Mobile Intelligent Tutoring System:
Moving Intelligent Tutoring Systems Off The Desktop

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by
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Dedications

To my daughters Madeline and Zora.

I embarked on this journey wanting to contribute to the education of children. With each mention of the word *children*, I envision your smiling faces. I love you both and dedicate this document to you as part of my testament of the strength and inspiration that children can give their parents.

Love,

Mom
Acknowledgments

Above all, I want to acknowledge my Lord and Savior, Jesus Christ, for enabling me to complete my courses, conduct research, and write this dissertation. I am overjoyed that He has chosen me as a vessel for His work. This dissertation would also not have been possible without the guidance and support of my advisors Dario Salvucci and Frank Lee. They helped focus my research and continually challenged me to improve.

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# Table of Contents

List of Tables ......................................................................................................................... ix

List of Figures ......................................................................................................................... x

Abstract .................................................................................................................................... xii

1: Introduction .............................................................................................................................. 1

1.1: The Digital Divide – Home & School .............................................................................. 1

1.2: Mobile Learning ................................................................................................................ 5

1.3: Research Questions .......................................................................................................... 6

1.3.1: RQ1- How might the design of an intelligent tutoring system be adapted for delivery on a mobile device? ......................................................................................... 7

1.3.2: RQ2- Can a mobile intelligent tutoring system provide learning gains greater than standard instructional activities? ................................................................. 8

1.3.3: RQ3- Which teaching strategy best supports a mobile intelligent tutoring system? ................................................................................................................................. 9

1.4: Document Organization .................................................................................................... 11

2: Background ............................................................................................................................ 13

2.1: Mobile Human Computer Interaction ............................................................................ 15

2.1.1: Mobile Human Computer Interaction Theories and Principles ................................. 16

2.2: Mobile Learning ............................................................................................................... 16

2.2.1: What is Mobile Learning? ............................................................................................ 16

2.2.2: Where is Mobile Learning Used? ................................................................................ 19
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2.3: Challenges in Developing Mobile Applications for Education</td>
<td>21</td>
</tr>
<tr>
<td>2.2.4: Mobile Learning Theories and Principles</td>
<td>22</td>
</tr>
<tr>
<td>2.3: Intelligent Tutoring Systems &amp; Cognitive Tutors</td>
<td>23</td>
</tr>
<tr>
<td>2.3.1: Use of Feedback</td>
<td>28</td>
</tr>
<tr>
<td>2.3.2: Use of Representations</td>
<td>28</td>
</tr>
<tr>
<td>2.4: Mobile Intelligent Tutoring System</td>
<td>29</td>
</tr>
<tr>
<td>2.5: Methods and Tools Used in this Dissertation</td>
<td>31</td>
</tr>
<tr>
<td>2.5.1: Cognitive Tutor Authoring Tools</td>
<td>31</td>
</tr>
<tr>
<td>2.5.2: Poor Man’s Eye Tracker</td>
<td>34</td>
</tr>
<tr>
<td>3: Poor Man’s Eye Tracking Study</td>
<td>37</td>
</tr>
<tr>
<td>3.1: Study Rationale</td>
<td>37</td>
</tr>
<tr>
<td>3.2: Participants</td>
<td>38</td>
</tr>
<tr>
<td>3.3: Materials</td>
<td>38</td>
</tr>
<tr>
<td>3.4: Data Sources</td>
<td>39</td>
</tr>
<tr>
<td>3.5: Procedure</td>
<td>39</td>
</tr>
<tr>
<td>3.6: Results</td>
<td>41</td>
</tr>
<tr>
<td>3.7: Discussion</td>
<td>43</td>
</tr>
<tr>
<td>3.7.1: General Guidelines For Mobile ITS Design</td>
<td>45</td>
</tr>
<tr>
<td>4: Developing a Mobile Intelligent Tutoring System</td>
<td>49</td>
</tr>
<tr>
<td>4.1: Implementation</td>
<td>49</td>
</tr>
<tr>
<td>4.1.1: Which Handheld Device Should Be Used?</td>
<td>49</td>
</tr>
<tr>
<td>4.1.2: Which Tutor Development Platform Will Be Used?</td>
<td>50</td>
</tr>
</tbody>
</table>
4.1.3: What Subject Domain Is The Focus? .......................................................... 51

4.2: Design.................................................................................................................. 51

4.2.1: Mobile Intelligent Tutoring System Interface ............................................ 52

4.2.2: Mobile Intelligent Tutoring System Activity................................................ 61

4.2.3: Mobile Intelligent Tutoring System Architecture........................................ 65

5: Mobile Intelligent Tutoring System Feasibility Studies........................................ 66

5.1: Participants ........................................................................................................ 67

5.2: Materials ........................................................................................................... 68

5.3: Data Sources ..................................................................................................... 68

5.4: The Feasibility Study Tutor .............................................................................. 69

5.5: Procedure ......................................................................................................... 70

5.6: Results............................................................................................................... 71

5.7: Discussion......................................................................................................... 75

6: Mobile Intelligent Tutoring System Laboratory Study......................................... 77

6.1: Participants ........................................................................................................ 78

6.2: Materials ........................................................................................................... 80

6.3: Data Sources ..................................................................................................... 81

6.4: Procedure ......................................................................................................... 81

6.5: Results............................................................................................................... 82

6.5.1: Analysis by Stage ......................................................................................... 89

6.6: Discussion......................................................................................................... 93
7: Conclusion ................................................................................................................................. 98

7.1: Discussion and Summary ........................................................................................................ 98

7.2: Answers to Research Questions .............................................................................................. 100

7.2.1: RQ1 - How might the design of an intelligent tutoring system be adapted for delivery on a mobile device? ........................................................................................................ 100

7.2.2: RQ2 - Can a mobile intelligent tutoring system provide learning gains greater than standard instructional activities? ...................................................................................... 101

7.2.3: RQ3 - Which teaching strategy best supports a mobile intelligent tutoring system? .................................................................................................................................................. 101

7.3: Future Work .................................................................................................................................. 102

7.3.1: Technical Investigations ........................................................................................................ 102

7.3.2: Identification of Tasks ......................................................................................................... 103

7.4: Final Remarks ............................................................................................................................ 104

8: List of References ............................................................................................................................ 105

9: Appendices ...................................................................................................................................... 115

Appendix 1: Feasibility Study and Laboratory Study Pre-test Questions .................................. 115

Appendix 2: Feasibility Study and Laboratory Study Post-test Questions ............................... 116

Appendix 3: Feasibility Study and Laboratory Study Formula Sheets ........................................ 117

Appendix 4: Mobile Intelligent Tutoring System Participant Survey ........................................ 118

Appendix 5: Mobile Intelligent Tutoring System Screens ............................................................ 120
List of Tables

Table 2.1 Comparisons of Mobile and Desktop Tutoring Systems Interactions .............. 14
Table 2.2 Mobile Intelligent Tutoring System Interface Components .......................... 32
Table 3.1 Locations of Interface Region Clicks ........................................................... 42
Table 3.2 General Guidelines for Mobile Tutor Design .................................................. 46
Table 4.1 Mobile Device Interface Styles ........................................................................ 54
Table 5.1 Identification of Student Errors ...................................................................... 73
Table 6.1 Distributions of Study Participants ................................................................. 79
Table 6.2 Identification of Student Errors ...................................................................... 80
Table 6.3 Comparison of Time Spent Using Tutor .......................................................... 89
Table 6.4 t-test Results Showing Effects of Tutoring Conditions .................................... 97
List of Figures

Figure 2.1 Integration of disciplines for the Mobile Intelligent Tutoring System .................. 13
Figure 2.2 Intelligent Tutoring System Model ................................................................. 25
Figure 2.3 Complex Tutor Interface ............................................................................... 27
Figure 2.4 Annotated Behavior Graph ........................................................................... 33
Figure 2.5 Masked Interface .......................................................................................... 36
Figure 2.6 Zoom Tutor Interface .................................................................................... 36
Figure 3.1 Unmasked Tutor Interface ............................................................................ 40
Figure 3.2 Masked Tutor Interface ................................................................................ 41
Figure 3.3 Eye Tracking Study Transitions ................................................................... 43
Figure 4.1 Facets of Tutor Design .................................................................................. 52
Figure 4.2 Menus on the interface from Active Math ..................................................... 56
Figure 4.3 Tabs on the interface from Algebra 1 Cognitive Tutor .................................... 57
Figure 4.4 Andes Physics Tutor Interface .................................................................... 57
Figure 4.5 First Tutor Interface Screen ........................................................................ 59
Figure 4.6 Second Tutor Interface Screen .................................................................... 59
Figure 4.7 Third Tutor Interface Screen ....................................................................... 60
Figure 4.8 Tree Cut to Shorten Problems ...................................................................... 62
Figure 4.9 Long Vs. Short Problems. ............................................................................ 64
Figure 5.1 Times When The Tutor Is Used .................................................................. 74
Figure 5.2 Locations Where Tutor Is Used .................................................................. 75
Figure 6.1 Problem Solving Stages and Experimental Condition ................................. 84
Figure 6.2 Effect of Stage ................................................................. 85
Figure 6.3 Interaction Between Stage and Had 101 ................................. 86
Figure 6.4 Interaction Between Stage, Pretest, and Posttest Scores ............... 86
Figure 6.5 Gain Scores By Stage and Condition .......................................... 87
Figure 6.6 Pre-test Scores By Stage and Condition ................................... 88
Figure 6.7 Post-test Scores By Stage and Condition .................................. 88
Figure 6.8 Interactions Between Condition and Variable Stage Gain ............. 92
Figure 6.9 Stage Gains by Treatment Condition ........................................ 94
Figure 9.1 Example Equation Stage Screen ............................................. 120
Figure 9.2 Example Variable Stage Screen .............................................. 121
Figure 9.3 Example Calculation Stage Screen .......................................... 121
Abstract

Mobile Intelligent Tutoring System:
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The prominence of computers in the 21st Century has caused educators to re-examine the needs of today’s K-12 students. The proposed 21st Century Skills center on the use of technology and thus millions of students are unable fully to master these skills due to their minimal access to technology. The Digital Divide, a correlation between an individual’s access to technology and their socio-economic status, is poised to prevent large segments of society from advancing and thriving in this technology based economy. One proposed solution to this lack of computing resources lay in the transformation of mobile devices, like cell phones, from single-purpose communication tools to multi-purpose computing resources. The smaller scale of mobile devices mandates the design of mobile learning applications be more than miniature desktop learning applications. Whether the applications are based on existing desktop applications or presenting new paradigms of learning activities there are human-computer-interaction and education concerns to address.

This thesis describes the design, implementation, and evaluation of a complete mobile intelligent tutoring system (ITS). The research questions investigated address the design and evaluation of the implemented system. To answer first question, “How might
the design of an ITS be adapted for delivery on a mobile device?" a set of general mobile ITS guidelines is described. To answer the second question, “Can a mobile ITS provide learning gains greater than traditional instructional activities?” data was gathered from a controlled study to compare the performance of students using the mobile ITS with those who did not. These data reveal that students using the mobile ITS achieved gains greater than students receiving standard instruction. The third question, “What teaching strategy best supports a mobile ITS?”, is answered through data gathered from the comparison of two teaching strategies, long and short. These data suggest that the long strategy, in which students are required to calculate the final answer to the problem, best facilitates student performance gains. This thesis lays the foundation for future research that explores the delivery of intelligent tutoring systems off the desktop as well as for research in methods of transforming desktop learning applications for mobile devices.
1: Introduction

This dissertation describes the design, implementation, and evaluation of a mobile learning application. This application aims to address the pedagogical needs of students using intelligent tutoring systems off desktop computers and outside of formal classroom settings. While the use of computers in formal education is increasing there remain millions of students without the computing resources to access intelligent tutoring systems. The transfer of the intelligent tutor from a desktop stationary platform to a handheld one has the potential to provide the benefits of intelligent tutoring systems to students who may not have the opportunity to use one otherwise. In addition, the introduction of a portable platform can provide support to students outside of the classroom. The tutor in this dissertation does not replace traditional instruction; instead, it provides students with intelligent support when instructors are not available.

1.1: The Digital Divide – Home & School

The world wide network of computers, the Internet, has facilitated the globalization of society [1]. While technology development was not the catalyst for this process, globalization would not be possible without it [1]. As a result, societies have begun to examine how to prepare and educate future generations to function, succeed, and thrive in this changing global society. In the United States in particular, educators and researchers have begun to address evolving educational needs examining the current education goals of schools [2, 3]. This evaluation has led to the definition of skills known as “21st Century Skills” [2, 3]. While there is no singular definition of what is required for students to succeed in this technology-based society, the new skills provide a
complement to core subjects such as reading, mathematics, social studies, writing, and science. The added skills include learning and innovation, as well as information, media, and technology literacy skills [2, 3].

One major assumption underlying the definition of 21st Century Skills is that students have access to the technology enabling them to learn, practice, and master these new competencies. However, there are large numbers of students who do not have access to technology in either home or school settings [4, 5]. The lack of access correlates to the student’s socio-economic status. For example, in the city of Philadelphia, less than half of the nearly 1.5 million residents have access to a computer at home [6]. In more affluent areas in the city, 90 percent of the residents have Internet access compared to less than 25 percent having access in impoverished areas [6]. Thus, millions of students throughout the United States do not receive the opportunity to become proficient in the skills required for success in the future because they simply do not have the technology to be able to learn and practice these skills. Likewise, in schools in which students do have access to technology they may still not be able to fully utilize the technology due to the lack of use in instruction, rather than access [7].

The difference in computing resources between communities, known as the Digital Divide, exists for many people with respect to gender, race, and ethnicity. Formally, the term Digital Divide is defined as the difference between individuals with access to computing and those without access to computing. This divide can be further subdivided into two categories: the First Digital Divide, which concerns actual access to
computers and computing equipment, and the Second Digital Divide which relates to computer usage [8].

A literature search would lead one to believe that the Digital Divide no longer exists in the United States. This is in part due to the United States Department of Education reporting in 2001 that 99 percent of public schools in America provide Internet access to students [4, 9]. These data suggest that all students in K-12 schools have an equal opportunity to utilize computers and access the Internet as needed as part of their academic curricula. However, a deeper analysis of the situation reveals another picture. For example, students in more affluent schools are more likely to use computer software that supports higher order thinking skills, whereas students in less affluent schools are more likely to use software for lower order thinking skills such as drill and practice [5].

With respect to the First Digital Divide, there does exist a relationship between the socio-economic status of an individual and the amount of access to computing and the Internet. In 2005 the National Council on Education Statistics reported that 83 percent of American families earning less than $15,000 per year report not having access to the Internet from any location, including home, school, or work [9]. This leaves only 17 percent of the families earning less than $15,000 per year with any Internet access at all [10]. This is in a stark comparison to the 17 percent of families earning more than $75,000 without Internet access versus 83 percent, of those with family income greater than $75,000, with access [10].

Further divides exist with respect to the access provided in K-12 school environments. Schools with larger percentages of minority students have reported a
greater student-to-computer ratio than schools with fewer minority students. In a 2006 survey of six Philadelphia Public schools computers revealed an average of 28 students sharing a single computer in a classroom [11]. Adding to the difficulties for these schools is the number of computers in some state of disrepair. For example, one classroom was reported to have eight iMac computers with eight keyboards but only three power cords and two computer mice shared among them [11].

The second Digital Divide, the divide concerning computer usage, examines how students from various communities differentially utilize computers and technology. Less affluent students report using the Internet more for entertainment purposes than for educational purposes, such as for social networking instead of for conducting research [12]. This difference in usage led to development of new curricular standards. States such as Pennsylvania and Massachusetts have created statewide standards for technology. For example, Massachusetts students in grades 6-8 are required to “identify and compare communication technologies and systems, i.e., audio, visual, printed, and mass communication” [13] while students in Pennsylvania are required to “explain and demonstrate basic computer operations and concepts” [14]. These standards are based on those set by the International Society for Technology in Education which state that students should be able to “demonstrate a sound understanding of technology concepts, systems, and operations” [15].

Efforts to narrow, and eventually close, the Digital Divide remain focused on providing access to computing as well as improving the curricular value of computers in the classroom. While developing solutions and approaches to educating future
generations, educators and researchers must recognize and acknowledge that there are digital equity issues and understand how to address them. The motivation for this dissertation is in part by a desire to develop educational technology that will contribute to the closing of the First and Second Digital Divides by developing and creating applications that are accessible to learners on either side of the divide.

1.2: Mobile Learning

As mobile devices become increasingly prevalent in society, researchers have sought methods to integrate them into educational settings. This integration has taken place in K-12, Higher Education, and Adult Learning environments to support student learning in a variety of domains including mathematics, science, and language [16-19].

Electronic Learning, or e-learning, is a term that includes web-based instruction, online learning, and other technology-based training [20]. As computer use became more pervasive in the 1980s and 1990s, the e-learning discipline grew and is now observable throughout educational systems today. It is predicted that mobile learning, or m-learning, will grow in a manner similar to e-learning, with the growth of mobile technology in our daily lives [21].

While no technology is capable of serving as a panacea for eliminating digital equity disparities, mobile devices do have the potential to provide lower-cost technology-based solutions to individuals and to schools without the resources to support computer labs [22, 23]. In addition to providing computing resources in schools, the use of mobile devices allows for lower-cost home computing solutions as well. The use of cellular phones for non-voice communications can transform them from single-use devices to
multipurpose computing tools for knowledge sharing and learning. This dissertation serves to show that mobile devices are able to serve as a delivery platform for intelligent tutoring systems. In addition, this project shows that applications delivered on mobile devices can provide support to learners in instances in which human support, i.e. an instructor or tutor, is unavailable.

1.3: Research Questions

The research questions posed in this section have foundations in the mobile learning, m-learning, and intelligent tutoring systems (ITS) literature. The primary motivation for many mobile learning applications is to increase learning and provide low-cost applications that are not dependent on a physical location [17, 24-26]. Likewise, researchers use intelligent tutoring systems to increase student achievement and provide a platform to enable better understanding of how individuals learn and how to more effectively teach [27-30]. Researchers in mobile learning and intelligent tutoring systems face common challenges with regard to integrating applications into classrooms. For example to be successful, either technology—ITS or m-learning—must be integrated into environments [31, 32].

The mobile intelligent tutoring system described in this dissertation serves to address open issues in the intelligent tutoring system and mobile learning disciplines. The approach to this research is founded upon two principles: (1) delivering an ITS on a mobile platform can improve the accessibility of intelligent tutoring systems and provide a low-cost tutoring solution and (2) m-learning applications are more complex than miniaturized desktop applications and thus require both conceptual and superficial
changes to existing desktop applications to be suitable for mobile devices. In this
dissertation, methods to develop, implement, and evaluate a mobile intelligent tutoring
system are described and these research findings will bring about new knowledge in the
aforementioned challenge areas.

Specifically, I will investigate these research questions:

- **RQ1:** How might the design of an intelligent tutoring system be adapted for
delivery on a mobile device?
- **RQ2:** Can a mobile intelligent tutoring system provide learning gains greater than
traditional instructional activities?
- **RQ3:** Which teaching strategy best supports a mobile intelligent tutoring system?

The next three subsections describe and expand on these research questions.

### 1.3.1: RQ1- How might the design of an intelligent tutoring system be adapted for
delivery on a mobile device?

At the foundation of this research is the claim that a functional ITS can be
designed for a mobile platform. The mobile ITS presented in this dissertation is built
upon a long line of proven research initiated at the HCI Institute at Carnegie Mellon
University, specifically the Cognitive Tutor Authoring Tools that have used to develop
and deliver intelligent tutors [33, 34]. The Cognitive Tutor architecture is the basis for
the mobile tutor because of the proven learning gains afforded by Cognitive Tutors [35-
37]. Desktop ITS research will be extend through this implementation of a mobile ITS
and adaptation of the existing architecture for mobile device platforms.
Researchers designed the Cognitive Tutor Authoring Tools specifically for the rapid development of desktop sized tutors. To be suitable for the smaller screen sizes of mobile devices, modification of the authoring tools interface components was required. The publishing template used for desktop delivery also required modifications to support Windows Mobile compatible web browsers.

Overall, this research question is aimed at devising a general approach towards the design of a Cognitive Tutor for a mobile device platform. The question seeks to uncover the various aspects of intelligent tutoring systems that require redesign for mobile device delivery. The mobile ITS developed in the context of this project offers one sample solution to this question. The dissertation also emphasizes the general principles behind the success of this tutor, with the understanding that researchers can embed these general principles into other tutoring systems for different domains and/or for other mobile implementation platforms.

1.3.2: RQ2- Can a mobile intelligent tutoring system provide learning gains greater than standard instructional activities?

This research will explore the effects of a mobile intelligent tutoring system on student achievement. One limitation of intelligent tutoring system research is the necessity for the student to either own or have access to a personal computer. In addition to computer ownership, the use of desktop systems places a limitation on when students can access the system because of the low portability of traditional computers. An ITS “off the desktop” will allow learners to access an ITS with the same ease and portability
as carrying a textbook. The goal of this research question is to understand the extent to which the mobile intelligent tutoring system positively affects student learning.

1.3.3: RQ3- Which teaching strategy best supports a mobile intelligent tutoring system?

The translation of a desktop tutor to a mobile platform requires the reconsideration of several aspects of a tutor’s design. A common shortcoming in mobile learning applications is the authors’ failure to understand that users interact with mobile devices differently than they do with desktop computers. Although the small devices could provide access to similar content and tools, the interaction between the human and the device is inherently different and therefore requires careful redesign to compensate for device differences.

Differences between the mobile and desktop platforms are due in large part to reduced screen real estate and limited input mechanisms. Each of these constraints poses unique challenges for intelligent tutoring systems. Desktop-sized interfaces traditionally include text, diagrams, and workspaces. Students utilize various sections of the interface as they answer a series of questions. However, smaller mobile device interfaces reduce the amount of information displayed to users by a factor of more than ten. (For example, a 20” widescreen desktop computer monitor displays approximately 1600x900=1,440,000 pixels, whereas a Windows Mobile device displays approximately 240x320=76,800 pixels.)

Another important difference is the input to the interface, both in terms of what input interaction techniques are available and in terms of what techniques are most usable
and/or comfortable in each domain. On desktop systems, users interact with a tutoring system using a full-size keyboard and mouse. In contrast, mobile ITSs provide limited interaction due to the use of keyboards with fewer keys, smaller buttons, and sometimes only number keys (in the case of phones). Therefore, mobile applications should not contain activities that require users to read and enter large amounts of text and detract from the user experience. This issue raises an additional challenge for mobile intelligent tutoring systems because researchers have conducted few studies to understand the efficacy of tutors without the large interface elements.

In addition to the interaction challenges, mobile ITS must be aware of the students’ context and activities as they engage in tutor interaction. Traditional tutoring systems ask students to solve problems in 30- to 40-minute sessions several times per week. The frequency and duration of such sessions may be very different in optimal use of a mobile system: The anytime, anywhere affordance of a mobile ITS makes it more amenable for more frequent but shorter sessions, enabling learners to use an ITS without the constraints of a desktop computer.

The change in usage, from long infrequent sessions to short and frequent sessions, can enable users to utilize time that may have otherwise been unproductive. Cui and Roto [38] name these short periods of time “micro-breaks” and define them as the “moments between planned activities such as waiting for a bus to arrive.” As researchers desire to develop content to fit into these micro-breaks, they will have to redesign tasks to accommodate this new pattern of use. Recognizing the need for task redesign motivates this project’s effort to reevaluate the problems presented to learners. The ITS community
has conducted little research into a means of modifying the modes and patterns of user interaction to accommodate mobile device delivery, and this is an important aspect of this dissertation.

The design of the mobile intelligent tutoring system resulted in two different teaching strategies; long and short. The long strategy provides students with intelligent tutoring support to identify equations and variables, as well as feedback on final calculation. In contrast, the short strategy provides students with similar identification support while performing the calculations for the students. Each strategy is an adaptation of desktop ITSs strategy. The goal of this question is to understand which teaching strategy best supports mobile device delivery of ITSs.

1.4: Document Organization

This dissertation is organized into the following chapters. Chapter 2 serves to provide a detailed review of the areas of intelligent tutoring systems, mobile learning, and mobile human computer interaction. The goal of this chapter is to provide a foundation and context for the mobile intelligent tutoring system research. Chapter 3 presents the results from an investigative study of user interactions with desktop-sized intelligent tutoring systems. Results from this study informed the design of the mobile intelligent tutoring system and contributed to the creation of general principles for mobile ITS design. Chapter 4 details the use of the mobile ITS principles and how they contributed to the design and implementation of the mobile intelligent tutoring system. Chapter 5 describes a field study of the designed and implemented mobile ITS. This chapter presents the results of a feasibility study and examines to-be-expected usage patterns for
the mobile ITS. Chapter 6 presents the results of a controlled laboratory study evaluating the efficacy of the mobile ITS as compared to traditional paper methods. Chapter 7 presents the conclusion of this thesis, research contributions, and outlines areas for future work.
2: Background

This project integrates three fields of research that contribute to the design and implementation of the mobile intelligent tutoring system, namely the Intelligent Tutoring Systems, Mobile Human Computer Interaction (HCI), and Mobile Learning disciplines, as shown in Figure 2.1. An intelligent tutoring system was selected as a platform to build upon because of its ability to improve student learning. The Mobile HCI field contributes an understanding of how to design applications that make for enjoyable user experiences. The Mobile Learning field contributes an understanding of how to integrate mobile learning applications into existing classroom settings. This section contains a description of each of the areas.

Figure 2.1 Integration of disciplines for the Mobile Intelligent Tutoring System
For the purposes of this dissertation, the term “mobile devices” includes standard cell phones (those without an operating system performing basic cellular voice communications), smart phones (those utilizing an operating system providing voice services as well as additional data processing applications), and personal digital assistants (PDAs providing data processing without voice capabilities). While laptop computers are portable in ways that desktop computers are not, users interact with them in ways that are more similar to desktop computers than they do with smaller devices. For example, laptops utilize full-size keyboards and larger interface screens and are less likely to be used for quick interactions while on the go; for example, using a laptop while standing up at a train platform would be very difficult, in contrast to using a phone or PDA. Instead, laptops are often desktop replacements with the affordance of portability. Table 2.1 shows a comparison of the input, display, connectivity, and delivery aspects between desktop intelligent tutoring systems and mobile intelligent tutoring systems.

<table>
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<tr>
<th>Table 2.1 Comparisons of Mobile and Desktop Tutoring Systems Interactions</th>
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2.1: Mobile Human Computer Interaction

Mobile human computer interaction (HCI) encompasses the study of users’ interactions with mobile devices. The field incorporates hardware design, software design, and user interaction with mobile devices. For example, mobile HCI hardware research examines the use of styluses and one-handed interactions of various devices. Likewise, from a software perspective, researchers have examined the design of interfaces to facilitate convenient displays of information. As the use of mobile devices in society becomes more pervasive, researchers will continue to seek to understand and characterize their use.

Mobile HCI poses challenges in five key design areas: mobility, widespread population usage, limited input and output facilities, incomplete and varying context information, and user multitasking [39]. With respect to mobility, users who employ mobile devices in locations away from desks or offices will likely not have support resources around them [39]. The use of multipurpose mobile devices, rather than single purpose computers, allows individuals from widespread populations (such as the elderly or very young children) to use computing resources without specialized training [19, 39-42]. Despite improvements in mobile device screen resolutions and input and output facilities, the devices mechanisms remain smaller than desktop computer mechanisms and therefore require different designs [18, 39]. The dependence on GPS, Wi-Fi, or cellular networks allows for new information to be delivered to users however the robustness and reliability of the networks can greatly affect user’s ability to access and effectively utilize this information [39, 43]. Providing support for users to multitask on
desktop computers is commonplace; however, this support must also be designed into mobile device applications due to the increased frequency of interrupted usage patterns [38, 39].

2.1.1: Mobile Human Computer Interaction Theories and Principles

Ballad [44] describes design principles that focus on guiding developers to design applications specifically for mobile devices rather than attempting to miniaturize existing desktop applications. For example, enabling users to receive informative feedback, just-in-time just-in-place information, and reducing short-term memory load [18, 45, 46].

This dissertation makes use of knowledge and principles from the mobile HCI discipline to understand how users interact with mobile devices and how these interactions are similar and dissimilar to desktop computers. With respect to intelligent tutoring systems, techniques from mobile HCI design are used to address the design challenges of mobility and limited input and output facilities through the modification of the desktop tutor’s interface as well as through the design of the mobile tutor’s teaching strategy.

2.2: Mobile Learning

2.2.1: What is Mobile Learning?

Mobile learning is an emerging discipline in the area of education. The field of mobile learning is approximately a decade old and has grown rapidly. As personal computer integration predicated computer-enhanced learning, a primary factor in the growth of mobile learning is the increasingly ubiquitous integration of cell phones into
society. For example, the second quarter of 2005 saw more than 190 million mobile devices and smart phones sold worldwide [47], and it is expected that by 2015 more than five billion people will utilize services via mobile devices [48]. In addition to cellular phones, there has recently been an increase in the use of non-phone wireless devices such as MP3 players (such as the iPod®) and personal digital assistants (PDA). While these devices do not perform voice services, they do have many of the same services as today’s smartphones including basic word processing and Internet access. This increase in wireless connectivity has led educators and researchers to investigate methods of integrating mobile devices into education. As the field continues to grow, researchers are increasingly investigating how mobile learning can benefit education for students and teachers alike.

Researchers have described mobile learning as an e-learning analog that uses mobile devices in place of desktop computers. This definition views m-learning as having the potential to serve in contexts similar to e-learning. A different perspective on m-learning, however, views the discipline as being able to provide support in contexts not previously available such as allowing students use mobile devices to dynamically update a wiki with their impressions of museum artifacts while on a class trip [49]. The integration of mobile devices with other technologies such as Bluetooth and GPS, enable mobile learning applications to provide context-aware applications to learners in a manner not previously realized. For example, students visiting museums have been able collaborate using mobile devices to play a scavenger hunt game. As students transition
through the museum the location aware devices receive information relating to the exhibit within their proximity and allows students to share this information with each other [50].

Recognizing that there is potential for learning anywhere and anytime, some researchers define mobile learning as including any environment that supports scenarios in which the learner’s mobility is germane to the educational environment. For example in an open field learners can freely travel with the devices to explore the natural surroundings and then relay the information to classmates in the classroom [51]. This definition also supports scenarios in which the learner is performing typical stationary tasks but the learning environment is mobile. For instance, Aderinoye’s description of a project supporting the learning of nomadic populations in Nigeria [24]: The nomads were provided with classrooms that could be constructed in 30 minutes, and used mobile phones as a means of communicating between course facilitators and nomadic learners that did not disrupt their nomadic lifestyle.

In contrast, Keegan proposed a more rigid definition of mobile learning requiring that the devices be restricted to the size “a lady can carry in her handbag or a gentleman can carry in his pocket” [31]. The devices are further described as those that users are likely to carry everywhere with them and are cheap and easy to use, e.g. cell phones, smart phones or PDAs. This stricter definition would prohibit the use of laptops, microcomputers, or other portable wireless devices. In this dissertation, Keegan’s rigid of mobile learning is adopted.

Although there may be a lack of a common definition for mobile learning, all these definitions center on the use of a mobile device. Researchers have used a variety of
approaches to integrate the mobile device and/or learning applications into existing learning environments. The research presented in this dissertation describes the design of a mobile learning application that leverages existing educational context.

2.2.2: Where is Mobile Learning Used?

When new technologies are introduced into education, researchers typically seek to capitalize on affordances of these technologies to improve existing learning environments or to create new ones. A review of the mobile learning literature yields three common strands of implementation, each seeking to enhance learning environments in some unique way. The first strand uses mobile learning applications to support communications between instructors and students as well as between peers [52, 53]. The second strand uses mobile learning to improve learning environments by providing a platform for the implementation of learning theories as well as support for learner collaboration [53, 54]. The third uses mobile learning to deliver educational material to learners [24, 55].

Mobile learning has been implemented successfully in science classrooms enabling students to use a constructivist approach towards learning. K-12 students conducting science field explorations have been able to gather and organize information while exploring an environment, such as a wooded forest, and transfer the information to desktop systems once they return to school [52]. Lai et al. [26] describe a m-learning application that facilitates students’ science knowledge acquisition. Their system uses the mobility afforded by the device to support learning in a natural environment, namely a garden. For example, students are able to record questions, orally or written, about the
studied environment during their field visit or receive prompts from the PDA to direct them to make deeper observations while providing them with background material when necessary. In this and similar instances, the use of m-learning provides students with real-time technology to support their science learning outside of the formal classroom setting.

Researchers also design mobile learning applications to support students in mathematics learning. Handheld math games have been shown to improve student performance as well as maintain students’ motivation and engagement with the technology [56]. Capitalizing on technology such as infrared and Bluetooth integrated into mobile devices researchers have been able to create ad-hoc networks enabling collaborative usage of mobile devices [52]. Such networks have been utilized to enable mathematics learners to collaborate on graphing activities [52]. In addition, educators use mobile learning applications for language learning and job training for learners in K-12, higher education, and adult education both formally and informally [40, 43, 49, 55, 57]. Adults learning English as a second language (ESL) have been shown to benefit from Short Message System (SMS) text messages containing vocabulary words [55].

One of the critical aspects of mobile systems is their ability to exploit context. As one example, mobile devices have been used to create context-aware interactive user experiences in museum settings [43, 57]. The integration of mobile devices with technology such as GPS, infrared, and Bluetooth enables mobile devices and applications to interact with other artifacts to provide individual experiences users. In the museum example, museum patrons are able to receive information regarding the artist or exhibit they are viewing in real time. As patrons move between exhibits, available information
changes to correspond with their location, thereby providing a unique experience that is fine-tuned to each patron’s personal tour of the museum space.

Mobile learning research has been focused on understanding the space of possible applications for mobile devices in education. Some researchers are guided primarily by the ability of the devices to provide adaptive environments, and others by the light weight of the devices themselves. Therefore, there are many possible characterizations of mobile learning, and pinning down one characterization has proven to be elusive. In the context of this research, the major affordances of mobile learning are low cost and portability: The low cost increases accessibility to the intelligent tutors, and portability increases the range and flexibility with which these tutors may be used.

2.2.3: Challenges in Developing Mobile Applications for Education

It is often difficult for educators, administrators, and even parents to view mobile devices as being useful for educational purposes because they have been predominately used for social purposes including phone communication and text messaging. The current educational system produces lesson plans, learning activities, and assessments based upon traditional educational models. However, the introduction of mobile devices enables students to interact and collaborate with one another in ways not previously realized. Therefore, educators must now determine how to design lessons and activities structured around this mobility and accurately quantify the results of the use of the technology.

The use of mobile devices also raises questions that relate to the implementation of the technology, namely the hardware and software. Previous trials of mobile learning applications reveal that concerns regarding device ownership, battery life, and network
connectivity can greatly affect the learning outcomes of students [58]. While these issues may be viewed by some as policy rather than research, I would argue that an understanding of these issues could provide information to inform the design of the applications themselves. For example, knowing that students may not have reliable Internet connections may cause a designer to create a standalone application or one that requires periodic synchronization to function properly.

Interestingly, researchers implementing and testing mobile learning applications have noted that there is potential for mobile learning applications to exist alongside traditional instructional tools [59]. While the use of mobile learning applications can be transformative, it is necessary to understand and consider the existing learning environment in which it is intended. While there are certainly instances in which a mobile learning application can provide an experience not possible without the technology [60], it seems plausible, and even likely, that this technology can co-exist and support traditional paper-based methods.

2.2.4: Mobile Learning Theories and Principles

While there are no widely adopted theories for mobile learning, a few researchers have put forth frameworks and principled guidelines for their development. For example, Sharples [61] puts forth a theory of four mobile learning based principles: (1) mobile learning can be distinguished from other types of learning activities; (2) mobile learning recognizes the learning that takes place outside of formal classroom settings to be valuable; (3) mobile learning should promote practices that enable successful learning; and (4) mobile learning considers the ubiquity of mobile devices in society. Others have
proposed principles based on shaping the content of the mobile applications [45]. For example, a user-centered approach to designing m-learning interfaces should take into consideration the manner in which mobile learning differs from other types of activities. Another principle that is important in the development of m-learning applications is the understanding of how students’ mobility will either be constrained by or supported by the device.

The research presented in this dissertation uses aspects of the aforementioned principles to examine learning outside the classroom and distinguish the teaching strategies of the mobile intelligent tutoring system from that of desktop-sized tutoring systems. This project utilizes an existing classroom structure and identifies a complementary role for the mobile intelligent tutoring system. This dissertation describes a system that provides supplemental support to students, outside of the classroom, when a human instructor or tutor is not available.

2.3: Intelligent Tutoring Systems & Cognitive Tutors

Intelligent tutoring systems have their foundation in the artificial intelligence and computer assisted instruction disciplines. Burns and Capps [62] describe the “intelligence” of this software as the collection of the five subsystems shown in Figure 2.2. The first is an expert model that represents the domain knowledge. This knowledge constitutes the understanding of the subject matter that an expert has in the tutored area. The second is the student diagnosis model. This model represents the knowledge and behavior of a student learning the domain. The third is the instruction module, which is responsible for recognizing student input and responding to student actions. The fourth is
the instructional environment that provides support to the learner. It can consist of the activity, the situation, and tools provided by the system to facilitate learning. The fifth component is the interface, an essential component that provides the means by which the user can communicate with the system. With respect to intelligent tutoring systems, it is the integration of the models that separate ITS technology from other forms of computer-aided instruction [63].

Intelligent Tutoring Systems assist students in mathematics, science, and language learning domains for learners in high school and higher education courses [64-66]. When integrated into school curricula students use the tutors during school hours in computer labs and classrooms. However, in K-12 environments interaction typically takes place on desktop computers in school computer labs. Students using tutors have been proven to have learning gains greater than peers not utilizing the tutor and receiving more typical instruction [35-37].
Traditionally, tutoring systems are developed for use on desktop-sized computers. The interfaces are often complex and but share common components, identified by Brown, et al. [67] as Problem Description, Student Workspace, and Student Status as shown in Figure 2.3. With respect to the tutor, each of these regions serves a specific purpose in the tutor’s efficacy. In the Problem Description area, users are provided with given information, a context for the problem, and a description of what students are solving. Workspaces provide students with charts, tables, or other space to organize data, or thoughts, and place problem answers. The Student Status provides feedback to the user.
regarding their performance in the tutor sequence as well as information regarding their performance on skills they are learning.

Cognitive Tutors are one specific class of intelligent tutoring system based upon computational theories of cognition [36, 68]. In Cognitive Tutors, cognition is programmed through the creation of cognitive models in the form of production rules. The production rules consist of a series of if-then statements describing the goals and sub-goals required to complete specific problem solving tasks. These tutors utilize cognitive models of learners and domain experts to provide individualized instruction to learners.

The Cognitive Tutor was developed in part as a response to the “2-Sigma Problem,” in which Bloom challenged researchers to develop methods providing individual tutoring to large numbers of students [37, 69]. Cognitive Tutors have been extensively researched and proven to improve student achievement of between one and 1.6 standard deviations greater than peers receiving traditional group instruction [37]. Cognitive Tutors are currently employed in approximately 2,600 school districts in the United States and utilized by nearly half a million students annually [68]. They are used as part of a curriculum that integrates classroom instruction with the use of the tutors. Student use the tutors approximately two days per week (40 percent of the total course time), and spend the remaining three days (60 percent of course time) receiving traditional group instruction in the classroom.
In this project, intelligent tutoring systems are a vehicle for delivering a mobile learning application. Specifically, Cognitive Tutors are the basis for the development of the mobile intelligent tutoring system. The extension of Cognitive Tutors to mobile platforms requires modifications to the authoring tools and delivery architecture as described in section 2.5.1.
2.3.1: Use of Feedback

With respect to intelligent tutoring systems, Corbett and Anderson [70] compared three types of feedback: immediate feedback with immediate error correction, immediate error flagging and student control of error correction, and feedback on demand with student control over error correction. The immediate feedback group yielded the greatest student improvement, even though the students themselves did not express a preference between the conditions. The primary conclusion from this research of feedback in intelligent tutoring systems is that students benefit from explicit guidance from the tutor.

Leveraging the fact that tutor feedback supports student mastery learning, researchers have investigated the use of feedback by varying its timing, immediacy, and tone, e.g., polite or impolite, to measure its efficacy in supporting student learning. The project described in this dissertation utilizes these results and employs immediate feedback as a means of encouraging student reflection. Reflection, in this capacity has been shown to be an effective mathematical problem solving strategy [71]. The feedback model in this project encourages reflective problem solving behavior to create a tutor design that is conducive to the mobile device delivery.

2.3.2: Use of Representations

Representations, in mathematics problem solving, enable students to organize, record, and communicate ideas [72]. The use of representations is deemed so important that the National Council for Teachers of Mathematics has included their use as a national standard for students [72]. Representations such as number lines, diagrams, and tables are integral components of Cognitive Tutors [36]. In the tutoring systems students
are typically provided with two different representations in the workspace, as shown in Figure 2.3, to allow students to transfer between computer-based solving methods and the paper and pencil methods they are familiar with. Due to the decreased screen real estate of mobile devices the mobile ITS described in this dissertation employ tables as the sole type of representation used in the tutor design.

2.4: Mobile Intelligent Tutoring System

Mobile ITSs have not been extensively researched. While recognizing that aspects of desktop tutors require modification for mobile device delivery, there has been little research aimed at identifying how to modify the tutors and which aspects of the tutor to change. The research presented in this dissertation presents a multi-faceted approach to a theory-based design for a mobile ITS.

The delivery of ITSs on mobile devices has the potential to provide the significant advantages of intelligent tutoring systems to a wider audience of learners. Despite the fact that nearly all schools provide Internet and computer access to students, a deeper examination reveals that the presence of technology does not equate to effective use of the technology [7]. One factor hindering use is the student-to-computer ratio in schools: in 2005, no school reported having one computer for each child with the lowest computer-to-student ratio being approximately 3-to-1 [9]. In 2005, 19 percent of schools provided handheld computers to students while 10 percent provided laptop computers for home use [10]. Although these numbers do not represent the majority of schools, they represent a 9 percent increase in handheld use from 2003 [10]. These numbers are indicative of a positive trend towards schools making use of handheld computing and
allowing students to coordinate technology use between home and school. This trend is also indicative of the potential that mobile and handheld devices have to deliver a one-to-one computing solution to the education community [73].

School systems without the financial resources to invest in and maintain large computer labs can, by using mobile devices, have the ability to provide learners with ITS technology. Students can more easily transport the tutors between home and school as well as share the mobile ITSs between students in the same school. The portability affordance of mobile ITSs can extend tutor use to outside of computer labs and traditional classrooms, thereby providing robust learning opportunities to students at home, after school, and in other locations. As mobile device technology improves, there is also the potential for mobile ITSs to execute as standalone applications, as opposed to client-server network based, thereby eliminating the need for an Internet connection of any type (wired or wireless).

While mobile devices can bring ITS technology to a wider range of audiences, the primary obstacle today is the lack of understanding of how to design and deliver mobile ITSs. One objective of this dissertation work is to begin to fill this void and put forth a theory-based design for a mobile ITS that takes into account the complexity of ITS development, while at the same time examining the additional changes that are required to design and deliver a mobile ITS. Although an important motivation for this research is narrowing the digital divide through the use of mobile devices, it is important to note that the project described addresses the technical aspect of delivering a mobile ITS rather than the issues regarding cost of and access to technology for individual users.
2.5: Methods and Tools Used in this Dissertation

2.5.1: Cognitive Tutor Authoring Tools

Cognitive tutors are very labor-intensive to develop, and the use of authoring tools greatly reduces the time developers spend creating the tutoring systems [74]. The Cognitive Tutoring Authoring Tools (CTAT) [74] allow for the straightforward design and development of intelligent cognitive tutors. The tools are primarily comprised of two components: an interface builder for creating the user interface, and a behavior graph recorder that helps to embed knowledge of possible student actions and errors.

The interface builder allows a designer to create a Flash interface for the tutor [75]. Designers drag and drop ready-made components to sketch out and build the system interface. The Flash components used in this project include: Done Button, Text Box, Radio Button, General Button, and CommShell as shown in Table 2.2.

Currently the CTAT interface components facilitate the design of desktop tutors. To accommodate the smaller dimensions of the mobile device interface and create scaled-down versions of the interface components the component’s Flash code was modified and recompiled. For example, the CommShell was scaled to 320 x 240 pixels from the desktop-sized original 200 x 500. The remaining components were scaled down to fit within the smaller CommShell. The project described in this dissertation makes use of the modified interface components to create the mobile ITS interface that is scaled for the smaller device.
The second component of the CTAT tools is the behavior graph recorder, which facilitates the creation of ITSs by allowing developers to explicitly demonstrate correct and incorrect actions rather than write complex computer programs. The primary benefit of demonstrating, rather than writing programs, is in saving the designer from having to know the details of cognitive modeling and programming to develop ITSs [76]. Generating behavior graphs by demonstration using CTAT has been proven to provide 1.4 to 2 times reduction in programming hours by tutor developers [74]. The artifact

<table>
<thead>
<tr>
<th>Component Name</th>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Done Button</td>
<td><img src="image" alt="Done" /></td>
<td>Indicates completion of problem.</td>
</tr>
<tr>
<td>Text Box</td>
<td><img src="image" alt="Enter text" /></td>
<td>Combined to create tables for data entry.</td>
</tr>
<tr>
<td>Generic Button</td>
<td><img src="image" alt="Button" /></td>
<td>Users can navigate through tutor screens, e.g., “Next”</td>
</tr>
<tr>
<td>Radio Button</td>
<td><img src="image" alt="Choice" /></td>
<td>Users can select desired answer.</td>
</tr>
<tr>
<td>CommShell</td>
<td><img src="image" alt="Communications" /></td>
<td>Responsible for the client-server communications between the interface and behavior graph.</td>
</tr>
</tbody>
</table>
produced from this demonstration process is a behavior graph. The graph is a visual representation of the problem solution space, shown in Figure 2.4. In these graphs, the nodes represent states where students are in the problem solution process. The edges represent actions that users take to transition between the states.

Figure 2.4 Annotated Behavior Graph
Underlying the behavior graph are algorithms that match user interface inputs to the behavior graph and trace the users knowledge. The first step in behavior matching is to determine the selection, i.e., which interface component is selected. The user’s action is then recorded and classified, e.g. a text field update or button press. Finally, the user’s input is recorded. Second, the triplet consisting of a \(<\text{selection, action, input}>\) are evaluated together to determine if the student’s behavior matches the behavior of a node in the graph. When the behavior triplet matches a graph node, the student’s state transitions to the next state in the graph. When the behaviors do not match, the student remains in the current state and receives the feedback programmed by the developer.

The behavior graphs generated during this research include both correct and incorrect solution paths. Correct paths demonstrate correct solutions leading to the successful completion of the tutored problems. However, incorrect paths demonstrate common student errors. The inclusion of student errors allows specific hints and immediate and targeted feedback to be presented to users when they commit specific known errors shown in the box of Figure 2.4.

2.5.2: Poor Man’s Eye Tracker

The use of eye tracking has been successful in providing insight into how users interact with interfaces by capturing information such as counts of user gazes, location of user gazes, and duration of gaze [77, 78]. Researchers use eye tracking data from users to explore information processing as well as provide researchers with insight into interface usability and design [79-81]. In addition to providing insight into the behaviors of users, eye tracking technology has been used as the basis for the creation of tools to
allow disabled individuals to control computers using eye movements [82]. However, the highly technical nature of eye trackers makes them expensive to use and difficult to set up [82, 83]. The creation of a “poor man’s eye tracker” enables researchers to get the benefit as an eye tracker without the great expense and difficult setup [84].

The Poor Man’s Eye Tracker works by creating interface masks that enable users to more easily view one region of a screen at a time. For example, the Active Math Intelligent Tutor interface was studied with four variations of a Poor Man’s Eye Tracker, two of which are shown in Figures 2.5 and 2.6 [85]. The variations include the use of masking, Figure 2.5, and zooming, Figure 2.6, to make areas viewable or obscure. This obscurity forces users to view one region at a time and transition between regions to complete tasks. The information obtained by poor man eye tracking investigations can be used to identify user’s shifts in attention without the difficulty in setup and expense of a head mounted eye-tracking setup [84].
Figure 2.5 Masked Interface

Figure 2.6 Zoom Tutor Interface
3: Poor Man’s Eye Tracking Study

3.1: Study Rationale

To understand how to transition an ITS from the desktop delivery to mobile device delivery, a small exploratory study was conducted to understand user interactions with the desktop-sized tutors. The desktop tutors are complex, and it is difficult to understand which of the components, such as problem text or workspace, students make use of most when solving problems. The Poor Man’s Eye Tracker study was conducted to provide insight into this issue. Additionally, the goal of this study was to seek an answer to the following research question:

- **RQ1** How might the design of an intelligent tutoring system be adapted for delivery on a mobile device?

Head mounted eye trackers have been used by Cognitive Tutor researchers investigating the use of eye movements to indicate student cognitive processes and understand the visual attention shifts that occur prior to and while student’s commit errors [78]. While they have been proven effective for understanding behavior and cognition they are also expensive and difficult to setup accurately [78, 84]. To overcome the expense and time of eye tracking, researchers have also used Poor Man’s Eye Trackers [85] as discussed earlier. This study utilizes a masked Poor Man’s Eye Tracker to explore user interactions with a desktop sized intelligent tutoring system.
The smaller scale of mobile devices makes displaying the previously mentioned ITS interface regions on one screen impractical. An alternative option for the mobile ITS interface is to distribute the interface areas to multiple screens allowing users to navigate between screens as necessary. This study was conducted prior to finalizing a mobile ITS interface design to understand how people transition between regions of desktop tutor interfaces. The results of this study will determine the most effective method of displaying information to mobile ITS users.

3.2: Participants

Eight paid students (three female, five male) undergraduate or graduate students at Drexel University answered an email advertisement to participate in this study. All students were at least 18 years of age. Institutional review board (IRB) approval was obtained to conduct this study and all students granted their informed consent. Students received $10 for their time.

3.3: Materials

Students used a desktop-sized intelligent tutor during the study specifically created for this study. The tutor consisted of four questions about geometric angle relationships such as complementary and supplementary angles. The tutor interface was modeled after an existing free demo Geometry ITS [68]. To solve each question students were required to identify the degrees of the angles in the diagram using the relationship between the unknown and known angles.
In the study, students accessed the tutor using a laptop computer. The tutor interface was comprised of four regions: diagram, hint, glossary, and problem. To complete the problems, users are required to interact with each of the interface components. To solve mathematical calculations the students used use a sheet of paper and a pencil if they desired.

3.4: Data Sources

Event logs detailing user interactions with the intelligent tutoring system are the source of data in this study’s analysis. As students clicked on the masks, their interactions were recorded in the background. The exact time of each mouse click and the clicked region name were recorded in the event logs.

3.5: Procedure

Prior to beginning the study, students were given a five-minute review of common geometry terminology, such as adjacent angles and complementary angles. Students were then shown an unmasked version of the interface, shown in Figure 3.1, to familiarize them with the interface components and regions. The unmasked interface is not the same as the masked version to prevent them from remembering the specifics of the problem and using their memory to solve the actual problems.

Students used a masked desktop-sized geometry intelligent tutoring system, shown in Figure 3.2, to solve four questions. To view any portion of the interface users touch the mouse cursor to the desired region and it is uncovered. To view another region,
users touched the desired region to uncover it, and the previously visible region is recovered by its mask. This setup allows only one viewable section at a time.

Figure 3.1 Unmasked Tutor Interface
3.6: Results

From the eight students there were 846 clicks logged in the four regions of the masked interface. Table 3.1 shows the distribution of the clicks and the average number of seconds spent on each region. Not surprisingly, the large majority of the clicks occurred on the problem (49.2 percent) and diagram (35.3 percent) regions of the interface. This result was expected because in order to answer the questions students would have to view the diagram and then refer back to the problem space to enter their
answers. The surprising result exists when examining user interactions by time spent in each region. Users spend almost as much time in the glossary (6.1 seconds per visit) as they did viewing the diagram (6.6 seconds per visit). Therefore, although users infrequently referred to the glossary they spent nearly as much time per visit using it as they did viewing the diagram.

<table>
<thead>
<tr>
<th>Region</th>
<th>Percentage of Clicks (%)</th>
<th>Total Time in Region (hr:min:sec)</th>
<th>Average time per region visit (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem</td>
<td>49.2%</td>
<td>1:00:23</td>
<td>8.3</td>
</tr>
<tr>
<td>Glossary</td>
<td>7.5%</td>
<td>00:06:31</td>
<td>6.1</td>
</tr>
<tr>
<td>Diagram</td>
<td>35.3%</td>
<td>00:33:00</td>
<td>6.6</td>
</tr>
<tr>
<td>Hint</td>
<td>7.8%</td>
<td>00:05:53</td>
<td>5.4</td>
</tr>
</tbody>
</table>

In total, users transitions between interface regions 669 times. Figure 3.3 shows the transitions that occurred between interface regions. Of the transitions recorded, 34.19 percent occurred from the Problem to the Diagram and 36.76 percent occurred from the Diagram to the Problem. Together, these approximately 70 percent of transitions took place as expected because students primarily used these two regions to solve the problems. The remaining 30 percent of the transitions were distributed across other regions, as shown in Figure 3.3. The remaining were the result of users seeking support to
answer the questions either by viewing hints or by referring to the glossary for definitions of geometry terminology.

Figure 3.3 Eye Tracking Study Transitions

3.7: Discussion

This study was initiated to explore methods to transform a large-scale complex intelligent tutoring system interface into a smaller scale interface. Prior to finalizing the mobile tutor’s interface design it was necessary to study user interactions with desktop
sized interfaces to understand how users transition between regions of the interface. Initially the regions, represented by individual masks, were to be located on separate screens using either menus or tabs to navigate between regions. While this approach may have worked, the results of this study led to a different interface design.

The first mobile ITS interface design was motivated by the 71 percent of transitions that occurred between the diagram and problem regions. It was assumed that those two regions would be placed on a screen together. This placement would allow the hint and glossary regions to be co-located on a separate screen to support the remaining transitions. However, when examining the data by amount of time spent per region it became apparent that although students did not refer to the glossary and hints as frequently they do so for relatively long periods. The length of time spent in these regions was interpreted to mean that the hint and glossary regions were as important to students solving problems as the diagram and problem statement.

The transitions between the remaining regions occurred when students were experiencing difficulty solving the problem and needed additional problem solving resources. It is conceivable that during these periods students were also experiencing frustration or confusion. The coupling of the notion that increased navigation distracts from user experiences and the average time spent per region data it was determined that when students experience frustration or confusion, as evidenced by the use of the glossary or hints, it is not desirable to have them navigate to additional screens for support.
Because of this study, it was concluded that the interface should not be subdivided by region function thereby causing users to navigate while solving the problems. Instead, the final mobile ITS interface was simplified to enable students to enter information on one screen and still have access to the hint feature. To reduce the navigation required while solving the problems the tutor automatically advances to subsequent screens as users input correct information. While there are multiple screens required to solve each problem each screen provides students with just in time information to provide all of the information needed to solve a particular sub-step in the problem solving process.

3.7.1: General Guidelines For Mobile ITS Design

In addition to the interface design, the data gathered in this study led to the natural grouping of steps rather than the division of the interface by groups. The following guidelines integrate results from the Poor Man’s Eye Tracking Study and existing, general, guidelines for mobile learning applications [44][46]. The guidelines developed are with respect to the Interaction, Interface Design, and Context areas of the mobile ITS.
Table 3.2 General Guidelines for Mobile Tutor Design

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Navigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Minimize user navigation required to answer questions (_1)</td>
</tr>
<tr>
<td></td>
<td>• Eliminate navigation to view entire ITS screen (_1)</td>
</tr>
<tr>
<td></td>
<td>• Eliminate need to find supplemental ITS information (_1)</td>
</tr>
</tbody>
</table>

**Consistency**

• Interaction with components should have a consistent function across screens and between problems

**Compatibility with chosen hardware platform**

• Interaction required should be compatible with hardware; e.g., touch screen using fingers or stylus vs. no touching and direction key navigation only

**Visibility**

• Users should know which problem is being solved \(_1\)
• Users should be able to differentiate between input and system-provided information
<table>
<thead>
<tr>
<th><strong>Interface Design</strong></th>
<th><strong>Consistency</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Wording and structure of questions should be consistent</td>
</tr>
<tr>
<td></td>
<td>• Layout and components used across screens and between</td>
</tr>
<tr>
<td></td>
<td>problems should be consistent</td>
</tr>
</tbody>
</table>

**Just-In-Time Information**

- Information needed to answer questions should be visible to
  the user when it is needed
- Users should not have to input information that is not directly
  related to the problem to be solved

**Simple Hierarchies**

- Screens should be ordered according to the natural problem
  solving steps

**Text**

- The amount of text, read or input, should be minimized

<table>
<thead>
<tr>
<th><strong>Context</strong></th>
<th><strong>Role Of Application</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Consider whether the application is for use in formal or</td>
</tr>
<tr>
<td></td>
<td>informal learning environments</td>
</tr>
<tr>
<td></td>
<td>• Consider whether the application will supplement or</td>
</tr>
<tr>
<td></td>
<td>compliment existing instructional activities</td>
</tr>
<tr>
<td></td>
<td>• Consider whether the application will require other</td>
</tr>
<tr>
<td></td>
<td>instructional materials or be independent, i.e. with or without</td>
</tr>
</tbody>
</table>
48

| | a text book or handouts, which can impact students ability to use anywhere or anytime$_1$
| | • Consider whether the problems can be answered during micro-breaks or long sessions$_1$

**Knowledge of User**

- Understand target users’ areas of weakness and strength
- Provide scaffolds, i.e., hints and feedback, in areas of targeted user weaknesses$_1$

$_1$ - represents guidelines unique to mobile ITSs
4: Developing a Mobile Intelligent Tutoring System

This chapter describes the design and implementation of the mobile intelligent tutoring system. This chapter contains descriptions of the design that was informed by data from the PMET Study, the mobile ITS guidelines previously described in section 3.7.1, and existing m-learning and ITS research. This chapter discusses the rationale for these decisions in the context of other possible options. It is important to note that the goal of the mobile tutor design was not to miniaturize a desktop tutor; instead, the goal was to create a mobile-specific intelligent tutoring system that takes advantage of the unique benefits of the mobile application and context.

4.1: Implementation

4.1.1: Which Handheld Device Should Be Used?

Prior to developing the mobile ITS several device types were evaluated for suitability for this project. The devices evaluated were mobile phones, smartphones, and PDAs. For the purposes of this dissertation mobile phones, or cell phones, are defined as cellular phones that primarily provide voice services to users. In addition to voice services, mobile phones provide limited data services, such as Short Message Service (SMS) for text messaging and Multimedia Message Service (MMS) for video and audio transmission. Smartphones are defined as mobile phones that run complete operating systems, provide standard interfaces, support email, and support document formats (e.g., PDF or Microsoft Office). PDAs are defined as devices with capabilities similar to smartphones, but with one key distinction in not providing voice services to users.
One benefit of mobile learning applications is their ability to provide low-cost solutions compared to desktop or laptop computers [23]. However the selection of either smartphones or mobile phones would have required an additional financial expense to pay for monthly fees for cellular service and additional data service monthly fees required for Internet use. Ultimately, a PDA was chosen for the present work due to its wireless Internet capabilities and lack of voice capabilities, which require monthly fees. It can be argued that mobile phones or smartphones are more general and devices that many users are likely to currently own. However, for this dissertation, monthly recurring costs were an issue and a reason not to select this option. In any case, the design framework and results from this research should generalize well to any of the previously described mobile devices. While the current state of mobile device hardware and software is platform dependent, we expect that between-device portability will rapidly increase in the near future, making the system compatible with a variety of devices.

4.1.2: Which Tutor Development Platform Will Be Used?

The tutor developed in this project is built upon the Cognitive Tutor architecture. The Cognitive Tutor architecture was selected as the tutoring model because of its longstanding use and proven success in many domain applications [35-37]. The research group responsible for the development of the Cognitive Tutor has created authoring tools, called the Cognitive Tutor Authoring Tools (CTAT), that enable rapid tutor development [33]. The CTAT package enables developers to create tutors that execute via a Flash Player or as a Java application. The Java option enables developers to create complex cognitive models of student and expert behavior. However, because this research is not
focused on developing detailed cognitive models, the Flash option was selected for its simplicity in development and ability to use Flash players which are readily available on millions of mobile devices [75]. The use of Flash also enables devices on multiple platforms to access the tutors, providing a level of platform independence that is more difficult to achieve with other frameworks.

4.1.3: What Subject Domain Is The Focus?

Mathematics was selected as the general domain for the tutor. Under the umbrella of mathematics, the topics of Compound Interest and Simple Interest were the domain for the tutor development. Compound interest is the concept of adding accumulated interest back to the principal so that interest is earned on the interest as well as the principal. Simple interest is the price paid for the use of borrowed money. Through the Mathematics Department Drexel University offers Math 101, a course to teach students the mathematics underlying financial mathematics. As part of the course students receive instruction on Simple Interest and Compound Interest. Students from majors including business, sports medicine, and psychology enroll in the course as part of their undergraduate prerequisites. This course was selected in an effort to develop a tutor that will assist students with a range of abilities and from multiple majors.

4.2: Design

The design of the mobile intelligent tutoring system focuses on three aspects of intelligent tutoring system development: interface, activity, and architecture, shown in Figure 4.1. Each aspect is based on the theories and principles reviewed earlier from the
disciplines of intelligent tutoring systems, mobile learning, and human computer interaction, as well as those put forth in section 3.7.1. The goal of the tutor is to be lightweight with respect to the interface and interactions without sacrificing its usefulness in an educational setting. The remainder of this section describes each aspect in detail.

4.2.1: Mobile Intelligent Tutoring System Interface

For mobile devices, the “interface” includes the graphical user interface (i.e. the screen display) and the mechanical interface (i.e. the input method). The design of the interface of the mobile tutor is based on the examining ways the users interact with mobile devices. The goal was to design this system to enable users to input and view data within the tutor in a manner that is consistent with what we know about how people use mobile devices and how people solve problems in ITSs.
4.2.1.1: Mobile Device Graphical User Interfaces

Mobile device interfaces vary in size and shape. They also vary in how they present information to users as shown in Table 4.1. For example, the use of list style interfaces enables users to easily find information on a screen without having to do much navigation. On the other hand, table based interfaces provide neat and tidy layouts for users from which they can open other applications. Although visually similar, menus differ from lists in that they provide a list of actions or commands, rather than information, that users can perform at any given time [44]. Tab interfaces are helpful because they easily allow users to see the desired information on one tab.
4.2.1.2: Mobile Device Mechanical Interfaces

The mechanical interface options for mobile devices fall into several categories: numeric keypad, “QWERTY” (standard) keyboard, and touch screen. With desktop computers users enter input to the computers using a full sized keyboard. When using full sized keyboards writing tasks can be easily accomplished. However writing a lot of text
on a mobile device can be quite time consuming and can distract from the users’ experience.

Numeric keypads common on mobile devices that serve as basic cell phones. These keypads are comprised of digit keys, 0-9, along with a few function keys such as “send” and “end.” The alphabetic characters, A-Z, are divided into groups of three and share keys with the digits. For example, the key for the number 1 can also be used to enter the letters a, b, and c. To determine which character is used, the user must press the key multiple times to scroll through the available character options.

On QWERTY keyboards, each letter of the alphabet, A-Z, has its own key. The digits 0-9 have their own keys or share those of some of the alphabet characters. These keyboards are more similar to full-sized keyboards than numeric keyboards are. However, the scale of mobile devices makes QWERTY keyboards a bit cumbersome to use.

Touch screens enable users to input characters by pressing the screen using a stylus or finger. Graffiti input enable users to write directly on the screen with a stylus and have their characters interpreted by the device. Another option available on touch screens are virtual keyboards which perform similar to full sized keyboard except that users have to enter one character at a time using the stylus.

4.2.1.3: Common Intelligent Tutoring System Interfaces

A survey of desktop-sized tutor show that interface styles including tabs, menus, and lists are combined to create interfaces to facilitate student problem solving [67]. Desktop-sized tutor interfaces enable students to read problems, view information, or
complete tables as shown in Figures 4.2 and 4.3. In desktop-sized tutors, users often enter labels for charts, graphs, and other information to aid in the problem solving process as shown in Figure 4.4. Some tutors even allow students to enter relevant formulas using alpha, numeric, and special keys shown in Figure 4.4.

![Figure 4.2 Menus on the interface from Active Math]
Figure 4.3 Tabs on the interface from Algebra 1 Cognitive Tutor

Figure 4.4 Andes Physics Tutor Interface
4.2.1.4: Mobile Intelligent Tutoring System Interface Design

The design of the mobile ITSs interface is based on the mobile human computer interaction principles of providing users with just-in-time information and information that is easily accessed. The mobile ITS interface guidelines in section 3.7.1 derived from the PMET study are utilized in the design of the mobile ITS as described in the remainder of this section. The interface uses a hierarchical method of presenting information to the users in which the tutor’s screens are organized in a tree-like fashion, grouping natural problem solving steps together on one screen thereby allowing users to answer questions in a sequenced fashion as shown in Figures 4.5-4.7. As they answer a sub-question, the relevant information is carried forward to subsequent screens. For example, once users correctly identify the correct formula to use they are shown the formula on subsequent screens. At any given time users are able to view the information that they need at that step on one screen thereby eliminating the need for tabs, menus, or navigation.
Figure 4.5 First Tutor Interface Screen

Figure 4.6 Second Tutor Interface Screen
The mobile tutor interface was designed to reduce the amount of input required by users in an effort to minimize the number of mechanical keystrokes needed to answer each question, i.e. the Interaction principle of Navigation described in section 3.7.1. To support this goal, table labels, representing variable names, are provided to minimize the amount of text entry required. Text entry is further reduced by requiring students to enter final values rather than formulas, which typically include a combination of numeric and alphanumeric characters and symbols, that require additional keystrokes and thus take additional time. The use of radio buttons allows users to quickly select and answer questions with one single press of the screen.
4.2.2: Mobile Intelligent Tutoring System Activity

The term “activity” as used in this dissertation describes the problems users solve when interacting with the intelligent tutoring system. In an effort to use the desktop-sized tutor as the basis for the mobile tutor, the activity portion was evaluated and modified using the Context guidelines presented in section 3.7.1. Traditionally users interact with the tutor to solve long complex word problems that require learners to complete multiple steps and utilize multiple representations. In Cognitive Tutors the student’s problems are designed to support tutor use for 20 – 40 minutes about 2 - 3 days a week [36, 68]. Often, supplemental applications are built-in, e.g., a glossary of terms, to assist students.

In an effort to design the mobile intelligent tutoring system to be more than a miniaturized desktop tutor, mobile tutor’s problems present students with short tasks, i.e. questions that can be completed in fewer than 5 minutes. In keeping with the interaction guidelines from section 3.7.1, the problems were also structured to minimize the amount of user input and navigation required to solve the tutor’s problems.

4.2.2.1: Which teaching strategy to implement?

The design of the mobile tutor’s teaching strategy is predicated on the hypothesis that students in the chosen domains tend to make errors in the initial problem solving stages of selecting formulas and identifying variables and not the later stage of calculating the final answer. In this instance, traditional desktop ITSs would provide tutoring support in each of these stages and include feedback on the sub-steps of the problem solving process. For example, interest rates, shown as percentages, require conversion to decimal format for use in formulas. Traditional tutors would provide
students with explicit support and feedback on methods of dividing numbers by 100 to derive a decimal value (e.g. 0.069) from a given percent value (e.g. 6.9%).

The mobile tutor’s teaching strategy provides students’ with reminders to perform the conversion yet does not explicitly instruct students on how to do the conversion. The difference in teaching strategies described above is depicted in Figure 4.8. The space in between the horizontal cuts imposed in the tree indicates the area in which the mobile ITS does not provide explicit support and the desktop ITS would.

![Figure 4.8 Tree Cut to Shorten Problems](image)

Figure 4.8 Tree Cut to Shorten Problems
4.2.2.2: Mobile Intelligent Tutoring System Teaching Strategy Design

In addition to changes in the overall teaching strategy of the mobile ITS, the tutor also provides two types of levels of tutoring support, long and short. In the short problems, students receive tutoring in the initial stages of the problem solving process; selecting the correct formula and identifying variable values. Upon correctly identifying the appropriate variable values, students do not have to actually solve the equation and compute the final answer. In this instance, students are shown the final answer and do not have to calculate it. However, in the long problems, the equation and variable tutoring support is the same as in the short strategy however, the students are required to solve the equation and input the final answer. In this strategy, long, the tutor provides feedback on their final answers. The difference between the short and long problems is depicted in the sequence of mobile ITS interfaces of Figure 4.9.

Although different from each other, these two strategies are an adaptation of desktop tutoring strategies in an effort to create a lightweight ITS, with respect to the interface and interaction, without sacrificing efficacy. The goal of the long strategy is to decrease the amount of time and interaction required to solve each problem. The reduction in problem solving time supports mobile delivery by using the context guidelines from section 3.7.1 while providing feedback on final calculations. By comparison, the short strategy seeks to further reduce the amount of time required for problem solving by allowing the tutor to complete the calculation step that learners, in this target population, do not have trouble with, per the context guideline regarding knowledge of the user. The hypothesis that users do not have trouble completing
mathematical calculations is evaluated in the subsequent feasibility study presented in Chapter 5.

Figure 4.9 Long Vs. Short Problems.
4.2.3: Mobile Intelligent Tutoring System Architecture

The tutoring system described in this dissertation makes use of the delivery system currently serving the Pittsburgh Science of Learning Center’s (PSLC) Learn Lab. To host an ITS on the PSLC’s servers a suite of files are configured to coordinate communication between the Flash interfaces, behavior graphs, event logging and data log storage. The resulting configuration of files is referred to as a curriculum.

Once the curriculum is complete, classes are set up using the Cognitive Tutor Teachers Toolkit application. The Teachers Toolkit allows researchers to correlate individual students with the set up curriculum. Because of this correlation, each student is able to access the tutor online via a URL that is unique to each student. The mobile intelligent tutoring systems described in this thesis were delivered via the Internet and hosted on the PSLC servers as described above. Event data logs capture all of the student interactions with the tutor. The PSLC provides a Data Shop that provides an interface for data analysis that visually displays user data anonymously [86].

As it currently exists the ITS architecture required minimal modifications to support the mobile device used in this research. This is due largely to the selection of a Window’s Mobile Device and the selection of the Internet Explorer’s Mobile Edition as a web browser. For compatibility with Internet Explorer’s Mobile Edition the html pages that embed the tutors required the removal of parameters that could not be processed by the browser.
5: Mobile Intelligent Tutoring System Feasibility Studies

A field study was conducted to understand if the designed mobile intelligent tutoring system could be accessed and used by students enrolled in a course. A goal of this study was to gather data to support the hypothesis that students have difficulty in the equation and variable stages and require less support in the calculation stage. Another goal of this study was to seek an answer to the following research question:

- **RQ1** How might the design of an intelligent tutoring system be adapted for delivery on a mobile device?

The research presented in this dissertation was motivated in part by the desire to create educational technology that can be used by students in their classrooms. This study was designed to evaluate the overall design of the mobile ITS and the feasibility of employing the tutor as part of a course. Homework, as an instructional practice, is the medium for evaluating the feasibility of the tutor. In many instances teachers are do not grade students’ homework and provide feedback on their errors; for example, in the Drexel University course, Math 101, on which this study is based (described shortly), the instructors do not grade homework. The use of a tutor in this scenario provides students with assistance while they complete assignments. This use of a tutor as homework has been explored for desktop systems [87] but not for mobile systems that can provide the ability to complete homework when students are not able to reach their desktop system.
Mobile tutors also allow for easier lending of equipment to students for portable use outside the classroom.

The Math 101 course textbook sections on Simple Interest and Compound Interest were the source of the tutor questions. The Compound Interest and Simple Interest tutor questions were divided into two types, short and long, as described in section 4.2.2.2. The short questions do not require students to calculate a final answer. The long questions do require a final solution to the problem to be input. Although emphasis is on the conceptual understanding of the problems, the long-answer questions are included to provide students an opportunity to calculate answers as required on their quizzes and exams. On the other hand, the short answer questions are included to decrease the amount of time it takes students to solve a problem.

5.1: Participants

Student participants were from Drexel University’s Math 101 course in the 2008-2009 Fall Quarter. The students were in three different course sections taught by one instructor. Fifty three students consented to participate. Due to attrition, the study concluded with data from 22 students, including 13 students in the experimental group and nine in the control group. Prior to beginning the study, Institutional Review Board (IRB) approval was obtained. The students were at least 18 years of age. They were from a variety of majors including Business and Sports Management and all were undergraduate students.
5.2: Materials

All students in the study were enrolled in the Math 101 course and either owned or had access to the course textbook, *Finite Mathematics and Applied Calculus* [88]. Students in the experimental group received, for the duration of the study, a Hewlett-Packard iPAQ 111 PDA to access the mobile tutor. The PDA executes the Window’s Mobile 5.5 operating system and measures 4.5 x 2.8 x 0.5 inches with a 240x320 pixel screen. Students in the control group received a packet of paper with each question pre-printed and space in which to write the problem solutions.

5.3: Data Sources

To determine a baseline of student knowledge and problem solving skills, students took a pre-test consisting of questions from the textbook that were not assigned for homework. All students in the course completed weekly quizzes as part of the normal course curriculum. These quizzes served as post-tests to show that the instruments used in this experiment to measure student gains are the same as those that students would typically encounter.

In addition to the pre- and post-tests, students completed a survey. The survey was designed to provide qualitative data about several areas of interest. The first area concerns the ownership and use of desktop computers, laptop computers, PDAs, and cell (or smart) phones. The second asks for a self-report of where students completed their homework, either on the PDA or on paper. The third set of questions inquires about the mobility of students. The survey also contains questions regarding student commutes and the types of activities they engage in during their commutes.
5.4: The Feasibility Study Tutor

Four tutors were developed for the Simple Interest, Compound Interest, Annuity, and Amortization topics covered in the Math 101 course. Though ultimately two mobile intelligent tutoring systems were tested in the field study: Simple Interest and Compound Interest. The questions in the tutor were modeled after the actual homework problems that students are expected to complete on a weekly basis as part of the normal course requirements. The feedback and hints were developed with one course instructor and a mathematics researcher to be comparable to the support a student would receive from a human tutor.

The Simple Interest tutor consisted of 12 questions providing students with an opportunity to practice solving questions utilizing three different formulas. The Simple Interest formula, \( I = Prt \), is used to find the amount of simple interest due on a loan. The Amount Due formula, \( A = P(1 + rt) \), is used to find the future amount due on a simple interest loan. The effective simple interest rate \( r_s = r/(1-rt) \), is used to find the rate charged when the lender deducts the amount of simple interest from the principal borrowed. These three formulas are taught to students together in the course and assigned as a unit for homework. The Compound Interest tutor consisted of 14 questions based on three formulas: the Compound Interest formula, \( A=P(1+r/m)^{mt} \), the Effective Rate of Return formula, \( A=P(1+r_e)^t \), and the Effective Rate of Interest formula, \( r_e=(1+r/m)^{m·t} - 1 \).

For each of the topics the questions were divided into long-tutoring and short-tutoring strategy questions. Both teaching strategies were implemented to provide students with problems that could be quickly answered, short, as well as provide them
with feedback on final answers, long. As part of their normal course work, including quizzes and exams, students routinely solve problems to completion and we did not want to put tutored students at a disadvantage by not providing them with an opportunity practice solving problems to completion.

5.5: Procedure

Prior to the start of the study, students enrolled in Math 101 were informed of the study and provided with an opportunity to participate. The students providing consent to participate in the study were randomly placed in one of two groups, experimental and control. Students in the experimental group used the mobile intelligent tutoring system to solve their homework problems. Students in the control group solved homework problems using traditional methods, i.e., paper and pencil with the textbook.

For the duration of the study, the mobile intelligent tutoring system questions replaced the assigned homework. Students in the experimental group used the tutors for one week to complete the assigned homework for the Simple Interest and Compound Interest topics. Students in the experimental group received a demonstration on how to use the PDA and the tutor itself and how to access the tutor using a wireless Internet connection. Students in the control group learned how to complete the paper packets.

As students completed questions using the tutor, their interactions were logged and stored on servers hosted by the Pittsburgh Science of Learning. All keystrokes and textual input is recorded by the tutor delivery service described in section 4.2.3. Although we are unable to independently determine location of the users when they are using the tutor, the tutoring service logging feature does provide time stamps for each recorded
action. The logged records detail the date and time of when students request help, receive feedback, and the specific answers and text input into the tutor.

The control group’s packet consisted of one sheet for each of the assigned homework problems. In addition to the question, there the sheet contained a space for the student to record their location and time when solving the problems. Students were provided with one packet for each topic of the study. At the conclusion of the study, all 22 students took the post-test administered during one of their class periods.

5.6: Results

Because this study was conducted during a university course, the participants could not be compensated for their participation, i.e., no payment or extra credit points. Therefore, although 22 students participated in the study, only three of the nine students in the experimental group completed at least half of the intelligent tutoring system’s problems in the Simple and Compound Interest topics. The lack of compensation coupled with the optional nature of the assigned homework likely contributed to the high attrition rate. Unfortunately, because of the low number of students, statistical analysis, including comparisons with the 13 students in the control group, was not possible. However, we can still examine the feasibility of using a mobile intelligent tutoring system as part of a course by examining the qualitative aspects of the tutoring system and learn from the experience to further enhance tutor design and efficacy. The following analysis used the student-tutor interaction data from the nine students in the experimental group.

The pre-tests and post-tests from the 22 student participants were used to determine the correctness of the hypothesis that students commit the majority of errors in
the equation and calculation stages rather than in the calculation stage of the problem solving process. For example, selecting the incorrect formula would be an equation stage error, whereas mathematical errors committed while solving an equation were classified as a calculation stage error. In this analysis each of the problem solving stages were scored independently. As a result, a student would receive credit for correctly solving an equation although they utilized incorrect variable values in doing so. While this method of scoring is different from that of the course instructor it does allow the calculation stage to be analyzed independent of the previous two stages.

Table 5.1 shows that on the pre-test 68 percent of the equations were identified correctly, by the 22 students, and 83 percent of the equations were correctly solved. While students on the post-test gained nine and ten percentage points on the equation and calculation stage, respectively, they experienced a slight decrease in mean score in the variable stage. This result supports the teaching strategy design decision to support students on three stages of problem solving, i.e. equation, variable, and calculation, described in section 4.2.2.1, and not tutor the explicit mathematical calculation steps because students experienced the greatest difficulty in completing the equation and variable stages of the problem solving process.
Table 5.1 Identification of Student Errors

<table>
<thead>
<tr>
<th>Stage</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation</td>
<td>68%</td>
<td>77%</td>
</tr>
<tr>
<td>Variable</td>
<td>77%</td>
<td>74%</td>
</tr>
<tr>
<td>Calculation</td>
<td>83%</td>
<td>93%</td>
</tr>
</tbody>
</table>

In total 66 event logs were recorded from the interactions of the nine students using the mobile intelligent tutoring system on the PDA. The most surprising result was evident during the analysis of the time of day in which students answered questions. More than half (56 percent) of the questions were answered when human tutors would not have been available (i.e., outside the Drexel Math Department tutoring office’s normal hours of operation, 10am to 6pm) as shown in Figure 5.1. This usage data provides evidence of the need for a mobile intelligent tutoring system that can be accessed by students when they have the greatest need rather than during specific office or tutoring service hours.
Each of the mobile ITS questions required students to indicate their location when they answered that specific question. Students were asked to select from a list of locations including home, work, a friend’s place, cafeteria, library, and other. The choices are a subset of locations where adult learners have been known to complete out of class assignments [61]. Among the nine student entering location data there were 86 locations identified. In this study, 61 percent of the questions were answered in the campus library, at work, or at home. This distribution is consistent with adult learners for whom 51 percent of learning took place either at home or in the workplace [61]. Although consistent, the distribution shown in Figure 5.2 differs from that of adult learners primarily because the majority of study participants were students who were not likely to be employed at the same rates as adult learners. The 62 percent of questions answered while students were not home supports the mobility affordance of the mobile ITS by
demonstrating that students solve problems from multiple locations, including those in which access to computers is not guaranteed.

![Locations Where Tutor Is Used](image)

**Figure 5.2 Locations Where Tutor Is Used**

### 5.7: Discussion

The mobile intelligent tutoring system presented in this dissertation represents a shift in traditional tutor design and implementation to support mobile device delivery. Pre-test and post-test data supported the hypothesis that student make a greater percentage of errors in the initial stages of identifying correct formulas and variables rather than in performing calculations. The data revealed that students were able to solve equations correctly however, the equations themselves were more likely to be incorrect and comprised of either an incorrect formula or incorrect variable values.

Data gathered during the field evaluation of the mobile ITS revealed that the tutor could provide instructional support to students outside of the classroom instruction time
and when a human tutor or instructor would not normally be available. However, our results raise some issues that will require future investigations for mobile ITS research. Although 56 percent of the questions were answered on campus in either the library or campus housing, students reported difficulty in either establishing or maintaining a Wi-Fi connection to the Internet and tutor despite the presence of a campus-wide wireless network. These connectivity problems required students to make multiple attempts to complete questions and prolonged the amount time spent completing homework assignments thus sabotaging the goal of completing questions in 2 or 3 minutes. However, it is worth noting that during development, implementation, and testing of the mobile tutors no connectivity issues were exhibited using non-campus wireless networks. Thus, it is assumed that the connection issues experienced during the study can be attributed to the on-campus wireless network rather than the tutors themselves. This environmental constraint may limit the use-anywhere nature of the mobile tutor though it is expected that as technology advances that wireless networks will provide more reliable support to mobile devices.

When integrated fully into courses, instructors and ITS developers must factor in connectivity issues that may arise and determine whom—the student or instructor—is ultimately responsible for overcoming the issues and how these issues may affect student performance. Therefore, future architectural research of mobile delivery of ITSs should include research on the feasibility of a standalone option or event caching to minimize the reliance on wireless communications.
6: Mobile Intelligent Tutoring System Laboratory Study

The feasibility study produced results that supported the hypothesis that students commit errors primarily in the early stages of the problem solving process rather than while performing the calculations to solve correct equations. User interactions in the field showed that a mobile intelligent tutoring system is able to provide support to students outside of the classroom at times when it is convenient to them and an instructor or human tutor may be unavailable. The goal of this study is to gather data to understand the efficacy of the mobile ITS and evaluate the teaching strategies implemented. The research questions addressed in this study include:

- RQ2 - Can a mobile intelligent tutoring system provide learning gains greater than standard instructional activities?
- RQ3 - Which teaching strategy best supports a mobile intelligent tutoring system?

The experiment described here was conducted to understand whether students using the tutor experience learning gains greater than their non-tutored peers do. The long and short-tutoring strategies were evaluated to understand the potential differences in learning that arises from each of these strategies.

In addition to comparing the performance of students using the mobile ITS to those who did not, this experiment was also designed to provide data in support of the following hypothesis:
• Students in both tutoring conditions will experience gains greater than those in the control group \((g_{ctl})\). However, students who are tasked with completing the entire problem solving process (long-tutoring condition) will achieve gains \((g_{ltc})\) greater than those who experience an abbreviated problem solving process and are shown the answer to the final calculation (short-tutoring condition) \((g_{stc})\), i.e. \(g_{ltc} < g_{stc} < g_{ctl}\).

• Students in the short-tutoring condition will answer the problems in a significantly shorter amount of time \((t_{stc})\) than the students in the long-tutoring condition \((t_{ltc})\), i.e. \(t_{stc} < t_{ltc}\).

Based on the above hypotheses we further hypothesize that students in the short-tutoring condition will achieve slightly fewer gains but will be able to answer the questions in a significantly shorter amount of time. In this instance, the shorter duration of the tutoring sessions compensates for the slightly diminished gains.

### 6.1: Participants

For this study, students from the Drexel University community were recruited using fliers placed in campus buildings and via email solicitation. The Psychology Department’s online research participation system, Sona, was as an additional method of advertising the study. Forty-nine students signed up to participate. Twenty-six of the students had previously taken Math 101 while 23 had not. Prior to the study Institutional Review Board (IRB) approval was obtained. The students were at least 18 years of age.
They were from a variety of majors including Psychology, Nursing, Engineering, and Business Administration.

The study used a 2x3 design to evenly distribute students who had previously taken Math 101, as shown in Table 6.1. Data gathered from the feasibility study, presented in Chapter 5, suggests that students had not mastered the tutored material on the post-test and could still benefit from tutoring on the Simple and Compound Interest topics. Table 6.2 shows that after receiving classroom instruction on the 11 out of 22 students were unable to correctly identify all of the Simple Interest and Compound Interest formulas and 21 of the 22 were unable to correctly identify all of the variables and perform the subsequent final calculations correctly. Therefore, students who had previously taken the Math 101 course were included in the study to examine the tutor’s ability to support novices as well as those with previous exposure to the course.

<table>
<thead>
<tr>
<th>Table 6.1 Distributions of Study Participants</th>
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</tr>
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<td>-------------------------</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Study Totals</td>
</tr>
</tbody>
</table>
Table 6.2 Identification of Student Errors

<table>
<thead>
<tr>
<th>Stage</th>
<th>Pre-test</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation</td>
<td>54.5%</td>
<td>50%</td>
</tr>
<tr>
<td>Variable</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Calculation</td>
<td>95%</td>
<td>95%</td>
</tr>
</tbody>
</table>

6.2: Materials

Students in the experimental groups used a Hewlett-Packard iPAQ 111 PDA. The PDA executes the Window’s Mobile 5.5 operating system and measures 4.5 x 2.8 x 0.5 inches with a 240 x 320 pixel screen. Students in the control group received a packet of paper with each question and space in which to fill in the solution.

In the feasibility study tutor (Chapter 5), the two teaching strategies, long and short, were merged together. The laboratory study was designed to isolate the effects of the tutoring strategies resulting in two versions of the tutor, long and short. The long-tutoring strategy required students to input calculated values for each problem, whereas the short-tutoring strategy did not. In each experimental condition, long, short, and control, students answered five questions on the topic of Simple Interest and five on the topic of Compound Interest, as described in section 5.4. The questions in the tutor were modeled after problems in the Math 101 textbook, *Finite Mathematics and Applied Calculus* [88]. The feedback and hints, developed with one course instructor and a
mathematics researcher, were comparable to the support a student would receive from a human tutor.

6.3: Data Sources

The data used in the study were collected from the sources described in section 5.3. The tutor was delivered using the Cognitive Tutor architecture described in section 4.2.3.

6.4: Procedure

The students were randomly placed in one of three conditions: the long-tutoring condition, the short-tutoring condition, and a control condition. The long-tutoring condition group was comprised of those who used the mobile intelligent tutoring system with the long-tutoring strategy that required students to derive and fill in final answers to the problems. The short-tutoring condition group was comprised of those who used the mobile intelligent tutoring system with the short-tutoring strategy that did not require students to produce final answers. The control group was comprised of students who solved the problems using paper and pencil. Calculators were available for students if they requested one.

Each student participated in a 90-minute session conducted in a research lab at Drexel University. Each was given a brief introduction to explain the study procedure and to ensure his or her willingness to participate. Following the introduction, students were given a pre-test consisting of three questions. During the pre-test all students were provided with a sheet of formulas, scrap paper, and a scientific calculator. Students were
instructed to finish the test in approximately 10 minutes but were allowed to take as long as needed to finish.

 Upon completion of the pre-test, students were provided 20 minutes of lecture-style instruction on the Simple and Compound Interest topics. This session provided students with explanations of applicable formulas and worked examples of each. The session notes were derived directly from the notes of a Math 101 classroom instructor.

 After the lesson, the control group received packets containing 10 pre-printed questions, one on each page. These questions are the same as the questions presented to users of the tutoring system. The long-tutoring condition group was given a PDA with the long-condition mobile ITS, and the short-tutoring condition group a PDA with the short-condition mobile ITS. A calculator and scratch paper was made available to students at their request. Students in the tutoring groups were given a demonstration of how to use the PDA and the tutor itself. Students in the control group were instructed on how to complete the paper packets. After each student completed the questions on the mobile ITS or on paper, they were given the post-test to complete. Just as for the pre-test, students were provided with a formula sheet and calculator during the post-test. Upon completing the post-test the students completed a short survey.

 **6.5: Results**

 Using the following criteria, which correspond to the first, second, and third stages of problem solving, each question was evaluated:

 1) **Equation:** Is the correct equation/formula used? (one point per question)
2) **Variables**: Are the relevant variables identified, including the variable to be solved for? (14 total points on the pre-test and 13 on the post-test)

3) **Calculation**: Is the final answer calculated correctly? (one point per question)

For the analysis, the problem-solving process was categorized in three stages, Equation, Variable, and Calculation as shown in Figure 6.1. The long teaching strategy tutor provides tutoring and feedback on the three problem solving stages, equation identification, variable identification, and calculation. This condition is most similar to the paper-and-pencil control condition in that students have to solve the equations and derive a final answer. The short teaching strategy tutor provides tutoring and feedback on the first two stages, equation identification and variable identification, and does not require users to solve the equation to derive a final answer.
A repeated measures analysis of variance (ANOVA) was conducted to evaluate overall student performance. The within-subjects variables were pre-post (pre-test versus post-test) and stage of the problem solving process (equation, variable, or calculation). The between-subject factors were treatment condition (long, short, or control), and whether or not students had previously taken Math 101 (had101).

A significant main effect was found for pre-post ($F_{(1,43)}=5.272$, $p<.05$), meaning that students’ scores increased significantly between the pre-test ($M=52.22$) and the post-test ($M=61.77$). The main effect for stage was also significant ($F_{(2,42)}=113$, $p<.01$) and is shown in Figure 6.2. The interaction between stage and had101, shown in Figure 6.3, was moderately significantly ($F_{(2,43)}=2.540$, $p<.1$) indicating that whether or not a student had prior exposure to the tutored material had a differential effect on test scores. The
interaction between pre-post and stage was moderately significant ($F_{(2,43)} = 8.495, p<.1$) indicating that student gains from pre-test to post-test varied according to the problem-solving stage, as shown in Figure 6.4. The main effect of condition was moderately significant ($F_{(2,43)}=2.779, p<.1$). All other effects and interactions were not significant ($p>.10$).

![Figure 6.2 Effect of Stage](image-url)
Figure 6.3 Interaction Between Stage and Had 101

Figure 6.4 Interaction Between Stage, Pretest, and Posttest Scores
The graph in Figure 6.5 depicts the gains from pre-test to post-test (i.e., the change in score) by condition and stage. The gain scores are representative of the repeated measures (pre- to post-test score differences) where the stage clusters highlight the main effect of stage. The between-subjects effect is depicted by the different shades of bars within each cluster. Figure 6.6 depicts the pre-test scores and Figure 6.7 depicts the post-test scores. We examine and discuss these effects in more detail in the sections that follow.

![Gain Scores By Stage and Condition](image)

**Figure 6.5 Gain Scores By Stage and Condition**
Figure 6.6 Pre-test Scores By Stage and Condition

Figure 6.7 Post-test Scores By Stage and Condition
Event data logs were analyzed to compare the amounts of time students spent during each of the tutoring sessions. The comparison was conducted using time stamps from students in the short-tutoring and long-tutoring conditions. Student data from the control condition was not included in this analysis because the students were not timed while answering the questions. Table 6.3 shows the amount of time students spent using the tutors in each condition. An independent t-test revealed no significant differences between the access times between the tutoring conditions, long vs. short.

<table>
<thead>
<tr>
<th></th>
<th>Average Time Of Tutoring Per Session (min:sec)</th>
<th>Average Time Of Tutoring Per Question (min:sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short-Tutoring Condition</td>
<td>Long-Tutoring Condition</td>
</tr>
<tr>
<td>Simple Interest</td>
<td>26:06</td>
<td>23:23</td>
</tr>
<tr>
<td></td>
<td>05:13</td>
<td>04:41</td>
</tr>
<tr>
<td>Compound Interest</td>
<td>24:48</td>
<td>26:16</td>
</tr>
<tr>
<td></td>
<td>04:58</td>
<td>05:15</td>
</tr>
</tbody>
</table>

6.5.1: Analysis by Stage

6.5.1.1: Equation Stage Analysis

A univariate analysis of covariance (ANCOVA) was conducted to further explore the main effect of stage found in the repeated measures ANOVA. The dependent variable was the equation post-test score. The fixed factor was the treatment condition, and the equation pre-test score was used as a covariate. (The use of pre-test scores as the covariate ensures that the post-test scores are an effect of the treatment condition and not
of student’s prior understanding of the tutored subjects [89].) The data revealed a significant between-subjects effect of condition for the equation post-test score ($F_{(3, 45)} = 18.253$, $p<.001$). A univariate ANOVA was conducted as an alternate method of comparing the equation stage pre-test-to-post-test gains. The dependent variable was the gain in equation score and the fixed factor was the treatment condition. A significant effect of condition was again found with this analysis ($F_{(3,46)}=5.296$, $p<.05$).

Data was analyzed with a paired t-test to compare the difference in scores between pre-test and post-test for the treatment conditions in the equation stage. The data revealed a significant effect for the long condition (pre-test $M=39.58$, post-test $M=72.91$) ($t_{(15)}=3.303$, $p < .05$), a moderately significant effect for the short condition (pre-test $M=60.78$, post-test $M=80.39$) ($t_{(15)}=1.829$, $p < .1$), and no effect was found for the control condition (pre-test $M=56.25$, post-test $M=68.75$).

6.5.1.2: Variable Stage

As in the equation stage, an ANCOVA was run with the dependent variable as the post-test score, the treatment condition as the fixed factor, and the variable pre-test score as the covariate [89]. The data revealed significant between-subjects effect for the variable post-test score ($F_{(3, 45)} = 12.816$ $p<.001$).

As in the equation stage, a univariate ANOVA was run with the variable gain as the dependent variable and treatment condition as the fixed factor. A significant between-subjects effect was found ($F_{(3,46)}=5.296$, $p<.05$) indicating that there is a significant difference between the gains achieved by condition. Follow-up tests were conducted to evaluate pair wise differences among the gains using a post-hoc test, Dunnett’s t-test. The
Dunnett’s t-test revealed a moderately significant difference (p<.1) between the gains of the long (M=17.41, SD=35.64) and control (M=0.96, SD=26.5) condition groups. The post-hoc pairwise comparisons revealed a moderately significant difference (p<.1) between the gains of the long (M=17.41, SD=35.64) and short (M=-1.55, SD=1.75) condition treatment groups. There was no significant difference between the gains of control and short groups.

A univariate ANOVA was conducted as a follow-up analysis to the repeated measures to evaluate the significant interaction effect between stage and had101. The dependant measure was the variable gain. The fixed factors were treatment condition and whether or not students had Math 101 (had101). In addition to the mildly significant between subjects effect for condition, previously discussed, an additional mildly significant between subjects effect was found for the interaction between condition and had101 (F(2,43)=2.516, p<.1). A follow-up pair wise comparison of variable gain means was conducted to evaluate the source of the differences. Figure 6.8 shows that the students in the long-tutoring condition without previous enrollment in Math 101 (M=33.65, SD=34.81) had greater gains than those with previous Math 101 enrollment (M=1.165, SD=30.12). In all other analysis, by either stage or condition, there were no significant differences in pre- or post-test scores and gains between students with and without previous enrollment in Math 101.
The results from a paired sample t-test, similar to the one run in the equation stage, show a moderately significant effect for the long condition (pre-test M=51.33, post-test M=68.75) \(t(15)=1.954, p <.1\). There was no effect for the short and control conditions. Therefore, the data suggests that in the variable stage, the long-tutoring strategy had a mildly positive effect on student performance.

6.5.1.3: Calculation stage

As in the previous stages, an ANCOVA was run with the dependent variable as the post-test score, the treatment condition as the fixed factor, and the variable pre-test score as the covariate [89]. A significant between-subjects effect was found for the
calculation post-test score \( (F_{3, 45} = 4.482, p<.05) \). A univariate ANOVA and paired t-test, described in section 6.5.1.1, revealed no significant effects.

This lack of improvement across treatment conditions, long, short, and control, is most likely a residual effect of the previous two stages as correctly calculating the correct answer requires the correct identification of an equation and correct identification of variables. If students did not perform those two steps correctly they would be unable to derive the correct calculation. On the pre-test three students scored 100 percent on all of the stages while one student, out of 49, correctly identified the equation and variables yet calculated the incorrect answer. The remaining 45 students (91 percent) committed errors in the equation and/or variable stages. On the post-test four students scored 100 percent on all of the stages while the remaining 45 students committed an error in the equation and/or variable stages.

6.6: Discussion

This data from this study suggests that the tutoring strategy has an impact on student’s problem solving performance. Figure 6.9 shows that among the three treatment conditions, students in the long-tutoring condition achieved gains greater than those using the short-tutoring condition and control condition. Students using the long-tutoring strategy received tutoring on the equation and variable stages and had to calculate and receive feedback on the final answer. In contrast, students using the short-tutoring strategy received tutoring on the equation and variable stages without having to calculate the final and therefore not receive feedback on calculations. While students in the control condition did receive tutoring or feedback in any of the stages.
Currently, there is no clear understanding of the cause of the difference in outcomes between teaching strategies. The remainder of this section describes two plausible explanations that may account for results described in this chapter. Although each explanation described is grounded in ITS or learning science research further investigations are needed to fully understand the cause of the variance of learning gains achieved by the study participants. The plausible explanations are as follows:

- Students’ participating in this study have an existing fluency with writing as a mode of problem solving because they practice in class, in homework and on exams using paper-and-pencil [90]. There is evidence that suggests writing can offer benefits in mathematics learning [90, 91]. Therefore, it can be hypothesized that the writing fluency in problem solving using paper-and-pencil is better supported by the long-tutoring condition in which students have to write to solve
for the final answer than in the short-tutoring condition in which they do not. Although students in the control condition also write to derive the final answer, they did not perform as well as the students in the long-tutoring condition because they do not receive the benefits of the mobile intelligent tutoring system providing the individualized instruction. The results from this study may support the integration writing with ITSs to better support students’ transfer problem solving media from the computer to paper and pencil.

- It is also possible that the process of solving the equation provides student with a more complete picture of the problem solving process. Using this rationale, it is possible that performing the calculations helps students to better understand the outcomes of the decisions in the equation and variable stages. This result is surprising in that performance in the earlier stage of equation bears some relationship to performance in the later stage of calculation. This result also opens the door for future investigations into the residual effects of having the tutor perform steps that are assumed easy. It was originally assumed that students would have minimally smaller gains as a result of having the tutor perform the calculation, i.e. those in the short condition, step however the gains of the students in the short-tutoring condition were more than minimally smaller than the gains of students in the long-tutoring condition.

An interesting finding of this study is that pre- to post- test gains varied by stage of problem solving process. Across all of the treatment conditions gains were achieved in
the equation and variable stages with the equation stage gains being significant, Table 6.4. This finding may indicate that certain tasks are more or less appropriate for the mobile intelligent tutoring system.

With respect to the hypothesis, i.e. \( g_{ltc} < g_{stc} < g_{ctl} \) and \( (t_{stc}) < (t_{ltc}) \), it was discovered that although the long-tutoring condition participants did perform better than the short-tutoring condition participants there was no significant difference between the duration of the problem solving sessions. Although further investigations are required to fully understand this effect, the following are two plausible explanations:

- Participants using the tutors experienced connectivity difficulties, similar to those described in section 5.7 that equalized the amount of time required for each to complete the problem. While students in the long condition were required to calculate the final answer, thus taking additional time, students in the short condition may have experienced network latency effects in pressing the “Next” button required to view the final answer and complete the problem.

- It is also possible that the amount of time required to solve the actual equation was minimal considering that students knew the correct formula and variables. Therefore, a short period was required to perform the calculations using a calculator.
Table 6.4 t-test Results Showing Effects of Tutoring Conditions

<table>
<thead>
<tr>
<th>Equation</th>
<th>Variable</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long</td>
<td>**1</td>
<td>*2</td>
</tr>
<tr>
<td>Short</td>
<td>*2</td>
<td>n/a</td>
</tr>
<tr>
<td>Control</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

1 indicates significant effect, 2 indicated mildly significant effect
7: Conclusion

7.1: Discussion and Summary

This dissertation has described research and results related to the design, implementation, and testing of a complete and functional mobile intelligent tutoring system. The research was motivated by the presentation of the state of computing within education and a description of mobile learning. Theoretical foundations and principles in the areas of intelligent tutoring systems, mobile learning, and mobile human-computer interaction lay the foundation for the design of the mobile intelligent tutoring system.

The interface study provided information regarding user interactions with desktop-sized ITS interfaces. Although students visited the primary regions, problem and diagram, more frequently they spent approximately the same amount of time in the supplementary regions, hint and glossary, as they do in the primary regions. Prior to this study the tutor’s interface design included multiple screens requiring user to navigate between screens to solve the problems. However, because of this study the problem was divided into natural problem solving stages, i.e. equation, variable, and calculation. The final mobile ITS design displayed each of the problem solving stages on a single screen. This grouping was the basis for simplifying the mobile tutor’s interface and minimizes the navigation required to solve the problems. Besides informing the interface design, the data from study also provided the basis for general mobile ITS design principles.

Results from the feasibility study showed that students could utilize the mobile tutoring system as a homework tutor as part of an undergraduate mathematics course. Students in this study were able to access the mobile tutor from multiple locations and
throughout the day and night using wireless Internet connections. The time and location information reveal that students complete out of class assignments when it is most convenient to them and when assistance, from either a tutor or instructor, is likely to be unavailable. This result provides evidence that a mobile intelligent tutoring system can provide just in time support to students outside of the classroom. Results from this study also show that the mobile device delivery of the described ITS was successful. It is important to note that the students’ use of the mobile ITS was restricted to the availability of a wireless network. This restriction is related to the current state of technology, e.g. handheld technology and wireless connectivity, rather than the design of the tutor itself. However, given the realities of the expense, e.g. Digital Divide, and lack of widespread availability of wireless networks the designers of future mobile ITSs may consider support for standalone delivery or data caching.

The laboratory study extended the feasibility study to gather data on different tutoring strategies, long and short, and compare each to traditional instructional practices. In this study, the data revealed that students using the long-tutoring strategy tutor improved their ability to identify equations and variables as part of the problem solving process. Furthermore, this study reveals that the performance gains varied by problem solving process stage and may indicate that certain tasks are more or less appropriate for the mobile intelligent tutoring system. Another conclusion of this study was that the long-tutoring condition provided students with the most gains. The long teaching strategy is represents the best approach to design and implement the mobile intelligent tutoring system.
Analysis of the time on task data from this study shows that students, in the long and short, were able to solve problems in approximately four minutes. The short duration of the problem solving sessions suggests that students could make use of the mobile ITS during micro-breaks.

While the time on task from the laboratory study shows that this use of the mobile ITS is possible, there was no evidence of this usage pattern of users in the event logs from the feasibility study. However, the use of homework as the instructional practice for the tutor may have led participants in the feasibility study to use the mobile ITS in long sessions as they do when completing other types of homework.

7.2: Answers to Research Questions

In the introduction of this dissertation, three research questions were posed. Through the design, implementation, and evaluation of the mobile ITS each of these questions were answered. This section describes the answers to the three research questions.

7.2.1: RQ1- How might the design of an intelligent tutoring system be adapted for delivery on a mobile device?

The design of this mobile ITS was initially based on principles and theories from the Intelligent Tutoring System, Mobile Learning, and Mobile HCI disciplines. In addition to these disciplines, results from the Poor Man’s Eye Tracking Study, described in Chapter 3, contributed to the formulation of general principles for the design of mobile intelligent tutoring systems.
The design of the mobile ITS involved the modification of three aspects of desktop ITSs: interface, activity, and architecture. The changes in each of the areas were the catalyst for the creation of general mobile ITS guidelines.

The guidelines presented in section 3.7.2 are intended to serve as the foundation for future mobile ITS research. The guidelines are a result of the PMET study and situate existing m-learning and ITS principles in the context of mobile ITSs. The list is not exhaustive and could be expanded upon using data gathered during the design and evaluation of mobile ITSs for additional domains and contexts.

7.2.2: **RQ2- Can a mobile intelligent tutoring system provide learning gains greater than standard instructional activities?**

In the laboratory study gains of students using the mobile ITS are compared to the gains of those who used traditional instructional methods e.g. paper and pencil. Students using the tutoring condition did experience an increase in post-test performance greater than students that did not use the tutor. As a result, it can be concluded that a mobile ITS can provide learning gains greater than standard instruction.

7.2.3: **RQ3- Which teaching strategy best supports a mobile intelligent tutoring system?**

The long and short teaching strategies were developed as a means of adapting desktop ITSs to mobile device delivery. It was hypothesized that the short strategy would be the most suitable for the mobile platform by enabling students to solve problems in a significantly shorter period. This hypothesis was not supported by the time-on-task analysis in the laboratory study in which students answered the questions in the same
amount of time in the two conditions. The results of the laboratory study revealed that the long condition, in which students calculate the final answer, provided students with the greatest amount of tutoring support. Based on these results it can be concluded that the long tutoring strategy best supports mobile ITS delivery because it provides students with the greatest benefit without increasing problem solving time.

7.3: Future Work

There are several potential directions for future work in the area of mobile intelligent tutoring systems. They can be summarized in two ways: (1) technical investigations to support tutor deliver off the desktop and (2) identification of tasks that are easily facilitated by the mobile devices and are consistent with how users interact with mobile devices.

7.3.1: Technical Investigations

The mobile intelligent tutoring system presented in this dissertation is an extension of the Cognitive Tutor brand of intelligent tutoring systems. The Pittsburgh Science of Learning Center hosted the tutoring system on a server. The architecture of the delivery system was designed to support desktop intelligent tutoring systems. Cognitive Tutor Authoring Tools (CTAT) developed expressly for desktop sized Flash-based interfaces facilitated the tutor implementation. This dissertation presents methods of utilizing the pre-existing tools and architecture to implement and host a mobile intelligent tutoring system.
To improve upon this method, the interface design and implementation additional widgets can be added to the existing suite of CTAT interface components. Modifications to the CommShell were implemented to allow the primary client-server communications shell to scale to the smaller interface. While the tutor in this dissertation was created for one specific mobile device, similar modifications can be made to the CommShell, and other components, to scale to variety of mobile device interface sizes. The iPAQ used in this instance did not utilize features available on smartphones or cell phones such as text messaging, GPS, or other applications. It is foreseeable that the inclusion of these, and other, features unique to mobile devices can extend the work presented in this dissertation to enhance the mobile tutoring experience. Qualitative data from the student surveys indicated that the slow speed of the tutor delivery service as well as connectivity issues motivate the exploration of an architecture that can support a standalone mobile tutor.

7.3.2: Identification of Tasks

Results from the laboratory study highlight the differences in tasks that mobile tutoring systems can support. The differences in gain by stage of problem solving process suggest that there may be tasks that are more appropriate for the mobile platform. The use of writing in the long-tutoring condition can potentially be supported using the handwriting recognition capabilities of many mobile devices. In addition, location-aware capabilities provide new methods that can allow students to learn by using the inherent mobility of the mobile device. The use mobile devices to create ad-hoc networks, via IR or Bluetooth, can facilitate student collaboration with tutoring systems that had previously been hampered by the lack of portability of desktop computers. Qualitative
feedback from users indicates that the repetition of using the stylus on the small interface distracted from the experience of the tutor. The identification of tasks that work with the mobile device interaction, rather than trying to mimic desktop interactions will contribute to enhanced user experiences.

7.4: Final Remarks

While conducting the research in the implementation and testing of the mobile ITS 36 PDA’s were purchased and distributed to 74 students (14 in fall, 9 in winter, 51 in spring) for use and testing. This result would have been difficult to duplicate using desktop or laptop devices. The results obtained through the field and lab studies show that students can feasibly utilize the tutor in a real course as well as achieve gains. Therefore the proof-of-concept mobile intelligent tutoring system presented in this dissertation, along with the results, and demonstration of dissemination of mobile devices show that the mobile intelligent tutoring systems can provide learner’s support any time and any where.
8: List of References


9: Appendices

Appendix 1: Feasibility Study and Laboratory Study Pre-test Questions

Name______________________________________________ Date____________

1. Find the simple interest on $1500 at 7% for 10 years.

2. Find the amount due on $7500 at 6.5% for 8 years 6 months if the interest is compounded annually.

3. How much would your parents have needed to set aside 16 years ago at 6.7% compounded semiannually to give you $60,000 for college expenses today?
Appendix 2: Feasibility Study and Laboratory Study Post-test Questions

Name_________________________________________ Date________

1. Find the principal of a loan at 7.6% if the simple interest after 9 years 3 months is $2109.

2. Calculate the present value of $9500 after 4 years 6 months at 8.4% if the interest is compounded quarterly.

3. Find the effective rate of a $10,000 zero coupon bond maturing in 12 years and selling now for $6,400.
Appendix 3: Feasibility Study and Laboratory Study Formula Sheets

\[ A = P \ (1+ rt) \]

\[ I = Prt \]

\[ FV = PMT \ \frac{(1+i)^n - 1}{i} \]

\[ PV = PMT \ \frac{1 - (1+i)^n}{i} \]

\[ A = P \ \left(1 + \frac{r}{m}\right)^{mt} \]
Appendix 4: Mobile Intelligent Tutoring System Participant Survey

Name __________________________

1) Do you own a desktop computer? ………………………… Y ☐ N ☐
2) Do you own a laptop computer? ……………………. Y ☐ N ☐
3) Do you own a handheld computer (PDA)……… Y ☐ N ☐
4) Do you own a cell phone? …………………………. Y ☐ N ☐
   a. If yes, do you have access to the Internet on your phone? Y ☐ N ☐
5) Do you use your computer for homework?……………… Y ☐ N ☐
6) Have you ever completed homework on a computer?…. Y ☐ N ☐
   On a PDA? Y ☐ N ☐
   On a cell phone? …… Y ☐ N ☐
7) Where do you complete homework for all classes? (Select as many as applicable)
   Home/dorm room ……… ☐ Public transportation……… ☐
   At friends place………… ☐ At work…………………… ☐
   In the library …………… ☐ Other (please indicate location)____________
8) Do you do homework daily?..................... Y ☐ N ☐
9) Do you do homework in one session?....... Y ☐ N ☐
10) What is your major? ______________________________
11) Do you live on campus?………………………………… Y ☐ N ☐
    a. If not, do you have access to wireless internet?…… Y ☐ N ☐
12) Do you commute to campus?………………………..Y ☐ N ☐
    a. If so, how long does it take?……………………… (hours/min)
    b. What mode of transportation to you use?…..
    c. Do you do homework during your commute?___________
    d. Did you do homework for this class on your commute? Y ☐ N ☐
13) What was your math SAT score? ________ verbal SAT score______
14) Have you previously taken Math 101?….. Y ☐ N ☐ If so, what grade did you receive?___
15) Did you take part in any summer math courses? ______________

16) Did you receive human tutoring or assistance with the course material during this study? Y □ N □
   a. If yes, from who? ___________________ (Drexel Learning Center, Course Instructor, etc.)
   b. What subjects were tutored? ______________________
   c. How much tutoring did you receive? ______ sessions _____ hrs/min
   d. Did the human tutor help you in ways the PDA tutor did not? Y □ N □ If yes, please explain. ________________________________
                                                                   ________________________________
                                                                   ________________________________
                                                                   ________________________________
                                                                   ________________________________
                                                                   ________________________________

17) Is there anything else you want to add about your experience or the use of the PDA tutor? (Answer on back if necessary)
Appendix 5:  Mobile Intelligent Tutoring System Screens

Figure 9.1 Example Equation Stage Screen
Figure 9.2 Example Variable Stage Screen

Figure 9.3 Example Calculation Stage Screen
The questions listed below were implemented as mobile intelligent tutoring questions using a sequence of interfaces, Equation, Variable, Calculation, similar to those in Figures 9.1-9.3.
Appendix 6: Feasibility Study Simple Interest Tutor Questions

1. Find the simple interest on $6000 at 6.5% for 8 years?
2. Find the simple interest on $825 at 6.58% for 5 years and 6 months?
3. Find the simple interest on $1280 at 4.8% for 3 months?
4. Find the interest rate on a loan charging $704 simple interest on a principal of $2750 after 4 years?
5. Find the principal of a loan at 8.4% if the simple interest after 5 years 6 months is $1155?
6. How much should be invested now at 5.2% simple interest if $8670 is needed in 3 years?
7. Find the term of a loan of $175 at 9% if the simple interest is $63?
8. What is the fair market price of a $5000 zero coupon bond due in 2 years if today’s long term simple interest rate is 3.54%?
9. What should be the term for a loan of $6500 at 7.3% simple interest if the lender wants to receive $9347 when the loan is paid off?
10. The doubling time of an investment is the number of years it takes for the value to double. This is the same as the number of years for the value to increase by 100%. What is the doubling time of a 5% simple interest investment?
11. What is the effective simple interest rate of a discounted loan at 4.6% interest for 3 years 6 months?

12. A firm charges 10% commission on the first $20,000 plus 5% of the excess over $20,000 for each buy and sell transaction. Find the simple interest rate earned including the commissions paid. Purchase 900 shares at $18.50 per share and sell them 4 months later at $26.75 per share.
Appendix 7: Feasibility Study Compound Interest Tutor Questions

1. What is the amount due on a $15,000 loan at 8% for 10 years if interest is compounded a) annually, b) quarterly?

2. What is the amount due on a $12,000 loan at 7.5% for 4 years 6 months if interest is compounded a) semiannually, b) monthly?

3. Calculate the present value of a $25,000 after 7 years at 12% if the interest is compounded a) annually, b) quarterly.

4. Calculate the present value of a $11,500 loan after 4 years 3 months at 8.4% if the interest is compounded a) semiannually, b) monthly?

5. Find the term of a loan that has 8.2% compounded quarterly to obtain $8400 from a principal of $2000?

6. Find the term of a loan that has 8.5% compounded monthly to increase the principal by 65%?

7. Use the “rule of 72” to estimate the doubling time (in years) for 9% compounded annually then calculate it exactly.

8. Use the “rule of 72” to estimate the doubling time (in years) for 6.1% compounded annually then calculate it exactly.

9. Find the effective rate of 18% compounded monthly [Note: This is a typical credit card interest rate, often stated at 1.5% per month].
10. Find the effective rate of 8.57% compounded semiannually?

11. In the mid-1990’s, a bond fund returned 10.43% compounded monthly. How much would a $5000 investment have been worth after 3 years?

12. How much would your parents have needed to set aside 17 years ago at 7.3% compounded weekly to give you $50,000 for college expenses today?

13. You have won $100,000 from a lottery. If you invest all of this in a tax-free money market fund earning 7% compounded weekly, how long do you have to wait to become a millionaire?

14. The People’s State Bank offers 4.2% compounded quarterly, while Statewide Federal offers a 4.1% compounded daily. Which bank offers the better rate?
Appendix 8: Laboratory Simple Interest Tutor Questions

1. Find the simple interest on $1280 at 4.8% for 3 months?

2. Find the principal of a loan at 8.4% if the simple interest after 5 years 6 months is $1155?

3. Find the term of a loan of $175 at 9% if the simple interest is $63?

4. What is the fair market price of a $5000 zero coupon bond due in 2 years if today’s long term simple interest rate is 3.54%?

5. The doubling time of an investment is the number of years it takes for the value to double. This is the same as the number of years for the value to increase by 100%. What is the doubling time of a 5% simple interest investment?
Appendix 9: Laboratory Study Compound Interest Tutor Questions

1. What is the amount due on a $15,000 loan at 8% for 10 years if interest is compounded a) annually, b) quarterly?

2. Calculate the present value of a $11,500 loan after 4 years 3 months at 8.4% if the interest is compounded a) semiannually, b) monthly?

3. Find the term of a loan that has 8.2% compounded quarterly to obtain $8400 from a principal of $2000?

4. In the mid-1990’s, a bond fund returned 10.43% compounded monthly. How much would a $5000 investment have been worth after 3 years?

5. How much would your parents have needed to set aside 17 years ago at 7.3% compounded weekly to give you $50,000 for college expenses today?
Appendix 10: Laboratory Study Lecture Notes

Section 2.1 Lecture

Simple Interest

The interest I on loan at principal P at simple interest rate r for t years is: \( I = Prt \)

Ex: Find interest on $300.00 loan for 6 months at 6%.

\( I = P \times r \times t \)

\( I = 300 \times 0.06 \times 0.5 \)

\( I = 300 \times 0.03 \)

\( I = 9 \)

Total Amount due on Simple Interest Loan

At end of loan, owe: Principal + Interest, or owe: \( P + I = P(1 + rt) \)

So, the total amount A due at the end is:

\( A = P(1 + rt) \)

Ex: What is the total amount due on loan of $1,000 at 5% interest for 4 years?

\( A = P(1 + rt) \)

\( A = 1000(1 + 0.05) \)

\( A = 1000(1.05) \)

\( A = 1050 \)
### Section 2.2 Lecture

<table>
<thead>
<tr>
<th>Simple interest formula</th>
<th>Compound interest formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A = P(1 + rt) )</td>
<td>( A = P(1 + r)^t )</td>
</tr>
</tbody>
</table>

* \( r \) - annual rate  
  \( t \) - years

\* \( A \) = future value \*  
\* \( P \) = present value \*

---

**How much should be invested now at 6.7% compounded weekly if $10,000 is needed in 6 years?**

\[ r = 0.067 / 52 = 0.0013 \]

\[ A = P(1 + r)^t \]

\[ A = 10,000 \times (1.0013)^{52 	imes 6} \]

\[ A = 10,000 \times (1.0013)^{312} \]

\[ A = 10,000 \times (1.0746) \]

\[ A = 10,746 \]
5. How long will it take to double an investment at 6% compound weekly?

\[ A = P \left(1 + \frac{r}{m}\right)^{mt} \]

\[ A = 2P \]

\[ \frac{2P}{P} = \left(1 + \frac{r}{m}\right)^{mt} \]

\[ 2 = \left(1 + \frac{0.06}{52}\right)^{52t} \]

\[ 2 = (1.00115385)^{52t} \]

\[ \log(2) = 52t \cdot \log(1.00115385) \]

\[ \log(2) = 52t \cdot 0.00115385 \]

\[ 50.11 = 52t \]

\[ t = \frac{50.11}{52} \approx 0.97 \text{ weeks or 11 weeks, 30 weeks.} \]

Rule of 72 estimate (for doubling time)

\[ \text{Doubling} = \frac{72}{\text{time}} \times 100 \]

So for \( r = 6\% \),

\[ \text{Doubling} = \frac{72}{0.06} \times 100 = 1200 \text{ years} \]

We know the Annual percentage yield \( \text{APY} \) or effective rate at interest.

\[ \text{APY} = \left(1 + \frac{r}{m}\right)^{m} - 1 \]

5. \( 7.9\% \) monthly \( \quad 6.97\% \) weekly

\[ r = \left(1 + \frac{0.079}{12}\right)^{12} - 1 \]

\[ r = \left(1.00658333\right)^{12} - 1 \]

\[ = 1.0732 - 1 \]

\[ = 0.0732 \]

\[ = 7.32\% \text{ is better} \]

\[ r = \left(1 + \frac{0.0697}{52}\right)^{52} - 1 \]

\[ r = \left(1.001326923\right)^{52} - 1 \]

\[ = 1.0714 - 1 \]

\[ = 0.0714 \]

\[ = 7.14\% \]
Effective rate of return for any investment returning $A$ after putting $P$ for $t$ years is found with $m=1$

$$A = P(1 + r_m)^t$$

What is effective rate of 10,000 zero coupon bond maturing in 6 years at 5500 now?

$$A = P(1 + r_e)^t$$
$$10,000 = 5500 (1 + r_e)^6$$

$$\frac{10,000}{5500} = (1 + r_e)^6$$

$$1.8182 = (1 + r_e)^6$$

$$1.048 = 1 + r_e$$

$$-1 = -1$$

$$0.048 = r_e$$

$$10.48\% = r_e$$
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