt, 2005). Animation can be used to present events (e.g. motions) that change over time. Animation helps learners visualize and create internal representations of how the system works. As a dynamic representation, animation can help learners understand complex processes in an explicit manner (Schnotz & Lowe, 2003).

Animation involves a complex interplay between top-down and bottom-up processes (Kriz & Hegarty, 2007). In order to grasp the information from the animation, learners must be able to extract thematically relevant information (Lowe, 2003).

An important area where animation is being used is in the simulation of control systems. Animation reduces the need of expensive equipment and increases safety. The use of the animated visualization of dynamic system motion can help enhance the perception and understanding of a system that is subjected to simulation (Kheir et al., 1996). At the same time, animation brings the simulations to life and helps to portray a sense of reality (Kheir et al., 1996). Previous research in the area of control systems has shown that students' conceptual understanding of simulation results and control design concepts can be enhanced significantly by their interaction with real time simulation and animation (Cheok et al., 1991; Cheok et al., 1993; Cheok &Huang, 1992; Cheok & Kheir, 1993).

An extension of this research topic involves the study of the role of individual learning characteristics in influencing the use of such systems (Plass et al., 1998; Riding, 2001). Thus, one research direction is to understand which factors contribute to a higher adaptability and drive the increased usage of CBLEs built with animation (Hoffler et al., 2010). Some of the factors that have been studied are prior knowledge and spatial ability (Hoffler et al., 2006; Huk, 2006; Isaak & Just, 1995). However, very little research has investigated if visual learners perceive their interaction with the learning environment differently than verbal learners do. Additionally, there is also a need to examine if the use of such systems can place a cognitive workload on individual learners with respect to their preference in learning (Schnotz et al., 1999).

In the next section, we discuss learning styles that are unique to every individual and are a useful classification to help drive design decisions.

2.2. LEARNING STYLES

In a learner-centered teaching, pedagogy should be based on learners' needs rather than on teachers' or institutions' needs and should be compatible with the use of information and communication technology. In education, research has aimed at understanding the individual differences in learning processes. These differences are called "learning styles."

Learning styles are defined as "characteristic cognitive, affective, and psychological behaviors that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment" (Keefe, 1979).Students are characterized by their preference of how they want to learn and how they operate on the information they learned (Corno & Snow, 1986).Previous research has shown that students are characterized by a variety of learning styles (Corno & Snow, 1986; Schmeck, 1988).

There are many different types of learning style models including Honey and Mumford's model (1984), Kolb's model (1984), and Felder and Silverman's model (1988). Each model classifies learning styles and provides different descriptions for the classification. In our research study, we used the Felder-Silverman model, a learning style model that is often used to study advanced technology-enhanced learning (Graf, 2007).

The Felder-Silverman model of learning style classification was chosen to classify students since it provides more depth in its classification and since it has a larger number of groups compared to other methods (Graf et al., 2007). Carver et al. (1999) stated that, "The Felder-Silverman Model is most appropriate for hypermedia courseware." Kuljis and Liu (2005) also suggested the Felder-Silverman model as the most appropriate model based on their research in which they compared various learning style models with respect to applications in e-learning and web-based learning systems.

2.2.1. The Felder-Silverman Model. The Felder-Silverman model (Felder & Silverman, 1988) is one of the most prominent models used to categorize engineering students` learning styles (Montgomery, 1995). In this model, students are categorized based on their learning preferences and on how they act on the learning.

1) The type of information the student prefer to perceive: sensory (such as sights, sounds, and physical sensations) or intuitive (such as memory, insight, and feelings).
2) The preferred sensory mode through which the information can be best perceived: visual (through pictures, animations, sounds, etc.) or verbal (through written and/or spoken instructions).
3) The student's preferred method to process the information: actively (i.e. via discussions or physical engagement) or reflectively (i.e. via introspection).
4) The way in which the student progresses towards understanding: sequentially (in incremental progression) or globally (understanding the big picture or in big jumps).

Visual learners remember best what they see. They tend to find diagrams, sketches, schematics, photographs, flow charts, or any other visual representation of course material that is primarily verbal and very useful to learn. Verbal learners, on the other hand, learn through words through written explanations and/or spoken explanations. They write summaries or outlines of course material in their own words, work in groups to have a more effective learning experience, gain an understanding of material by hearing classmates' explanations, and learn even more when they do the explaining.

In engineering education, studies have attempted to relate learning style to learning outcomes in order to make engineering education more effective. The results show that learning style theory is a potential tool for guiding the design and improvement of courses and for helping students to improve their individual performance (Carver et al., 2005). Eder and Hubka (2005) presented various learning styles as one element in their model of educational design as a transformational process that takes a student from an input state to an output state. Each student has a unique combination of knowledge, skills, attitudes, values, and learning style (Eder & Hubka, 2005). In order to increase a student's success in engineering education, one must understand the student's individual learning style and provide instructional methods and environments accordingly (Kyun et al., 2009). Researchers in applied fields have found that an individual's learning style can be a better predictor of his or her success in a particular situation than general intelligence or situational factors are (Kyun et al., 2009).

One way to address diverse learning styles is to use computer-based learning. In addition, an awareness of the pedagogical needs of various learning styles can result in the development of a more effective computer-based learning system. By assessing the learning style of students, interfaces for education software should be designed to cater to a variety of different learning styles (Kramer-Koehler et al., 1995). A study conducted by Azvedo et al. (2004) proved that, while the use of CBLE resulted in a large gain in the conceptual understanding in one group of students, it resulted in very little or no gain in another group of students. For this study, students were divided into two groups based on the shift in their mental models in understanding: (a) high jumpers (higher conceptual learners) and (b) low jumpers (low conceptual learners) (Azvedo et al., 2004). Educational researchers and instruction designers suggest that one of the causes for this perplexing difference in the performance of individuals could be learning styles (Streufert & Nogami, 1989; Hayes & Allison, 1994).

Learning experience, described as the transaction that takes place between a learner and the instruction environment, is different for each learner (Parrish, 2009). It is not enough to provide students access to different tools and/or learning environments without taking the learner into consideration (Bates & Leary, 2001). Therefore, these learning environments must be designed with consideration of the end user. In order to design such a system, a user-centered design process must be followed. One of the hallmarks of this approach is to evaluate the system by following a distinct interactive system evaluation using the end users as participants (Granic, 2008). This is called a "usability evaluation."

2.3. USABILITY TESTING

According to the International Organization for Standardization (Bevan, 2001) usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." Usability is an important aspect of an interactive learning system. A higher usability in a learning system would facilitate an increase in user satisfaction and user acceptance that would result in the increased adoption of the system (Danao, 2010).

Research in the area of human-computer interaction has provided numerous principles and design guidelines to help designers build usable systems. However, following the design guidelines alone is not a substitute for a distinct system-wide interactive evaluation in order to ensure usability (Granic, 2008).In order to build highly usable systems, an iterative process that involves design, evaluation, and redesign is essential (Hartson et al., 2003). This approach takes into consideration the users' natural behavior and includes any constraints on the ability to learn and perform so that the interfaces are more intuitive, easier to use, easier to learn, and free of performance errors.

Usability testing requires representative users to work on typical tasks using the system or the prototype (Ardito et al., 2006). The results from the evaluation provide evaluators with an understanding of how the user interface supports the user while carrying out the tasks.

Over the years, many analytical usability evaluation methods have been developed. Each method addresses a particular type of usability issues. Some of the popular methods of evaluation are the Heuristic Evaluation method (Nielsen, 1994) and the Cognitive Walkthrough method (Cuomo &Bowen, 1994; Desurvire, 1994; Dutt et al., 1994). Another method that is being used frequently to study and identify usability issues is the eye tracking method (Poole & Ball, 2006).

2.3.1. Eye tracking. Eye Tracking is a method in which eye movement data over a visual stimulus is collected. This method allows researchers to ascertain the position of the eyes as they move over a visual stimulus. Thus it provides researchers with information on the distribution of visual (overt) attention over different objects (e.g. words in a sentence or different areas of GUI) in term of what they see, for how long, and in what order (Scheiter & Van Gog, 2009). Previous research in the area of visual attention has suggested that what is being currently fixated at is an indication to what is being processed in the mind (also called eye-mind hypothesis) (Just & Carpenter, 1980). Eye tracking can thus provide researchers with a dynamic trace of user's attention over a visual display (Poole & Ball, 2005).

In order to understand how eye movements can help in quantifying users' attention towards the interface elements it is important that we understand the relationship between eye movements and cognitive processes.

2.3.1.1. Eye movement and attention. Previous research in the area of neuroscience and psychology has argued that studying attention independently of eye movements is misleading and misguided (Findlay & Gilchrist, 2003). Jacob (1995) suggests that a complete theory of visual processing needs to include an account of eye movements. In order to understand how eye movement and attention work it is imperative that we understand the physiology of the eye.

The human eye is composed of three layers enclosed by three transparent structures. The outermost layer consists of cornea and sclera. The middle layer consists of choroid, cillary body and iris (Hammoud, 2008). And the innermost layer consists of the retina. The figure 2.1 below shows the cross section of the human eye.

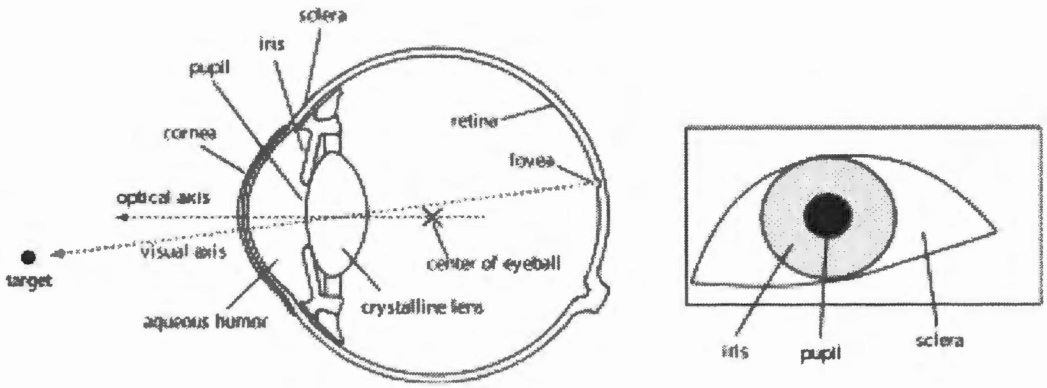

Figure 2.1. Cross-section of the human eye (Hammoud, 2008)

When an individual looks at an object, an image of the object falls on the retina. The retina is composed of special light sensitive cells called cones and rods that convert the light signals to optical information and transmit it to the brain via the optical nerve. However, the distribution of these cells is not even. The center of the retina called the fovea (foveal vision) has higher densely packed cells that gradually become sparser towards the periphery of the retina (parafoveal vision) (Pashler, 1998). The figure 2.2 below shows the different regions of human vision.

The fovea covers approximately one degree field of view, that is, a one-degree angle with its vertex at the eye, extending outward into space. Thus the fovea provides much higher acuity vision than the surrounding areas. The eye does not move smoothly over the visual field (Duhowski, 2003). Eye movements are made to reorient the eye when visual input from a particular location is of special importance so that the object of interest falls upon the fovea and the highest level of detail can be extracted (Pashler, 1998). This movement during which the eye focuses on an object is called a fixation.

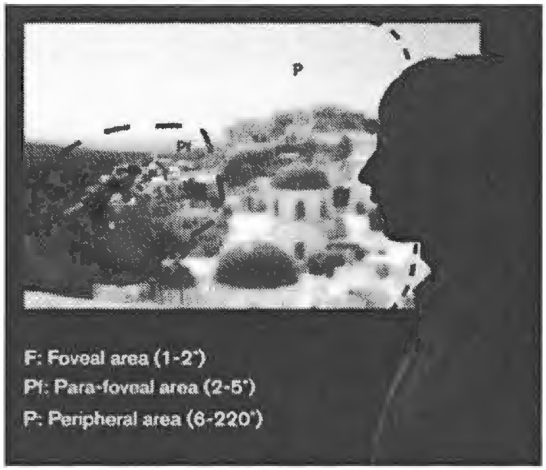

Figure 2.2. Different regions of human vision (Hammoud, 2008)

The duration of each fixation is in the range of 250-300 milliseconds (Salvucci & Goldberg, 2000). In order to get to the fixation or move to the next fixation the eye goes through a movement termed "saccade" (Pashler, 1998). The saccade is used to orient the eyeball so that the desired portion of the visual scene falls upon the fovea (Pashler, 1998).

Saccades are rapid, ballistic eye movements (high acceleration and deceleration rates) that last 30-120 milliseconds from planning to execution (Palmer, 1999). Since the saccade is ballistic, its destination must be selected before movement begins; since the destination typically lies outside the fovea it must be selected by lower acuity peripheral vision (Pashler, 1998). If an object that might attract a saccade suddenly appears in peripheral vision, there is a 100-300 milliseconds delay before the saccade occurs. No information is perceived during a saccade as the perception is inhibited to prevent the viewer seeing a blur. Information can only be perceived when the eyes are relatively still i.e. during a fixation (Duhowski, 2003). Thus a complete scan path consists of fixation during which information is encoded and saccades to move to then next fixation. The figure 2.3 below shows the complete scan path with fixation and saccades.

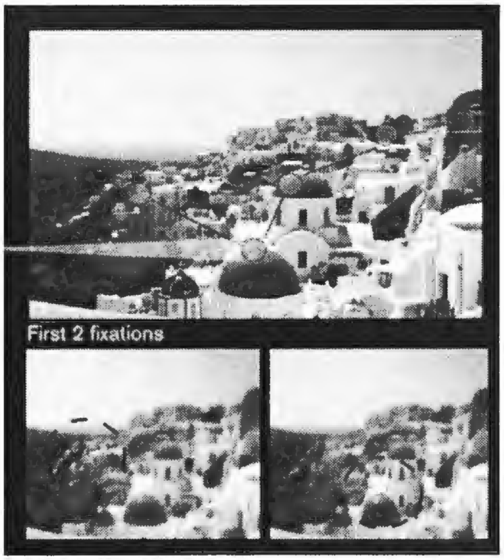

Figure 2.3. Complete scan path with fixation and saccades (Hammoud, 2008)

Tracking these eye movements can provide researchers with valuable clues on how users process information. Active vision ensures the availability of high quality visual information to support perceptual and cognitive processing as well as behavioral activity, and help in simplifying a variety of complex interactions both visual and cognitive in nature (Ballard, 1976; Ballard et al, 1997; Churchland et al., 1994).

In the next part we briefly discuss some of the eye tracking technologies and how modern eye trackers work.

2.3.1.2. Eye tracking technology. A variety of eye tracking technologies have been developed since the first reported use of the methodology (Rayner & Pollatsek, 1989). In general, eye tracking methodologies can be classified into two types: those that measure the position of the eye relative to the head and those that measure the orientation of the eye in space also called, “point of regard” (Young & Sheena, 1975). From a technological stand point eye tracking techniques can be broadly classified into four different types: electrooculography (EOG), scleral contact lens/search coil, photo-oculography or video-oculography (VOG) and video based combined pupil and corneal reflection.

Electrooculography relies on electrodes placed around the eye to measure differences in electric potential to detect eye movements (Duchowski, 2003). This method was widely used previously and still in use. The sclera contact lens/search coil is one of the most accurate methodologies to measure eye movements (Duchowski, 2003). However, this method is also the most intrusive. It involves the wearing of specialized lenses that has a metal coil embedded around the edge of the lens; eye movements are measured by fluctuations in an electromagnetic field when the metal coil moves along with the eyes (Duchowski, 2003). The third technique involves the measurement of various distinguishable features of the eye such as the apparent shape of the pupil, corneal reflections and the iris-sclera boundary using video camera (Duchowski, 2003). Nowadays most of the modern eye trackers utilize the pupil centered corneal reflection to measure point of regard (Goldberg & Wichansky, 2003).

Modern eye trackers consist of specialized chassis that houses standard LCD monitor along with an eye-tracking unit located at the bottom (Poole & Ball, 2005). The eye tracking unit contains two sets of IR led emitters and IR cameras to track both eyes. These are called binocular systems as they track both the eyes. The eye tracker also houses a specialized microcomputer that runs sophisticated image processing algorithms to identify relevant features, including the eyes and the corneal reflection patterns (Duhowski, 2003).

The overall setup consists of an eye tracker connected to a dedicated desktop/laptop computer running specialized software to create tests (setting the stimulus), record the eye movements and help in data analysis. During tracking, the eye tracker fires the near infrared diodes to generate reflection patterns on the corneas of the eyes of the user (Poole & Ball, 2005). These corneal reflections are also called as purkinje reflections (Duhowski, 2003). The light from the LED enters the retina and large portion of it is reflected back and in the process illuminates the pupil (called Bright pupil effect see figure) (Poole & Ball, 2005). The corneal reflections from the infrared light appear as a small yet sharp glint as shown in figure 2.2 below.

An infrared camera collects these reflection patterns, together with other visual information about the person. Sophisticated image processing algorithms in the software identify relevant features, including the eyes, corneal reflection patterns and the center of the retina (Duhowski, 2003). Complex mathematics is used to calculate the three-dimensional position of each eyeball, and finally the gaze point on the screen, i.e. where the user is looking. As each individual has unique eye properties that needs to be mapped to the three dimensional eye model built into the eye tracker, a calibration needs to be performed (Duhowski, 2003). This calibration generally uses a 5-point (95% accuracy) system. In the calibration phase individuals are asked to follow a dot on the screen, if the eye fixes for a longer than a certain threshold and is within a certain area, the system records pupil centered corneal reflection relationship to specific a coordinate (x, y) on the screen (Poole & Ball, 2005).

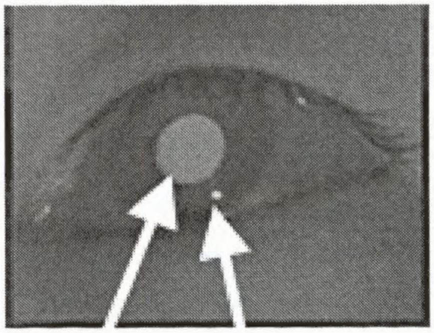

Figure 2.4. Corneal reflections showing glint (bright-pupil effect)

In the next section we will discuss relevant literature on the role of eye tracking in studying learning and finding usability issues.

2.3.2. Using eye movements to evaluate interface usability and cognition. The use of eye movements has tremendously befitted the psychology community as they can provide an insight into problem solving, reasoning, mental imagery, and search strategies (e.g., Ball et al., 2003; Just & Carpenter, 1976; Yoon & Narayanan, 2004, Zelinsky & Sheinberg, 1995).The use of eye movements in studying cognitive processes has been documented by Rayner (1998). One of the most important areas where eye tracking could be applied is in revealing moment to moment processing activities (Rayner, 1998). An important study in this area is the eye-mind hypothesis (Just & Carpenter, 1980) which suggests a close link between the gaze and attention. It suggests that there is a relationship between what is currently looked at and the current visual processing.

The "eye-mind" hypothesis indicates what a person observes is assumed to indicate the thought "on top of the stack" of cognitive process (Just & Carpenter, 1980). This means that eye movement recordings can provide researchers with a trace of the user's attention on an interface. Other eye tracking measures such as fixations (stationary eye movements) can indicate the processing time on the area that was fixated (Hyönä, 2009).

2.3.2.1. Visualizing eye tracking data. Eye tracking data can be visualized using two popular formats called gaze plots and heat maps (Goldberg & Wichansky, 2000).

The Gaze Plot visualization shows the sequence and position of fixations (dots) on a static media, (e.g. an image or a scene). The size of the dots indicates the fixation duration and the numbers in the dots represent the order of the fixations. Gaze plots can be used to illustrate the gaze pattern of a single test participant throughout the entire eye tracking session, or of several participants in a short time interval (Duhowski, 2003).

Heat maps on the other hand are aggregated over multiple participants. These can be of great value when creating reports, papers or presentations, as they help you to summarize large quantities of data in an intuitive way. A heat map uses different colors to show the number of fixations participants made in certain areas of the image or for how long they fixated within that area (Duhowski, 2003). Red usually indicates the highest number of fixations or the longest time, and green the least, with varying levels in between.

For relative duration heat maps which were used in this paper, the duration of each fixation is divided first by the media viewing time and then added. Once all the fixations values have been added together, color values are added to all the points, with the warmest color (red) representing the highest value.

2.3.2.2. Quantitative eye tracking data. In practice, the process of inferring useful information from eye-movement recordings involves the defining of "areas of interest" over certain parts of a display or interface under evaluation, and analyzing the eye movements which fall within such areas (Poole & Ball, 2005). In this way, the visibility, meaningfulness and placement of specific interface elements can be objectively evaluated and the resulting findings can be used to improve the design of the interface (Goldberg & Kotval, 1999).

One important measure that is obtained from the eye tracking data is the total fixation duration. This total fixation duration is one of the most popular measures used by researchers to measure a user's attention towards an interface element in the area of multimedia learning with graphics (Mayer, 2010). The total fixation time on relevant areas reveals the perceptual processing during learning. A study by Schmidt-Weigand et al. (2010) used fixation time on visualization and text and found that learners spent more time viewing visualizations with spoken text than with written text. To rephrase, this metric measures the sum of all fixation durations that are within the area of interest. The total fixation time on the relevant areas reveals the perceptual processing during learning.

2.3.2.3. Previous eye-tracking research related to learning. Previous research in the area of learning using eye tracking has focused primarily on reading research (Hyona & Niemi, 1990; Just & Carpenter, 1980; Rayner, 1998). Later research focused on the other areas of learning such as through pictures and text and problem solving. Current research has focused on the use of eye movements in evaluating multimedia based learning (Schmidt-Weigand et al., 2010; Kaakinenn et al., 2002). For example, Boucheix & Lowe (2010) looked at learning through animation and found that visual signals improved the perceived learning outcome.

Hegarty and Just (1993) studied how learners attempt to integrate verbal and pictorial information. Eye tracking data from the study revealed interesting findings. Results showed that the processing of the diagram appeared to be largely text-guided, in that participants first read a text in increments before constructing a spatial mental model based on the pictorial information. An important effect seen by researchers among student learning through multimedia learning is the split-attention effect (Ayres & Sweller, 2005). This effect indicates that two mutually referring but separately presented information sources (text-picture combinations, cf. Mayer, 2005), hampers learning as compared to an integrated presentation format. However, more research is needed to understand how different presentation techniques i.e. mutually representative but presented separately can hamper learning in comparison to presenting information in an integrated approach. It is hypothesized that this could be due to high processing demands imposed by visual search and mental integration, but the exact nature of these processes is unknown, and so is whether these processes are the same for all learners (Scheiter & Van Gog, 2009).

Hannus and Hyoñä (1999), Hegarty and Just (1993) conducted research in this area using eye tracking. Hannus and Hyoñä (2009) studied how children process illustrated texts. Results from their study showed that children focused on reading the text, and mostly ignored the illustrations and individual cognitive abilities moderated identification of relevant material. Another research analyzed the eye movements of newspaper readers in response to different designs of information graphics and related text (Holsanova et al., 2008). Results from the study suggest that when the text and graphic are placed separately, readers treat the text and graphics as separate units, making fewer attempts to integrate the information from both sources. The results from the study can be an explanation why the split-source formats tends to hamper learning in comparison to integrated formats (Ayres & Sweller, 2005). One reason why split- source formats hamper learning can be attributed to the fact that it is difficult to simulate a proper mental representation (Scheiter & Van Gog, 2009). Holsanova et al. (2008) also showed that arrangement of graphic elements could influence processing of the graphic elements.

Arranging multiple graphical elements in a way that suggests a logical, serial reading path leads to more intensive processing of the graphic and more integrative saccades as opposed to following a radial pattern.

Thus research in this area demonstrates how the presentation of media can affect the visual attention, and by doing so contribute to our understanding of why combining information from texts and graphics is supported by certain designs of multi-representational environments and hampered by others (Scheiter & Van Gog, 2009). An important extension to this research is to understand if cognitive preferences can affect visual attention towards multi-representational environments (Mayer, 2005).

In the next section we look at the cognitive workload measure which can be measured using the pupil dilation measure from eye tracking.

2.3.3. Cognitive workload. Cognitive workload is a multi-dimensional concept. One way to define it is "the cognitive workload of a task represents the level of attentional resources required to meet both objective and subjective performance criteria, which may be mediated by task demands, external support and past experience" (Young & Stanton, 2004). This definition is based on the assumption that attentional resources have a finite capacity beyond which any further increase in demand results in performance degradation.

Physiological, performance-based, and self-assessment techniques all have been used to measure cognitive workload (Paas et al., 2003; Farmer & Brownson, 2003; Kobus & Morrison, 1905). The typical performance measures of cognitive workload have included indices such as time to complete tasks, reaction time, correct solutions, memory retrieval time and correctness, time estimation, rate of physical activity and speech, spoken disfluencies, and multimodal integration patterns (Ho &Spence, 2005; Oviatt, 1995; Oviatt et al., 2006; Oviatt et al., 2003; Paas et al., 2003). In contrast, subjective measures of cognitive workload interrupt a person's work and they cannot be collected as real-time measures (Farmer & Brownson, 2003). The more promising physiological measures for assessing cognitive workload, such as brain activity, is reflected in EEGs and the eye monitoring of pupil size (Oviatt, 2005).

2.3.3.1. Pupil dilation. Previous research has suggested that dilation of the pupil is the best single index to measure autonomic indication of effort followed by increase in skin conductance (Colman & Pavio, 1969; Kahneman et al, 1969). An important requirement of a physiological measure of mental effort is that it should be sensitive to both within-task and between task variations (Kahneman, 1973). A perfect measure would be one that would enable the measurement of mental effort that different people invest in a given task. Measurement of the pupil diameter satisfies the first two requirements by providing a sensitive indication of both between task and within task variations of effort (Goldwater, 1972).

The claim that pupil dilations can indicate cognitive workload was made by Hess and Polt (1964). They observed a striking correspondence between mental arithmetic problems and magnitude of dilation during the solution period. This relationship between cognitive load and pupil dilation was later confirmed in numerous contexts: performing arithmetic calculations (Bradshaw, 1968; Payne et al., 1968); short-term memory tasks of varying load (Kanheman & Beatty, 1966); pitch discriminations of varying difficulties (Kahneman & Beatty, 1967); standardized tests to measure concentration (Bradshaw, 1968a); sentence comprehension (Wright & Kahneman, 1971); paired-associate learning (Colman & Paivio, 1970; Kahneman & Peavler, 1969); imagery tasks using abstract and concrete words (Paivio & Simpson, 1966, 1968; Simpson & Paivio, 1968). In all the situations discussed above, the amount of dilation increased with task demand or difficulty.

There exists a relationship between pupil dilation and attention even in the absence of specific instructions. An example is the research that found observed dilations of the pupil when participant looked at pictures (Libby & Lacey, 1973). Largest dilations occurred during exposure to attention grabbing and interesting pictures (Kahneman, 1973). Pratt (1970) observed that pupil dilations varied with unpredictability of random shapes to which participants were exposed. Thus, it is evident that complex and interesting pictures, like difficult tasks, attract attention and demand a relatively large investment of effort (Kahneman, 1973).

An important requirement of an adequate measure of effort is within-task sensitivity. Many studies have confirmed the suggestions that the size of the pupil at any time during performance reflects participant's momentary involvement in the task (Hess, 1965). This is indeed true as the fidelity of the pupil response permits a second-by-second analysis of task load and effort. An example is the research done by Kahneman and Beatty (1966), who showed that presentation of each successive digit in a short term memory task, was accompanied by a dilation of the pupil.

The pupil dilation measure is a relatively fast response and major dilations can occur within one second after the presentation of the stimulus depending on how demanding the stimulus is (Beatty & Kahneman, 1966). Beatty and Lucero-Wagoner (2000) identified three important task-evoked papillary responses (TEPRs): (a) mean pupil dilation, (b) peak dilation, and (c) latency to the peak. These measures typically increase as a function of a user's cognitive workload (Beatty & Lucero-Wagoner, 2000). In this study, mean pupil dilation was used for measuring cognitive workload.

2.4. PERCEIVED LEARNING OUTCOME

Perceived learning outcome refers to the perceived knowledge gained by the students through the use of different methods of teaching or studying. A learning outcome includes statements that describe the knowledge, skills, and attitudes that learners should have after successfully completing a learning experience or program.

Methods of teaching or studying typically include reading textbooks, performing experiments in a laboratory setting, and using information technologies. The assessment of learning outcomes often includes quantitative measures for notions such as motivation to learn, real world applicability, and knowledge or learning awareness. These perceived learning outcomes were adapted from the study of a comprehensive learning system by Hall et al. (2006).

3. RESEARCH MODEL AND THEORY

3.1. SECTION OVERVIEW

The research model (Jain et al., 2009) used in this study is a multi-dimensional model that allowed us to test various aspects such as the user acceptance of the technology. This model was developed by incorporating various constructs from different literature. The proposed model can be used in a full-scale evaluation of IT based learning technologies. It can objectively measure the user's acceptance of the technology, the learning outcome associated with the usage of the technology, and if the technology is designed to accommodate the unique learning styles of students. In this section, we discuss how this robust model was developed by incorporating highly tested constructs from previous literature.

3.2. TECHNOLOGY ACCEPTANCE MODEL

There are many models used in previous studies to study IT user acceptance. Some of them are the Theory of Reasoned Action (TRA) (Fishbein & Ajzen, 1975) which is considered to be the ancestor of all IT acceptance models. Another model is the Technology Acceptance Model (TAM) which was also developed from TRA by incorporating the perceived usefulness and perceived ease of use constructs. The theory of planned behavior (TPB) is another model used to study user acceptance which is also based on TRA and includes the perceived behavioral control construct (Ajzen, 1991). The Unified theory of Acceptance and Use of Technology (UTAUT) is a unified model developed by Venkatesh et al. in 2003 which includes constructs from all other user acceptance models such as TRA, TPB, TAM, etc.

One of the models that have been extensively tested, studied, and used in prior literature for studying the user acceptance of technology is the Technology Acceptance Model (TAM) (Davis, 1989;). TAM has been proposed to specifically explain computer/IT usage behavior and thus was considered apt for this study.

The Technology Acceptance Model suggests that the perceived ease of use of the technology together with the perceived usefulness influences a user's attitude towards the technology and, consequently, his or her intention to use it. The perceived usefulness is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" and the perceived ease of use of the technology is "the degree to which a person believes that using a particular system would be free of effort"(Davis, 1989). The perceived ease of use and the perceived usefulness of the technology determine the user's attitude towards the technology, which, in turn, affects the users' intention to accept the technology. Attitude is defined as "the favorable or unfavorable feeling towards that particular behavior" (Fishbein & Ajzen, 1975).

The Technology Acceptance Model provides a basis for a practical and effective "user acceptance testing" that predicts the degree of user acceptance of a new system based on self-reported measures from users who have limited exposure to the system (Shneiderman et al., 2006). Since TAM has proven to be an effective model in predicting users' intentions to adopt or use new technology, it can be applied to study the acceptance of relatively new technology. Since, RDS was a relatively new system we used TAM in our research model.

Since IT learning systems are specific to a group of users, none of the existing models can reflect the motives of the e-learners, thus requiring addition of more motivational factors specific to the system (Ong et al., 2004). Many variables from the previous models such as perceived ease of use and perceived usefulness have been used to explain the acceptance and the intention to use a system (Ong et al., 2004; Teo, 2009). Other researchers have used additional factors such as facilitating conditions and social conditions (Teo, 2009), perceived playfulness (Moon & Kim, 2001), self-management of learning (Smith et al., 2003), enjoyment (Yi & Hwang, 2003) specific to the system and relevant to the learning procedure in order to explain the intention to use a system.

In our research since we wanted to study the effect of learning styles and learning outcome, these constructs were used along with the TAM and a research framework was thus developed by Jain et al. (2009).

3.3. LEARNING STYLES

The Felder and Silverman (1988) model was added into this study as a moderating variable and was used to classify students based on their preference of learning. This model allowed us to test if the technology was designed to accommodate the unique learning characteristics of the student.

3.4. PERCEIVED LEARNING OUTCOME

The Felder and Silverman (1988) model was further extended by including new variables, such as perceived learning outcome (Hall et al., 2006), which allowed us to measure the students' learning after using the learning system. The extended model allowed us to measure if students had an increase in their perceived knowledge on the subject after using the system, which is the important goal of the learning system.

3.5. RESEARCH MODEL

A diagram of our research model is shown in Figure 3.1. This model allowed us to evaluate the learning of the student in the subject matter after using the technology objectively. It helped us understand if the technology accommodated the unique learning styles of the students. The research model also helped us test the user acceptance of the technology by evaluating if the students perceived their use of the system to be easy and useful to them.

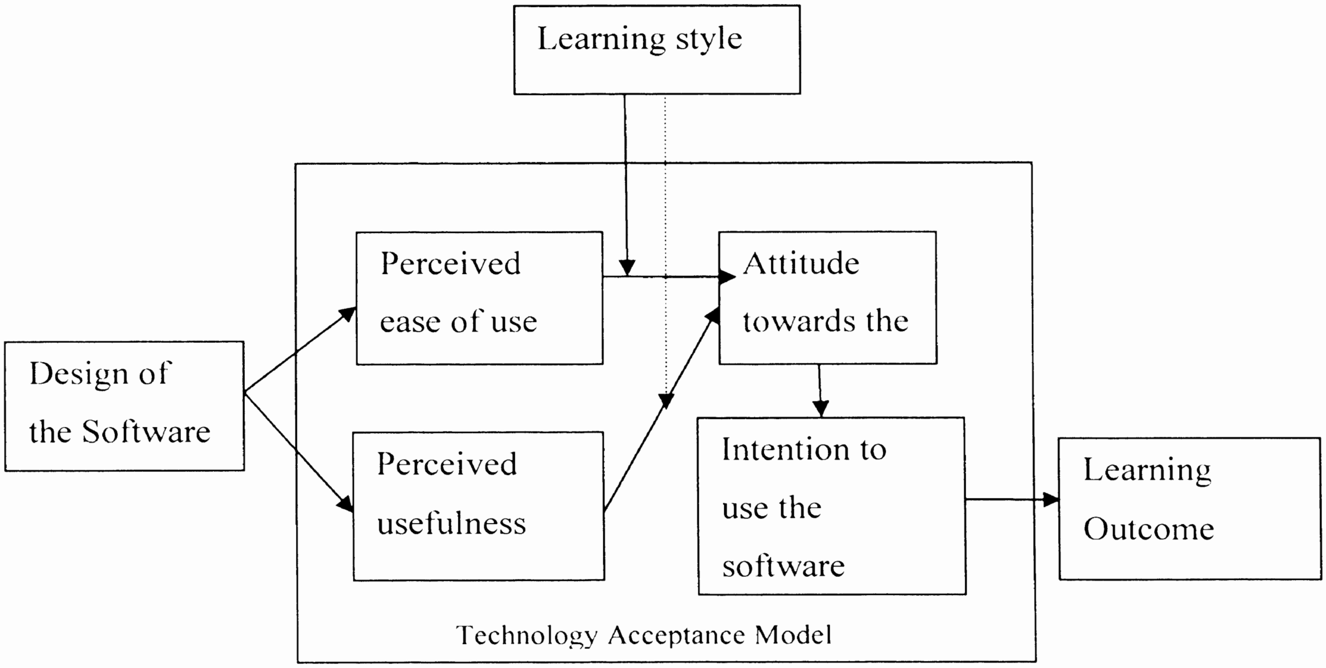

Figure 3.1. Research Model

4. PROJECT BACKGROUND

4.1. OVERVIEW

The Rapid Development System (RDS) is a hardware/software educational technology that has been under continuous development by the Mechanical and Aerospace Engineering Department at Missouri Science and Technology with funding from the National Science Foundation. The RDS technology was developed to provide hands-on experience to students enrolled in control systems classes that are part of the mechanical engineering curriculum.

4.2. RDS PHASE II

The present research was limited to Phase II A and Phase II B. The first phase, RDS Phase I, was excluded from the research for two reasons. First, the interface used in this phase (see figure 4.1.) did not include the animation element as a part of the interface. Second, the sample size of students who participated in the research in this phase was very small (three participants). Nevertheless, the RDS Phase I was a major breakthrough attempt in providing students with a practical hands-on control laboratory environment that illustrated some of the basic aspects of control engineering, modeling, simulation, and implementation.

RDS Phase II was a major improvement over RDS Phase I. It was re-designed with major improvements such as the inclusion of a completely revamped intuitive graphical user interface (GUI).The overall interface was widened. An interactive help menu was created to provide step-by step help instructions to the user.

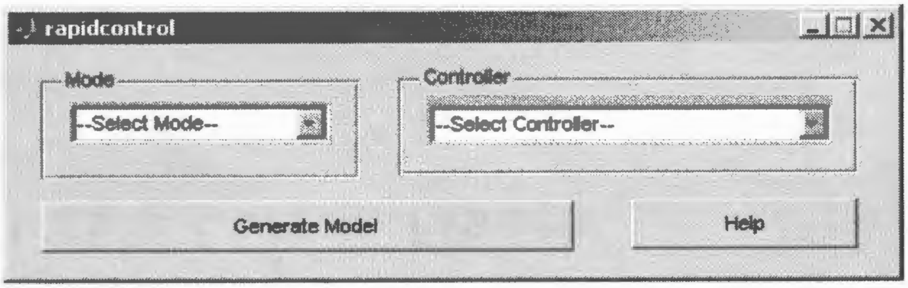

Figure 4.1. The RDS Phase I main interface.

This menu was made accessible by clicking a prominently visible help button. A second inclusion was a tip box, which provided the user with simple guidelines on the usage. The third inclusion was a feedback box that flashed messages, which guided the user in the initial stages. The fourth major inclusion was an animation that helped visualize the control process (a simulation of the physical Computer Numerical Control (CNC) and provided a more interactive way of learning. The software also provided time-response plots that showed how the system responds to external excitations, which is also an important aspect of learning control systems (Kheir et al., 1996).

RDS Phase II has a graphical user interface with three main modes: (a) simulate, (b) emulate, and (c) implement. In the simulation mode, the student simulates the linear axis system that includes their controller and detailed models of the interface hardware and linear axis. In the emulation mode, the simulation is performed on the computer hardware that will implement the controller. In the implementation mode, the controller is deployed on the hardware system and experimental data is gathered. The physical linear axis position can be adjusted by pushing the Jog button on the main interface as shown in figure 4.2. Pushing the Jog button opens up the Jog interface as shown in figure 4.3. This interface allows the student to move the linear axis in the positive or negative direction in three increments. The target computer then acts as an interface between the hardware. This utilizes the XPC real–time operating system.

Figure 4.2. The RDS Phase II main interface.

Minor improvements were made to the RDS interface from Phase II such as the inclusion of an email button so that students could email the resulting plots and data sheets. A larger evaluation was conducted using more subjects for this round of the evaluation. The participants were undergraduate students from the Mechanical Engineering department who were taking the control systems class.

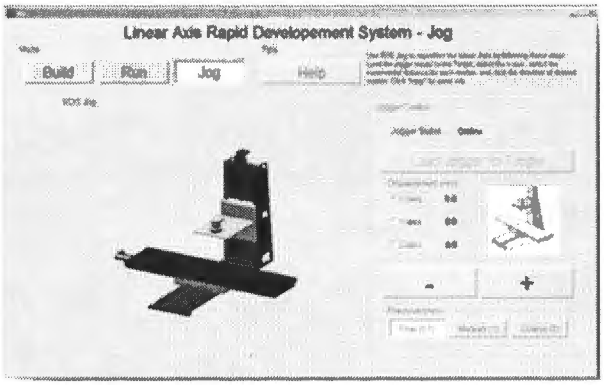

Figure 4.3. The Jog function interface.

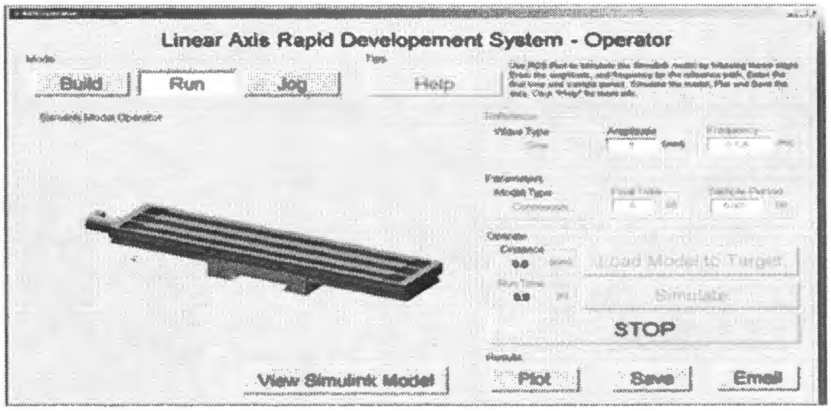

Figure 4.4. The simulate function.

5. DATA COLLECTION

5.1. OVERVIEW

In this section, we discuss how participants were recruited for testing in Phase II A and in Phase II B. We then discuss the research procedure that was followed as a part of the testing of the RDS system.

5.2. PARTICIPANTS

The participants for this research were 34 (31 male and three female) students enrolled in their senior year in the "ME 279: Automatic Control of Dynamic Systems" class.

5.3. RESEARCH PROCEDURE

First, the participants were given a pre-questionnaire that contained questions on demographics, learning styles, and interest in science. This pre-questionnaire was collected from all participants one month prior to the evaluation. As a part of the evaluation, students were asked to develop their controller to use with the RDS system (this was incorporated as part of a class assignment).

In the evaluation process, each participant was given a brief run-through on the RDS system. After this run-through, the entire setup was introduced to the participant. Each subject was then given a task list that included four tasks:

1. Use the Jog function (eye tracking was used).

2. Simulate your controller.
3. Emulate your controller.
4. Implement your controller (eye tracking was used).

Next, every participant underwent an automatic eye-tracking calibration. After this calibration, the participant was asked to perform the tasks. The participant's eye movement data was collected using the eye tracker while they were performing the tasks. Eye fixation data and the number of fixations were obtained using the eye tracking software.

After each task, the recordings were stopped and new recordings were performed before the beginning of the next task. When all of the tasks were completed, each participant was asked fill out a questionnaire that contained questions on technology acceptance constructs, learning outcome constructs, and interest in science constructs (Appendix A). Each participant was then interviewed regarding their background with control systems, issues using the system, and recommendations for the system.

5.4. INSTRUMENT

All of the questions in the questionnaires (both pre/post) were adopted from previous literature and were 7-pointLikert scale-based questions.

The pre-questionnaire contained questions on learning style (see Appendix A). These learning style questions were adapted from "The Index of Learning Styles Questionnaire" (Felder & Soloman, 2001).The survey contains questions related to four domains: (a) visual or verbal, (b) active or reflective, (c) sensitive or intuitive, and (d) sequential or global. For this study, only the questions concerning visual and verbal learners were taken into consideration.

Felder et al. (2005) found estimates of a reliability score from 0.56 to 0.77 using the Cronbach's Alpha statistical technique. In an unpublished study, Felder and Spurlin (2005) and Livesay et al. (2002) examined the Index of Learning Styles survey responses from 584 learners at North Carolina State University and found Cronbach's alpha coefficients to be in the range of 0.55 to 0.76.

The post questionnaire (Appendix 2) contained questions from three constructs: (a) interest in science, (b) the Technology Acceptance Model (TAM), and (c) learning outcome. The questions from the TAM had questions on the perceived ease of use (Davis, 1989), the perceived usefulness (Davis, 1989), the attitude towards the system (Shirley & Todd, 1995), and the intention to use the system (Gefen et al., 2003). The questions for the learning outcome were adopted from Hall et al (2006).

For measuring attention on different parts of the interface, we created an area of interest on the part of the interface that we were interested in testing. We then calculated the total fixation duration on an area of interest. This is one of the most popular measures used by researchers to measure a user's attention towards an interface element in the area of multimedia learning with graphics (Mayer, 2010). To rephrase, this metric measures the sum of all fixation durations that are within the area of interest. The total fixation time on the relevant areas reveals the perceptual processing during learning. A study by Schmidt-Weigand et al. (2010) used fixation time on visualization and text and found that learners spent more time viewing fixations with spoken text than with written text.

Another useful byproduct of the eye tracking data is the pupil dilation measure. A study by Gerven et al. (2002) found that mean pupil dilation is useful in measuring the task evoked-pupillary response i.e. cognitive workload, especially for young adults. Various studies have shown a reliable link between cognitive processing and changes in pupil dilation (Hess & Polt, 1964; Nakayama et al., 2002; Iqbal et al., 2005).

5.5. DATA ANALYSIS

Data obtained from questionnaires was analyzed by performing t-tests, one way ANOVA, multivariate tests, correlation and regression using SPSS. The TAM model parameters were tested using regression and correlation. The perceived learning outcome was calculated by taking the average of the constructs such as learning from the lab, motivation from the lab, real world learning from the lab, and knowledge gained after doing the lab. The comparison between perceived learning outcomes for different modes was analyzed using t-tests and multivariate tests. The knowledge gained before and after using the system was compared using paired t-tests.

Attention measures were obtained from the eye tracking data. An area of interest (AOI) was created over the animation part of the interface as shown in Figure 5.1. The total fixation duration was calculated by adding all the fixation durations together inside the area of interest.

Pupil dilation was calculated individually using the pupil diameter values obtained from the eye tracker. For each trial, a baseline pupil diameter was determined by calculating the average pupil size during a period of 100 milliseconds preceding the onset of the interface.

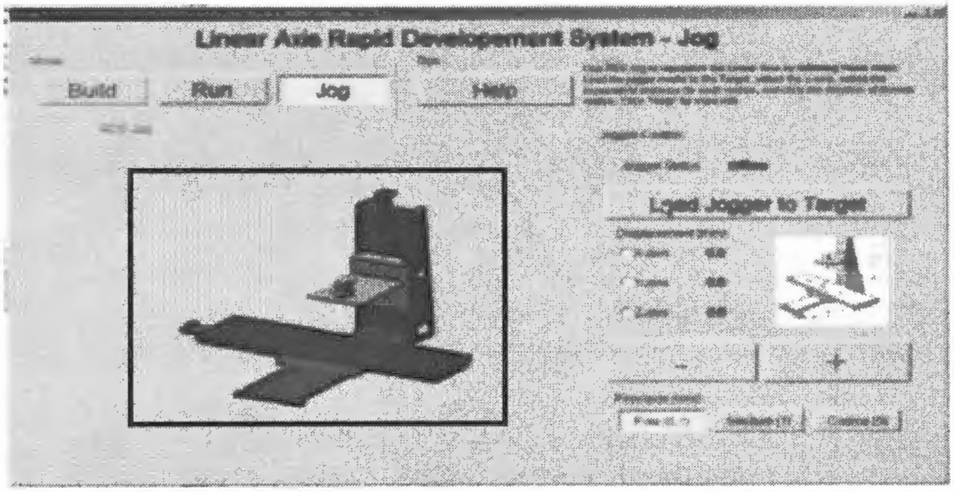

Figure 5.1. Area of interest: animation

The pupil dilation was calculated by subtracting this baseline from the pupil diameter for each data point until the completion of the task. This difference score was converted to a percentage of the corresponding baseline value (Moresi et al., 2008).

$$\text{Pupil Dilation} = \frac{\text{Pupil diameter} - \text{Baseline}}{\text{Pupil diameter}} \times 100$$

6. QUESTIONNAIRE DATA RESULTS

6.1. SECTION OVERVIEW

In this section, we discuss the results of the questionnaires that measure the following constructs from the research model: learning styles, interest in science, technology acceptance model and perceived learning outcome.

6.2. DEMOGRAPHICS

A total of thirty four students participated in the RDS Phase II B study. Of the thirty four students, 31 of them were male while 3 were female.

6.3. TASK PERFORMANCE

Almost all of the participants were able to complete all the tasks without the need of a prompt (table 6.1.). According to UA7, task performance measures indirectly affect the person's attitude towards the system.

Table 6.1. Task performance

Task	Description	Number of participants
1	Use the Jog function.	33
2	Simulate and select the controller. Generate	34
3	Emulate and select the controller. Generate	34
4	Go back and implement a preexisting	34

6.4. QUANTITATIVE ANALYSIS

6.4.1. Learning styles. The chart in figure 6.1.validates previous research that most engineering students are visual, sensing, and active learners (Felder & Brent, 2005). Of the 34 students who participated in this study, 26 of them were visual learners, 20 of them were active learners, 31 were sensory learners, and 31 were sequential learners.

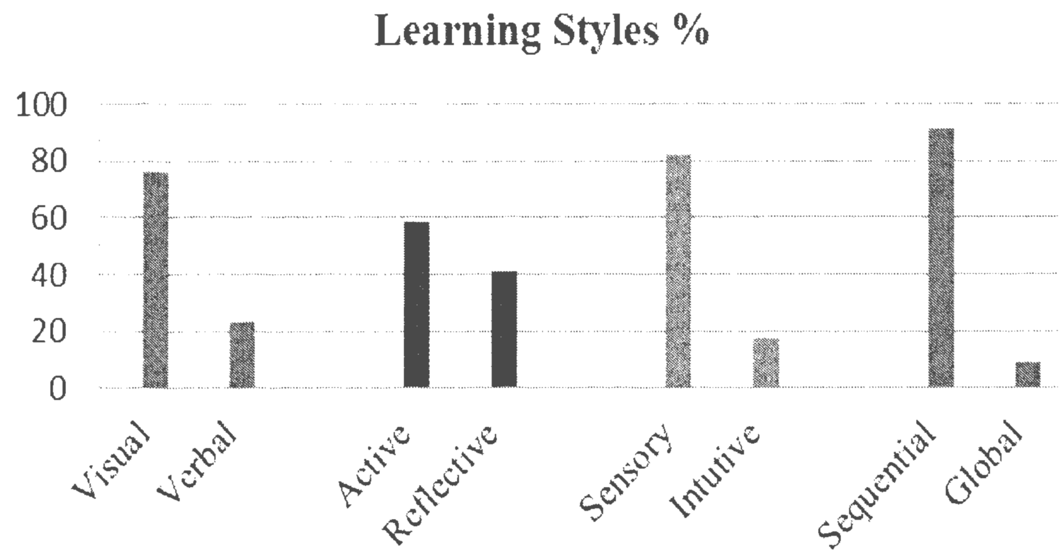

Figure 6.1. Learning styles.

6.4.2. Interest in science. The analysis of interest in science constructs pre (before being exposed to RDS) and post (after being exposed to RDS) showed significant improvements (see figure 6.2.). The category of career interest in science showed the maximum improvement followed by the enjoyment in science.

We also found an increase in the pre-post for General interest in science. However t-test revealed no significant changes. Paired samples t-tests were conducted on the interest in science constructs for the pre and post questionnaires. The results indicate a significant difference in career interest in science (t = -3.848, p = .001) and enjoyment in science (t = -3.198, p = .003).

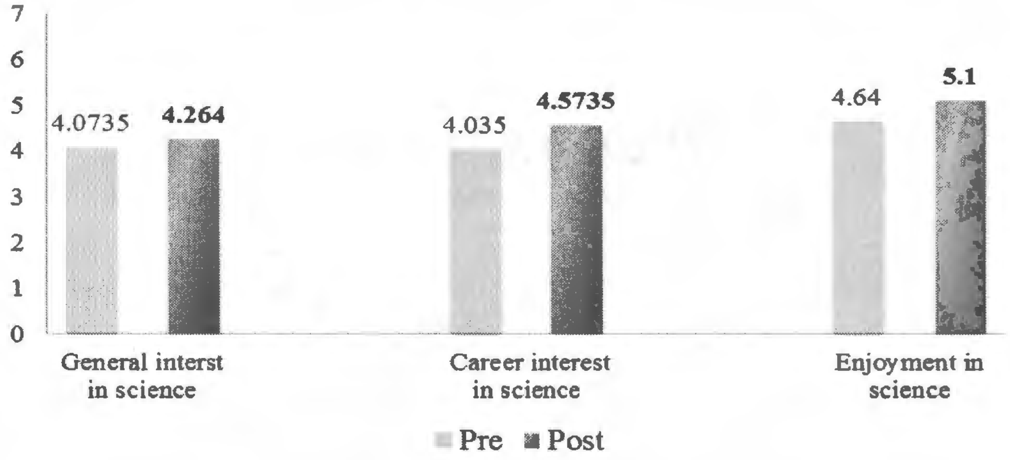

Figure 6.2. Interest levels in science.

The results of the test are shown in table 6.2. below.

Table 6.2. Paired samples t-test

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1 Pre vs. post GS	-.19	.74	.12	-.45	.06	-1.49	33	.14
Pair 2 Pre vs. post CS	-.54	.82	.14	-.83	-.25	-3.84	33	.00
Pair 3 Pre vs. post ES	-.46	.85	.14	-.76	-.17	-3.19	33	.00

6.4.3. Perceived learning outcome. An analysis of the results from the perceived learning outcome showed the real world applicability of the RDS system to be high in comparison with lecture and notes. The results are shown in figure 6.3. below.

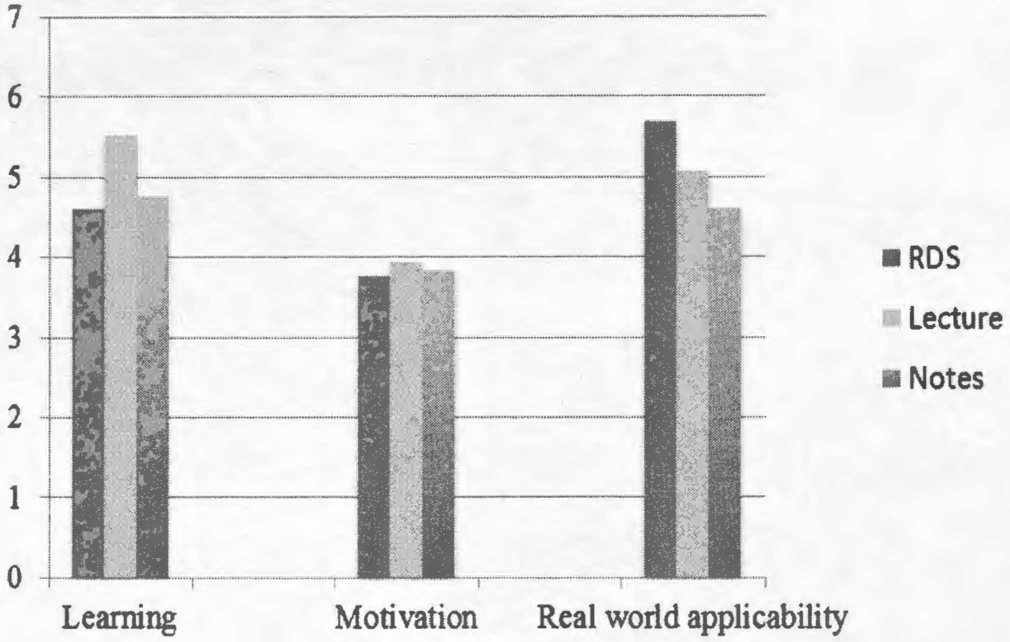

Figure 6.3. Comparison between learning through RDS, lecture, and notes.

In order to test the significance between the three variables i.e. learning through lectures The results show a significant multivariate effect for real world applicability and learning, notes and labs (RDS) a multivariate test was conducted. A one-way MANOVA revealed a significant multivariate main effect for real world applicability (Wilks' λ = .54, *F* (2, 32) = 13.648) and learning (Wilks' λ =0.815, *F* (2, 32) =3.621).The results of the multivariate tests are shown in table 6.3.

Table 6.3. Multivariate test results

		Value	F	Hypothesis df	Error df	Sig.
Learning	Pillai's Trace	0.18	3.62a	2	32	0.03
	Wilks' Lambda	0.81	3.62a	2	32	0.03
	Hotelling's Trace	0.22	3.62a	2	32	0.03
	Roy's Largest Root	0.22	3.62a	2	32	0.03
Motivation	Pillai's Trace	0.03	.59a	2	32	0.55
	Wilks' Lambda	0.96	.59a	2	32	0.55
	Hotelling's Trace	0.03	.59a	2	32	0.55
	Roy's Largest Root	0.03	.59a	2	32	0.55
Real World Applicability (RWE)	Pillai's Trace	0.46	13.64a	2	32	0
	Wilks' Lambda	0.54	13.64a	2	32	0
	Hotelling's Trace	0.85	13.64a	2	32	0
	Roy's Largest Root	0.85	13.64a	2	32	0
a. Exact statistic						
b. Design: Intercept						

A one way ANOVA was conducted for learning, motivation and real world applicability constructs of perceived learning outcome for comparing the perceived learning outcome between lecture, lab and notes. The results showed that there was a significant difference (p=0.001) in the means of real world applicability between lecture, labs and notes. A Turkey post-hoc test revealed that the perceived real world applicability through labs was significantly different from notes (p=0.000).There was no significant difference in the perceived learning and motivation between the three modes of instruction i.e labs, lectures and notes. The results of one way ANOVA are shown in table 6.4. below.

Table 6.4. One way ANOVA results for perceived learning outcome

		Sum of Squares	Df	Mean Square	F	Sig.
Motivation	Between Groups	.54	2	.27	.17	.83
	Within Groups	152.94	99	1.54		
	Total	153.49	101			
RealWorld	Between Groups	20.25	2	10.12	7.72	.00
	Within Groups	129.82	99	1.31		
	Total	150.07	101			
Learning	Between Groups	10.29	2	5.14	2.38	.09
	Within Groups	213.91	99	2.16		
	Total	224.2	101			

6.4.4. Knowledge gained. The students also felt that they gained an increase in their perceived knowledge after using RDS, which establishes the fact that RDS could be used as part of the course-curriculum and which proves its role as a learning tool. The chart in figure 6.4.shows the knowledge gained by the students before and after using RDS. However it should be noted that we measured the perceived knowledge from the perceived learning outcome (Appendix B).

In order to test the significance between both the constructs i.e. perceived knowledge prior to using RDS system and perceived knowledge after using the system we conducted a paired samples t-test.

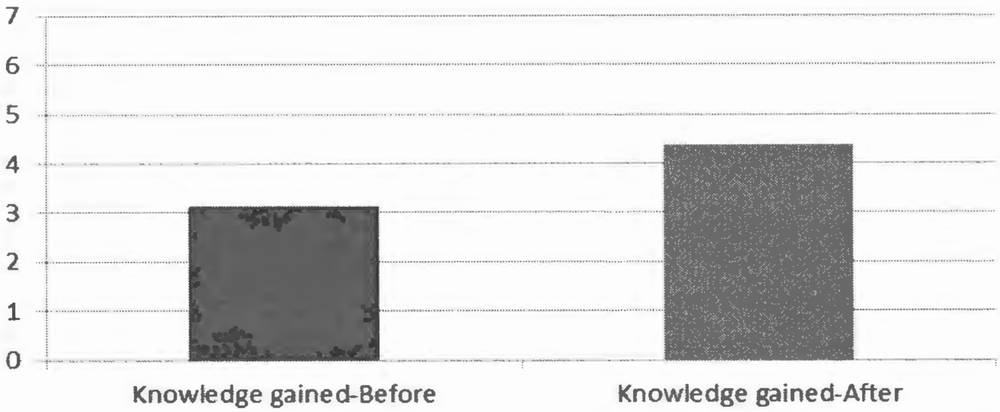

Figure 6.4. Knowledge gained before and after using RDS.

Paired t-test conducted on the knowledge before and after using RDS revealed significant increase. The results of the paired t-test showed a significant difference in the perceived knowledge gained (t= -6.076, p = .000) and are shown in table 6.5.

Table 6.5. Paired samples t-test for perceived knowledge gained

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Knowledge Gained Before Using RDS – Knowledge Gained After Using RDS	-1.26	1.21	.2	-1.68	-.84	-6.07	33	.00

6.4.5. Technology acceptance constructs (TAM). Results from the Technology acceptance constructs revealed that students rated the RDS system as easy to use, useful in their jobs and had favorable attitude towards the system. The results also show relatively low intention to use RDS. One of the plausible reasons for this can be attributed to the fact that all the participants were undergraduate students and most of them did not expect to use RDS in classes other than in the senior year class (ME 279). Figure 6.5. shows the values of various TAM constructs.

Regression analysis was conducted between attitude as dependent variable and perceived usefulness and perceived ease of use and independent variables. The model was found to be significant (R^2=0.812) and accounted for 80% variance in the attitude towards the system.

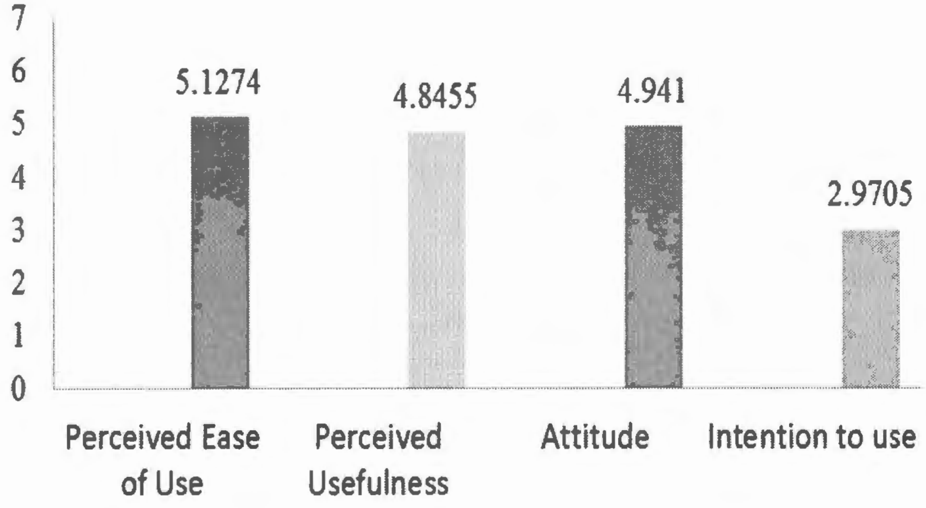

Figure 6.5. Technology acceptance constructs.

Perceived usefulness significantly predicted the attitude towards the system ($p=0.000$, $\beta=0.105$). The results of the regression analysis are presented in table 6.6 and 6.7 below.

Table 6.6. Regression model summary

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.90[a]	.81	.80	.45	.81	67.14	2	31	.00

a. Predictors: (Constant), PU, PEOU

Table 6.7. Coefficients of regression

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.03	.48		.07	.94
	PEOU	.13	.11	.11	1.17	.24
	PU	.87	.10	.82	8.33	.00

In order to test the relationship between the various constructs of the technology acceptance model & the intention to use a correlation test was conducted between attitude towards the system, intention to use the system and perceived learning outcome. The results revealed that the correlation was significant between attitude, intention to use and the perceived learning outcome. This shows that the constructs are highly related and thus proves strong relationship between all the constructs used in the model.

The results of the correlation are presented in table 6.8. below.

Table 6.8. Results of correlation

		Attitude	Intention	LO
Attitude	Pearson Correlation	1	.62**	.46**
	Sig. (2-tailed)		.00	.00
	N	34	34	34
Intention	Pearson Correlation	.62**	1	.40*
	Sig. (2-tailed)	.00		.01
	N	34	34	34
LO	Pearson Correlation	.46**	.40*	1
	Sig. (2-tailed)	.00	.01	
	N	34	34	34

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

7. EYE TRACKING RESULTS

7.1. SECTION OVERVIEW

In this section we discuss the qualitative findings from the eye tracking methodology and report usability issues with the interface. We utilize the quantitative data from the eye tracking to study the impact of the use of the animation on the attention of two learning styles of students: visual and verbal. Pupil dilation measures from the eye tracking data are used to study if there is any significant difference in the cognitive workload between the two learning groups. For this part of the results, we used the combined data from two evaluations to increase the sample size and to improve the validity of the results. The same interface was used in both the evaluations.

7.2. DEMOGRAPHICS

A total of 50 students participated in the evaluation. Of these, 39 were visual learners and the remaining 11 were verbal learners.

7.3. RESULTS

7.3.1. Overview. The eye tracking results were used to triangulate the results from the survey data and to collect objective eye movement data on the interface. From a qualitative point of view, the eye tracking data provided us with two important visualizations: (a) gaze plots and (b) heat maps. Gaze plots display a static view of the gaze data for each image of the stimuli. It helps in visualizing the scan path of the participant over the interface. Each fixation is illustrated with a dot and the radius of the dot represents the length of the fixation. Each dot is embedded with a number that indicates the order of the fixation.

Another powerful visualization is the heat map. The heat map allows researchers to visualize the gaze behavior of an entire group. A heat map is composed of a background image (stimulus) on which a heat map layer is superimposed. The heat map layer is obtained by combining the gaze data from multiple participants. To differentiate between looking behavior, heat maps uses the temperature analogy to reflect higher fixations versus lower fixations. In the heat maps generated from our data, we used the color red to indicate higher fixations and the color green to indicate lower fixations.

In this section, we divide the results from the eye tracking data into two parts: (a) qualitative where we discuss the results from the gaze plots and heat maps and (b) quantitative where we discuss the attention and cognitive workload measure with respect to the survey data.

7.3.2. Qualitative analysis. In order to help us easily deduce the results, we reduced the number of fixation data points by shrinking the timeline to the first five seconds for a few of the results. From Figure 7.1., we noticed that the user immediately noticed the Jog button as part of the first task in which the users had to use the Jog function. It can be seen that, based on the order of fixations 1, 2 and 3, the user was able to easily identify the Jog function button.

In the Figure 7.2., we see that the user did not read the pop-up message that appears when a user is saving the data. The pop-up message box has important information on how to understand the saved data when it is opened elsewhere.

We found that the users generally dismissed the pop-up message box without reading it. Generally, in gaze plots on pop-up message boxes, researchers see fixations on the message which indicates the user has read the message.

Figure 7.1. User notices the Jog button.

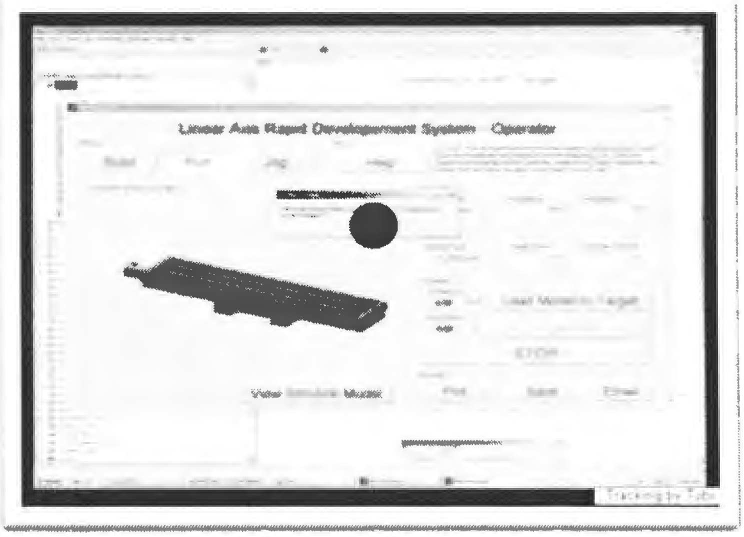

Figure 7.2. Gaze plot shows user did not notice pop up message.

However, in this case, we did not notice any fixations on the message, which suggests that the users did not read it. The figure 7.3. shows the heat map related to the pop- up message.

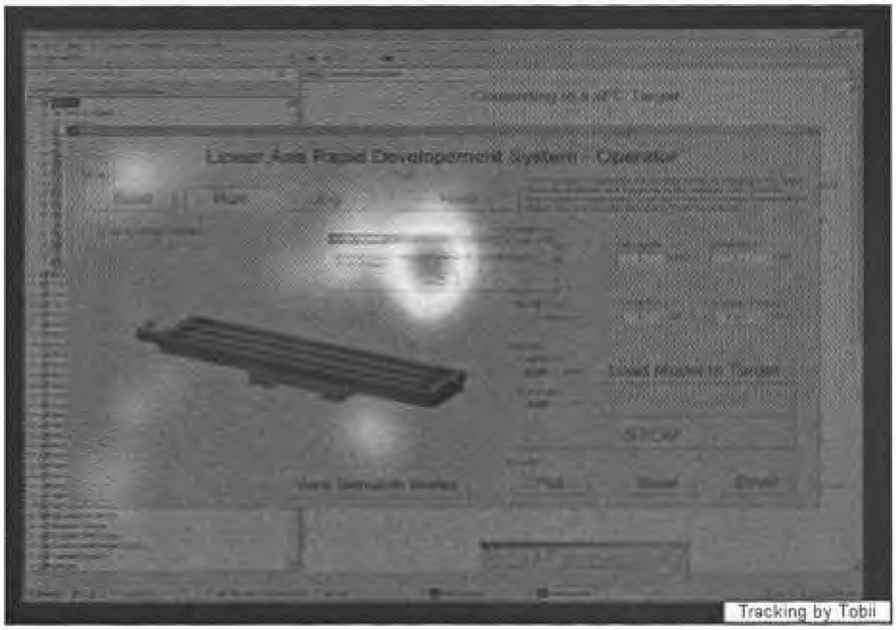

Figure 7.3. Heat map show users did not notice pop up message.

In Figure 7.4., we see from the gaze plot that the users did not read the pop-up dialog box that suggests that the user verify whether he/she has checked the help page before inserting the controller. Most of the users instantly dismissed this message as soon as they encountered it as shown in figure 7.5. Therefore, the interface should minimize the number of pop-up message boxes and use them only for displaying important messages.

Figure 7.6. shows the gaze plot of a participant on encountering an error message, which popped up when XPCTarget™, specialized software that enables students to execute Simulink models, was not connected to the target CNC system.

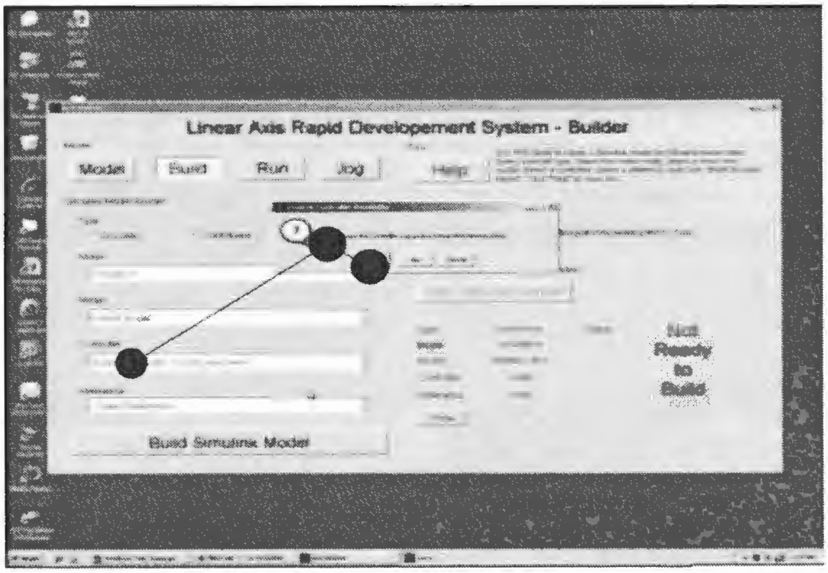

Figure 7.4. Gaze plot shows user did not notice pop up dialog box.

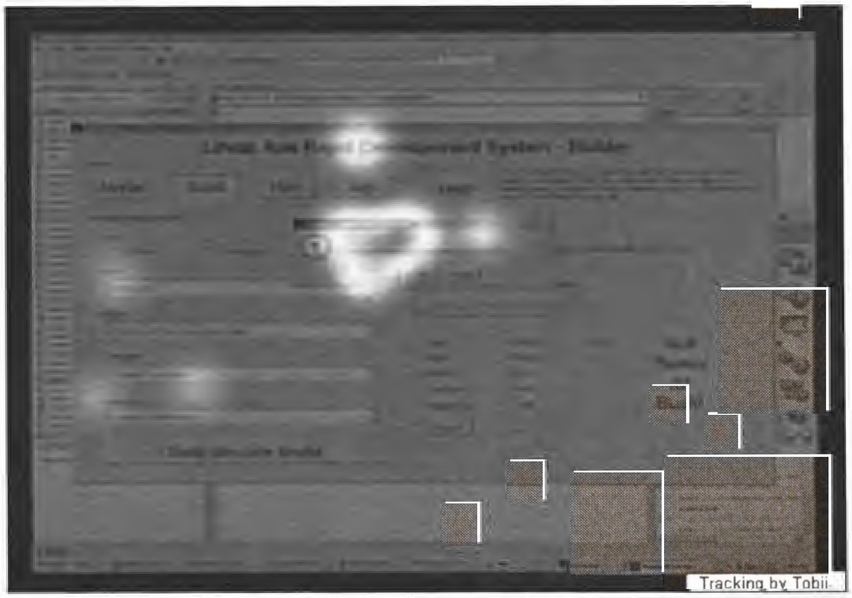

Figure 7.5. Heat map shows users did not notice pop up dialog box.

The gaze plot as seen in figure 7.6. indicates that the user is frustrated, which can be noticed from the rapid saccade movement. Previous research in the area eye tracking with respect to interface usability attributed rapid saccade movement over an interface to difficulty in understanding how to operate the interface (Goldberg & Kotval, 1999).

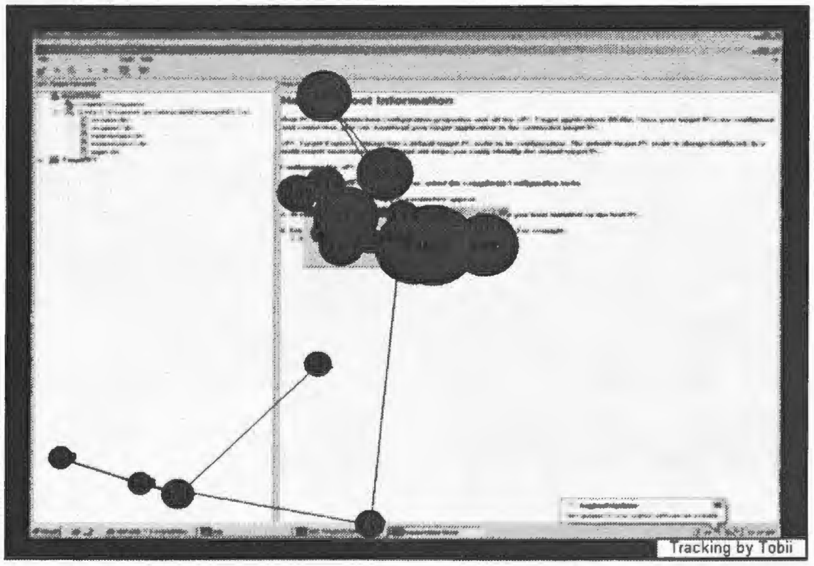

Figure 7.6. Rapid saccade movements.

An analysis of the heat maps suggests that all the important areas of the RDS interface received copious attention. As can be seen in figure 7.7., the red indicates that higher attention was paid towards the animation part of the interface. Since the buttons were designed to be highly usable with a large font size and a large button size, the users were able to notice the buttons easily. In this heat map, we notice that the area around the Jog function button has a higher focus as this was first task where users had to use the Jog function. On the right side is the operation panel to control the Jog function. This also received copious attention from the users as it is an important part of the task and the interface.

Figure 7.7. Heat map of Jog function.

Figure 7.8. Heat map of help menu.

Figure 7.8. shows the heat map of the help menu. An analysis of the heat map suggests that the users were able to read the help menu easily. However, many users did not scroll to the bottom part of the help menu where pictures provided additional guidance.

7.3.3. Quantitative analysis. For this part of the analysis, we used the quantitative measures from the eye tracking data. We used the total fixation duration to measure the attention towards the animation part of the interface. The pupil dilation measure was used to measure the cognitive workload on the interface. We then used these measures in combination with the survey data to study the impact of learning styles on the perceived learning outcome, the perceived ease of use, attention, and cognitive workload. We use the methods outlined in data analysis (section 5.4) for extracting attention and pupil dilation measures.

7.3.3.1. Effect of learning style on attention towards animation. The moderating role of learning styles on the student's attention towards the animation part of the interface was measured using one way ANOVA. This analysis revealed that the attention towards the interface differed significantly between both the groups [F (1, 44) = 6.929, p = 0.017]. The results are shown in table 7.1. below.

Table 7.1. ANOVA for attention towards animation

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	.02	1	.02	6.12	.01
Within Groups	.16	44	.00		
Total	.19	45			

7.3.3.2. Effect of learning style on cognitive workload. A one-way-between-subjects ANOVA was conducted to compare the difference in the cognitive workload between the visual and verbal learning groups. A significant difference was observed between both the groups at the p<.05 level for the three conditions [F (1, 44) = 31.427, p = 0.00].The results are shown in table 7.2. below.

Table 7.2. ANOVA for cognitive workload

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	.008	1	.008	31.42	.00
Within Groups	.011	44	.00		
Total	.019	45			

7.3.3.3. Effect of learning style on perceived ease of use. A one-way between-subjects ANOVA was conducted to compare the difference in the perceived ease of use (PEOU) between the visual and verbal learning groups. The one-way ANOVA revealed significant differences both the groups. Result showed difference between both the groups i.e. visual and verbal at the p<.05 level for the two conditions [F (1, 44) = 24.040, p = 0.00].

The results are shown in table 7.3. below.

Table 7.3. ANOVA for perceived ease of use

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	15.67	1	15.67	24.04	.00
Within Groups	28.68	44	.65		
Total	44.35	45			

7.3.3.4. Differences in perceived learning outcome. A one-way ANOVA between subjects was conducted to compare the difference in the perceived learning outcome between the visual and verbal learning groups. There was a significant difference between the perceived learning outcome for both the groups at the $p<.05$ level for the three conditions [F (1, 44) = 10.352, p = 0.02].The results are shown in table 7.4. below.

Table 7.4. ANOVA for perceived learning outcome

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	7.48	1	7.48	10.35	.00
Within Groups	31.79	44	.72		
Total	39.28	45			

8. DISCUSSION AND IMPLICATIONS

8.1. DISCUSSION

In this thesis, we conducted a usability evaluation of a computer-based learning system that was designed to impart practical knowledge and serve as a complementary instructional laboratory to the theoretical class. We utilized eye tracking in conjunction with surveys in evaluating the Rapid Development System, a computer-based learning system for teaching control design/insertion in the mechanical engineering curriculum. The test validated the usefulness of the eye tracking technology in providing additional insights into users' cognitive aspects while interacting with the learning system. Overall, the results from the research suggest that the RDS system was well received by the participants.

The results from the study related to the learning styles validated previous research findings that most engineering students are visual learners (i.e. they prefer learning through a visual medium), which bodes well for the highly visual RDS interface. We found that the students had a higher interest in taking up careers in science after using the system. Students reported an increase in enjoyment in science after using the system. Result also showed high real world applicability of RDS system in comparison to lectures and notes. Students also reported an increase in their perceived knowledge after using the system.

The eye tracking results validated the results from the survey analysis. The gaze plots and the heat maps indicated that the participants were able to identify important areas of the interface, such as the tip box and help button, which were newly developed.

However, we noticed a few minor usability issues with the interface for which we provide recommendations. Implementing these changes should be helpful in the further refinement and improvement of the RDS interface.

The eye tracking data indicated that users did not read the dialog message on the pop-up box. This was observed in the eye tracking data of multiple participants. Our suggestion to the design team would be to increase the size of the dialog box and to increase the font size of the message. It is well-known in the area of user experience that increasing the size of the interface element will increase the user's attention towards it (Fitts, 1954). Another tip for the developers is to include with the legend information in the data file, so the students can easily understand the data output.

The eye tracking results also indicated that users did not read the message that pops up when they are inserting the controller. Our suggestion is to remove this pop-up box.

Again, results from the eye tracking data indicated that one user was frustrated when the error "Connecting XPC to target" popped up on the user's screen. This was observed from the gaze plot of a user where the user's rapid saccade movement was observed. Researchers have found that saccadic eye movements precede attention and that a close relationship exists between them when processing complex information tasks (Hoffman & Subramaniam, 1995; Stelmach & Herdman, 1997). Research in usability using the eye tracking method attributes rapid saccade movement over an interface to difficulty in understanding (Goldberg & Kotval, 1999).

The development team should ensure that the error message "Connecting XPC to target" does not pop up when the user is performing tasks since it can increase the cognitive workload on the user. We suggest that the developers include a button to connect the XPC to the target directly or that the user should be transferred directly to the help page that provides instructions on how to reconnect the system once the user clicks on the dialog button.

Before students begin using the RDS system, a brief mini-video should be shown to explain the RDS system and to provide an overview on how it can be used, its capabilities, and its rich feature set. This video would help to reduce the initial cognitive workload of students using the system.

The quantitative data from the eye tracker provided us with metrics that helped us in studying the differences between both the learning groups with respect to attention and cognitive workload. We also looked at other constructs such as the learning outcome and the perceived ease of use. The results indicated that the learning style of the student played a significant role in determining their attention towards the interface and their cognitive workload. The visual students had a lower cognitive workload than the verbal students did. The results from the study confirmed objectively the previous finding that visual learners prefer visual medium (Felder &Silverman, 1988). However, more research is required to study the effect of learning style on attention, cognitive workload, and other constructs.

8.2. IMPLICATIONS

The results from this research prove once again that usability testing with the end users is very important while designing user interfaces. Usability testing helps to identify problems with the interface and provides valuable cues to make the interface more usable. The results from the learning styles of the students reaffirm previous research that most of the engineering students are visual learners. Hence, educational interfaces for engineering students should be designed with consideration of the learning styles of students.

The results from our study also confirm previous findings that computer-based learning environments help increase the amount of learning when they are used as part of the educational curriculum. We also found that students reported having a higher interest in science after using the system. Both of these results suggest that additional courses and disciplines in engineering should encourage the use of computer-based learning environments to inculcate the practical training of theoretical concepts.

The initial results from our study suggest that the differences between visual and verbal learners have an impact on how these groups perceive the attention paid towards the interface, the cognitive workload, and the perceived learning. These results suggest that designers should carefully cater to each of these groups by designing various features into computer interfaces that assist the learning styles of both these groups. However, additional research should be conducted with a larger sample size to confirm these findings. Also, additional research should be conducted with other categories of learners such as sensory versus intuitive learners and active versus reflective learners.

This study also helps prove the reliability of the research model that was used to guide the testing. We believe that this model can be valuable for guiding the evaluation of other educational learning systems.

9. CONCLUSION

The results of this study provide valuable suggestions to the developers and designers of computer-based learning environments to include features that would make interfaces more usable. Regardless of the learners' educational background, instructors have an enormous task meeting individual learning styles while teaching. Using CBLEs as part of a course to increase student interest in the course and to provide them with real world learning will help instructors to accomplish this task successfully.

Our research also reaffirms the importance of including usability testing with target users as a hallmark of designing user-centered design philosophy. The results from the eye tracking reports validate the significance of using this methodology in evaluating interfaces.

The results from the study also validate the research model that was used to guide the evaluation. Further collaboration with other universities and researchers should be sought to help in further refining the model to allow educational researchers to use our model in guiding their evaluation of learning systems.

The results from our study confirm that the use of the RDS system helped to improve students' knowledge and resulted in an increase in real world learning. Our results also confirm previous findings that computer-based learning systems should be used as a part of the learning curriculum.

We also found few minor usability issues with the RDS system, which should be eliminated to further increase the usability of the system. By increasing the usability of the system, the cognitive workload can be decreased which would enable students to work distraction-free and, thus, would maximize learning. We also provide recommendations on new features, which, if followed, could help increase the appeal of the system.

The results of the eye tracking quantitative data yielded statistically significant differences between the visual and verbal learners with respect to their cognitive workloads and attention levels. These results suggest that interface designers should use various strategies to reduce the cognitive workload and to increase a user's attention to relevant areas in order to maximize learning.

However, it should be noted that this research had a few limitations. The sample size for the verbal group was very small in comparison to the visual group. The use of physiological measures such as pupil dilation can be contaminated by subjective and environmental factors. Hence, additional detailed research should be conducted using large sample sizes and to further control the external factors that can affect subjective measures.

Further research in this area should look at how other dimensions of the learning styles, such as active versus reflective learning and sequential versus global learning, to gain a better understanding of how these characteristics affect the attention and the cognitive workloads of students.

APPENDIX A.

PRE QUESTIONNAIRE

Please circle the answer that applies best to you.

1. When I have to work on a group project, I first want to

(a) Have "group brainstorming" where everyone contributes ideas.

(b) Brainstorm individually and then come together as a group to compare ideas.

2. In reading nonfiction, I prefer

(a) Something that teaches me new facts or tells me how to do something.

(b) Something that gives me new ideas to think about.

3. When I get directions to a new place, I prefer

(a) A map.

(b) Written instructions.

4. When writing a paper, I am more likely to

(a) Work on (think about or write) the beginning of the paper and progress forward.

(b) Work on (think about or write) different parts of the paper and then order them.

5. When I am learning something new, it helps me to

(a) Talk about it.

(b) Think about it.

6. I am more likely to be considered

(a) Careful about the details of my work.

(b) Creative about how to do my work.

7. When I see a diagram or sketch in class, I am most likely to remember

(a) The picture.

(b) What the instructor said about it.

8. It is more important to me that an instructor

(a) Lay out the material in clear sequential steps.

(b) Give me an overall picture and relate the material to other subjects.

9. In a study group working on difficult material, I am more likely to

(a) Jump in and contribute ideas.

(b) Sit back and listen.

10. I prefer courses that emphasize

(a) Concrete material (facts, data).

(b) Abstract material (concepts, theories).

11. When I meet people at a party, I am more likely to remember

(a) What they looked like.

(b) What they said about themselves.

12. When I solve math problems

(a) I usually work my way to the solutions one step at a time.

(b) I often just see the solutions but then have to struggle to figureout the steps to get to them.

APPENDIX B.
POST QUESTIONNAIRE

For the following questions, please indicate the extent to which you agree or disagree with the following statements.

Scale – (Strongly disagree (1) – Strongly agree (7))

1. Using Rapid Development System enables me to accomplish tasks more quickly.
2. Learning to operate Rapid Development System is easy for me.
3. I find it easy to get Rapid Development System to do what I want it to do.
4. Using the Rapid Development System is a good idea.
5. Using Rapid Development System improves my learning outcome.
6. My interaction with Rapid Development System is clear and understandable.
7. I predict to use the Rapid Development System in the next six months.
8. Using Rapid development system would make it easier to understand control design/insertion.
9. I find Rapid Development System to be flexible to interact with.
10. I like the idea of using the Rapid Development System.
11. I find Rapid Development System useful in learning control design/insertion/insertion.
12. It is easy for me to become skillful at using Rapid Development System.
13. I intend to use the Rapid Development System in the next six months.
14. I find Rapid Development System easy to use.
15. Using the Rapid Development System would be pleasant.
16. I plan to use the Rapid Development System in the next six months.
17. I learned a great deal of information about control design/insertion from this week's lab.

18. I learned a great deal of information about control design/insertion from class lectures.
19. I learned a great deal of information about control design/insertion from the class text.
20. I found this week's lab on control design/insertion to be very motivational.
21. I found the class lectures over control design/insertion to be very motivational.
22. I found the class textbook's coverage of control design/insertion to be very motivational.
23. This week's lab activity over control design/insertion was applicable to "real world" engineering.
24. The class lecture over control design/insertion was applicable to "real world' engineering.
25. The text book coverage of control design/insertion was applicable to "real world" engineering.
26. Before the lab activity that covered control design/insertion, I knew a great deal about the subject.
27. After the lab activity that covered control design/insertion, I knew a great deal about the subject.
28. I would like to belong to a science club.
29. I would dislike being a scientist.
30. Science lessons are fun.
31. I get bored watching science programs on TV.
32. I would like to work with people who make discoveries in science.
33. I dislike science lessons.

34. I would like to be given a science book or a piece of scientific equipment as a present.

35. I would dislike a job in a science laboratory.

36. School should have more science lessons each week.

37. I dislike reading books about science in my leisure time.

38. Science lessons bore me.

39. Working in a science laboratory would be an interesting way to earn a living.

40. Science is one of the most interesting school subjects.

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