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An Electronic Interface to Aid in Learning How to Play a Musical Instrument

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An Electronic Interface to Aid in Learning How to Play a Musical Instrument

An Interactive Qualifying Project proposal to be submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract
Learning how to play an instrument is a difficult endeavor requiring great investments of time, effort, and money. Many people have aspirations to play an instrument such as the guitar, but lack the positive reinforcement and technical knowledge required to become skilled at playing music on their own. Musicians need to know not only how to physically control their instrument, but also how to read music notation. Music notation is constantly changing and evolving. This project investigates the possible fusion of recent technological advances with traditional music notation. This project intends to create a hardware and software suite which will serve as a tool to facilitate learning how to play the guitar, even if the user has little or no prior musical experience. The suite is composed of a physical controller designed like a real guitar and a software game which allows the user to learn in an engaging and reinforcing setting. It provides a more conducive environment for learning about the guitar by using a physical interface similar to an actual guitar, strong visual aids, and positive reinforcement through game mechanics. The use of this interface was then evaluated using public surveys and testing in order to draw a final conclusion on the utility of such an electronic interface and the success of this specific implementation.
# Table of Contents

Chapter 1: Introduction .............................................................................................................. 7

1.1 Music Notation..................................................................................................................... 7

1.2 Problems with Traditional Notation ................................................................................. 8

1.3 The Ideal System ................................................................................................................. 9

  1.3.1 The Need to Redevelop Music Notation ................................................................. 9

  1.3.2 Intuitive Notation ..................................................................................................... 10

  1.3.3 The Loss of a Common Musical Standard ............................................................. 11

1.4 Attempts at Reform .......................................................................................................... 12

  1.4.1 Guitar Tablature ...................................................................................................... 13

  1.4.2 Klavarskribo ........................................................................................................ 14

  1.4.3 Issues Concerning Reform ....................................................................................... 16

  1.4.4 The Future of Reform ............................................................................................. 17

1.5 Project Goals ..................................................................................................................... 17

Chapter 2: Guitar Education .................................................................................................... 20

2.1 Self-Taught ....................................................................................................................... 20

2.2 Learning with an Instructor ............................................................................................ 21

2.3 New Developments ......................................................................................................... 22

  2.3.1 Tablature Readers ................................................................................................ 22
<table>
<thead>
<tr>
<th>Chapter 3: Proposed Approach</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Introduction</td>
<td>35</td>
</tr>
<tr>
<td>3.2 Hardware</td>
<td>35</td>
</tr>
<tr>
<td>3.3 Software</td>
<td>37</td>
</tr>
</tbody>
</table>

Chapter 4: Implementation ................................................................. 41

| 4.1 Introduction            | 41   |
| 4.2 Software                | 42   |
| 4.3 Data Protocol           | 43   |
| 4.4 Hardware                | 44   |
| 4.4.1 Circuitry             | 44   |
| 4.4.2 Guitar Body           | 48   |
| 4.4.3 Strumming             | 49   |
| 4.4.4 Microcontroller       | 53   |
| 4.4.5 Universal Serial Bus  | 54   |

| 4.5 System Integration      | 55   |

Chapter 5: Performance ........................................................................... 57

Chapter 6: Conclusions ............................................................................ 64
6.1 Making Instruments More Accessible and Easy to Learn ........................................ 64

6.2 A Low-Cost MIDI Instrument ................................................................................. 65

6.3 A New Type of Music Notation ................................................................................ 66

6.4 Turning Rhythm-Action Gamers into Actual Musicians ........................................... 67

6.5 Summary .................................................................................................................... 68

Chapter 7: Future Work .................................................................................................. 70

7.1 Guitar Improvements ............................................................................................... 70

7.1.1 Guitar Body ........................................................................................................... 70

7.1.2 Strumming Mechanism ......................................................................................... 70

7.1.3 More Accessible Frets ......................................................................................... 71

7.1.4 Wireless ............................................................................................................... 71

7.1.5 MIDI Out ............................................................................................................. 71

7.1.6 Ability to change tuning ...................................................................................... 72

7.1.7 More Guitar Controls ......................................................................................... 72

7.2 Software Improvements .......................................................................................... 72

7.2.1 Graphical Improvements ...................................................................................... 72

7.2.2 Guitar Pro/Additional Music Files ................................................................. 73

7.2.3 Multiplayer/Online Play ...................................................................................... 73

7.2.4 Personal Customization Options and Unlockables ............................................. 73
References ........................................................................................................................................... 74
Appendix A- Performance Survey ......................................................................................................... 77
Appendix B- Business Plan ..................................................................................................................... 80
  Executive Summary .............................................................................................................................. 82
  The Need ........................................................................................................................................... 84
  The Market ......................................................................................................................................... 85
  Competitive Landscape/Prior Art ......................................................................................................... 86
  Benefit to Society ............................................................................................................................... 86
  Implementation .................................................................................................................................. 87
  Financial Analysis .............................................................................................................................. 87
  Marketing .......................................................................................................................................... 88
  Licensing .......................................................................................................................................... 88
  Accounting Details ............................................................................................................................. 88
Appendix C – Electronic Datasheets ....................................................................................................... 91
Chapter 1: Introduction

1.1 Music Notation

As soon as ancient man created the first crude musical instruments and began arranging the first melodies, the need to store the musical instructions in some form of music notation arose. The earliest known forms of music notation were created around 1800 B.C. by the Hurrian people in Northern Mesopotamia. Tablets were discovered that contained notation for vocal hymns. Since then, music notation has continued to evolve. Around 1250 B.C. the Babylonian people created a more advanced form of music notation. Music historians are currently debating the exact interpretation of the notation. However, they all agree that the notation indicates the names of strings on a lyre.

Throughout history, more and more systems of music notation developed all around the world. Rather than having an instrument-independent music notation system, these early notations were developed to represent the music of specific instruments (Gaare 17). All of these notations filled a few basic common needs.

The greatest benefit of a music notation system is the fact that it facilitates the learning of new songs. Without a notation system, the only way for musicians to learn a song would be to listen to it firsthand. There was no practical technology developed to record sound until Thomas Edison’s phonograph cylinder in 1877 A.D. Therefore, the only way to learn a new song would be to hear it played live or receive instruction from someone else who already knew the song. Once music notation was developed, musicians could just read the song from a tablet or
scroll and know how to play it without having ever heard it before. Songs could rather easily be
stored on tablets or paper and passed down through generations.

However, the invention of sound recording devices did not disband the uses for music
notation. There are many other uses. It is often very difficult to “play by ear,” or, in other
words, learn a song solely by listening to it and attempting to reproduce it on one’s own
instrument. Even expert musicians might require listening to a piece several times to decipher
all of its musical subtleties. Conversely, with complete instructions represented in music
notation, the musician could just read the notation and play along with it.

Additionally, many songs are long and complex, making it difficult to memorize them
without some sort of reference or guide. Music notation allows musicians the ability to have
playing instructions in front of them to read from during a live performance. Also, distributing
sound recordings can often be complicated, expensive, or impractical; whereas distributing a
printed notation is much simpler and cost effective.

1.2 Problems with Traditional Notation

Clearly, music notation has many purposes. Since its inception, notation has constantly
been changing and evolving to build upon the prior knowledge and to remove problems from
previous systems.

This trend is continuing today. New inventions, new instruments, and new stylistic
arranging techniques have all caused traditional sheet music notation to incorporate additional
symbols. Over time, composers have realized that it is often very difficult to represent complex
arrangements using the standard notation symbols. Composers such as John Cage, George
Crumb, and Pierre Boulez have all created new notation symbols since they could not satisfactorily convey their intent using the previous symbols (Griffiths). However, as more and more additions are made, sheet music can become bloated with so many symbols that it becomes very difficult to read.

The traditional system of notation has many other flaws. The biggest flaw is that it is not very intuitive for beginners to read, and it takes years of careful study to truly understand and become a master. Simply looking at the notation does not convey the sound that the note should create nor the action required on the instrument to produce that sound.

The large amount of symbols requires lots of memorization. Staff lines are non-exclusive, meaning that depending on the clef and octave, any note, such as an “A” note, could appear on a line or on a space. This non-exclusivity, in conjunction with differing clefs, accidentals, and key signatures, makes reading sheet music very short-term memory-taxing and math intensive. The vast amount of symbols also makes it very difficult to read and write complex or fast-paced pieces since the staff will quickly become cluttered with symbols.

1.3 The Ideal System

1.3.1 The Need to Redevelop Music Notation

All of these flaws cause some musicians to think that a new system of notation should be developed altogether. The current system has not seen any major changes since the eighteenth century. Starting a new system would incorporate, from the beginning, the many
new additions to music over the past three centuries. In the current systems, these new musical elements were added later and tend to cause bloated sheet music.

Creating a new system also allows the possibility of taking advantage of the vast technological improvements made since the eighteenth century. For example, cheap, portable electronics allow operations that used to require tedious amounts of calculations by human hand to be done almost instantly in a small electronic device. Visual displays, such as liquid crystal displays and light-emitting diode displays, allow information to be displayed and changed in real time.

Additionally, improvements in audio technologies have huge potential for the future of music notation and performance. Entire orchestras can be recreated using computers connected to speaker systems and hard drives containing large sound banks of sampled instruments. The computers receive musical instructions according to the Musical Instrument Digital Interface (MIDI) standard. MIDI encapsulates the same basic instructions a human musician receives when he or she reads sheet music.

1.3.2 Intuitive Notation

Erhard Karkoschka wrote *Notation in New Music*, a book detailing the history and future of music notation. Regarding future systems of notation, he said, “The visual event must be apparent as the direct translation of the auditory event, requiring as few additional thought processes as possible” (Notation in New Music 10). According to him, as well as many other music scholars, the most important quality in any notation system is how intuitive it is for the musician to play by reading it.
Since there are thousands of different musical instruments, making a single system that proves intuitive for players of all different types of instruments would be impossible. One cannot use a single system of symbols to convey meaning to a flautist blowing on a flute, a guitar player plucking strings, and a drummer hitting drums without sacrificing a lot of simplicity and intuitiveness. Traditional sheet music notation is able to convey meaning to all types of instruments, however, it does so at the cost of the flaws discussed above.

1.3.3 The Loss of a Common Musical Standard

One of the biggest reasons for the success of traditional notation was the fact that it was common to nearly every instrument. This allowed music publishers to print a single version of a song and have it be purchased by players of all instruments. Piano players who wanted to play a piece of music written in guitar tablature, for example, would have to go through a lengthy and tedious process of converting each note to traditional notation in order to play the piece on the piano.

However, with the vast technological improvements since the eighteenth century and the widespread availability of cheap and portable electronics, the need for a notation common to all instruments disappears. Computer chips offer the ability to perform millions of calculations per second. They can be programmed to almost instantly convert from one instrument’s notation to another instrument’s notation. The results could be displayed on a video screen for the musician to read from. According to Gaare, “Not far in the future, a conductor may be able to have a score electronically transposed into any notation system he or she prefers, in concert key. The conductor will still be able to communicate verbally to the players, even though the players are reading other forms of notation” (Alternatives to
Traditional Notation 19). The fact that the individual musicians are reading different notations
does not hinder the ability of the ensemble to perform since the conductor still has the ability
to visually and verbally interact with his or her players.

1.4 Attempts at Reform

According to musicologist Mark Gaare “Traditional notation has survived the test of
time and is read by musicians around the world, but there are many musicians who desire,
devise, or use alternative systems” (Alternatives to Traditional Notation 17). Since the
traditional music notation system was developed in the Middle Ages, there have been hundreds
of proposals of alternative notation systems. In his book, Source Book of Proposed Music
Notation Reforms, Gardner Read compiled a list of and analyzed 391 systems of notation that
have been proposed from 1764 to 1987. In describing the history of notation reform, he said,
“Since roughly 1700, composers and theorists, pedagogues and amateur musicians have put
forward with notable regularity proposals to simplify, to improve, or to supplant the prevailing
system” (Source Book of Proposed Music Notation Reforms 1).

However, while some have been moderately successful and are still implemented today,
none have been universally accepted by the worldwide music community. The most popular
and successful alternatives that have been proposed are a few select tablature notations. Also,
with the rising prevalence of computers in the role of song production, digital notational
systems have been developed to take advantage of the computer’s ability to output audio and
video.
1.4.1 Guitar Tablature

Gaare describes tablature as “notation [that] is a direct visual representation of the physical techniques used to produce music on a given instrument.” According to him, many experts in the music community “consider [tablature] superior to traditional notation” (Alternatives to Traditional Notation 17). Guitar tablature has become very popular among amateur guitarists in the past century. Dissatisfied with the ambiguity of traditional notation, they desired a notation that reflected the playing style of the guitar. Guitar tablature was adapted from the tablature of earlier stringed instruments, such as the lute. An example of guitar tablature, with its corresponding sheet music notation, is shown below in Figure 1.

![Figure 1: Sheet Music and Corresponding Guitar Tablature (Gaare)](image)

The six lines labeled “TAB” represent the six strings on the guitar. The numbers represent the fret where that string should be played. Numbers stacked on top of one another are played at the same time. Most guitarists prefer tablature because no mental math or conversion is required to determine where to position one’s hand on the fretboard or what
string to pluck. Additionally, there are less symbols than in sheet music. As more complex music pieces are played, tablature will remain less cluttered than sheet music.

1.4.2 Klavarskribo

Another successful alternative notation is Klavarskribo (Klavar), or keyboard tablature. It was developed in Holland in 1931. The Klavar Music Foundation, which promotes Klavarskribo, says “to play a conventional score requires mental contortions that have nothing to do with musicianship, so that millions of music lovers are held back from making their own music, not by any lack of ability, but by the absurdity of an obsolete system” (Klavar Music Foundation). Klavar hopes to provide a much more intuitive notation system that will open up piano playing to even more people.

The layout of the tablature is reminiscent of a player piano roll. The page is read from top to bottom, and different pitches of notes are placed horizontally in accordance to the keys on the piano. A sample of Klavar and its corresponding representation in sheet music notation is shown below in Figure 2.
Natural notes (white keys on the piano keyboard) always fall in open spaces and are always colored white, whereas accidentals (the black keys) always fall on a line and are colored black. Measures are divided by dotted horizontal lines. Gaare says that “the main reason for using Klavarskribo instead of traditional notation is that it simplifies the written score. It eliminates the need for sharps and flats because each of the twelve notes has its own unique location on the staff. It also eliminates the confusion of multiple clefs” (Alternatives to Traditional Notation 20).
Guitar tablature and Klavar are just two good examples of some fairly successful alternative notations. Many guitar books incorporate guitar tablature, and there are thousands of songs written in guitar tablature freely available for download on the internet. Klavar, while relatively unheard of in the United States, is very popular in Europe. Over twenty five thousand songs have been transcribed to Klavar. Gaare says, “it is estimated that one third of the musicians in Holland read Klavar, and one half of the music sold in Holland is in Klavar” (Alternatives to Traditional Notation 20). However, traditional sheet music notation is still the de facto standard.

1.4.3 Issues Concerning Reform

The biggest issue that opponents of reform often raise is that if notation systems such as guitar tabs or Klavar are superior, how come none of the hundreds of attempts at reform successfully usurped traditional notation? In The Notation of Western Music, musicologist Richard Rastall blames the relative conservatism of musicians. According to him, most musicians, working on the time scale of their own lives, regard notation as a static” (Rastall). Musicians who already know and understand the current system and have been working with it their whole lives have no big motivation to abandon what they know and learn something new. Publishers of sheet music will not print in a new notation that has no real market. Teachers have no motivation to teach a system to their pupils that has very little literature to use. According to Gaare, to be successful, “Any change that occurs will need to be a grass roots movement from the bottom up if it is ever to be accepted. MIDI is an excellent example of a music standard that developed with no owner, trademark, copyright, or patent involved. [It]
was developed by a group of synthesizer manufacturers who decided to cooperate for the good of the industry” (Alternatives to Traditional Notation 22).

1.4.4 The Future of Reform

The one major element all of these systems have in common is that they are all static. They are just text and symbols printed on paper. They do not implement anything dynamic such as audio or animated video.

In the past decade there has been a huge surge of rhythm-action music games. These implementations have only explored a purely entertainment purpose, however. They all have some type of animated notation. However, the notation and the controller are simplified so much that they lose most, if not all, musical relevance to the actual instrument they represent.

There have been some attempts to bridge the gap and create realistic notation that utilizes dynamic, animated notation in the form of a game or a learning tool. However, they have failed not because the general public rejected these systems but because the designers were unable to produce the required hardware and software. However, new innovations in hardware design have opened up the possibility of making cost-effective, reliable consumer grade hardware.

1.5 Project Goals

This project will investigate the effectiveness of animated notation in two categories. The first category is how well it can serve as a replacement for traditional notation. The second category is how well it can serve as learning tool to help aspiring musicians learn an instrument.
Additionally, the latest hardware technology will be surveyed and different realistic instrument controllers will be evaluated for their effectiveness as learning tools.

Specifically, this project will focus on the guitar. To truly make music reform happen, it must appeal to the people. Right now the guitar is an extremely popular instrument. A 2006 study in the United Kingdom revealed that twenty-four percent of students, age eight to eleven, who learn an instrument play the guitar. The trend continues throughout the age groups. Of the fifteen to sixteen-year-old students who learn to play an instrument, twenty-five percent learn to play the guitar (School of Rock). In the United States guitar sales have tripled over the last decade, going from one million in 2000 to over three million in 2009 (The Music Trades).

In addition to the popularity of the guitar as an instrument, guitar simulations have also become very popular recently. In 2005, the video game publisher RedOctane released a rhythm-action game called Guitar Hero. It instantly became a worldwide phenomenon, selling over 25 million copies worldwide. Its success created a spur of other guitar rhythm-action games, the most notable being Activision’s Rock Band, which has sold over 13 million copies worldwide. In just the five short years since the original release in 2005, Guitar Hero has become the third-largest video game franchise of all time (Video Game Charts).

While this report will, for the most part, focus on the guitar, it should be noted that most of the information herein holds true for other instruments.

The goal of this project is to gain an understanding of the future of music notation. This project has two main objectives. The first is to investigate the possibility of notation reform using animated notation, and gain understanding of potential problems associated with it. The
second is to gain some feedback from volunteers on different notation systems. The goal of this project is not to create a new and entirely comprehensive notation system. Nor is it intended to create a replacement for any instruments or education systems. It is merely to investigate the possibilities, experiment with current technologies, and gain an understanding of the potential problems on the way to complete notation and education reform. Creating new standards that are ready sufficient and ready to implement worldwide would require more time and input from the leaders of the music community. Those goals are beyond the scope of this project.
Chapter 2: Guitar Education

There are many ways to learn how to play the guitar. However, they can all be grouped into two categories – methods that provide feedback, and methods that do not provide feedback. Guitarists who learn to play the guitar through methods that do not provide feedback are typically called “self-taught.” Regardless of how one learned to play the instrument, all guitarists need to learn some type of music notation, whether it is traditional sheet music, guitar tablature, or both. Learning a notation allows the musician to receive instructions on how to play songs.

2.1 Self-Taught

Historically, being self-taught meant that one would pick up a guitar and experiment playing it until one was able to produce sounds satisfactorily enough. Over time, and with technological advances, various tools were created to assist aspiring guitarists with learning the instrument.

The first tool that was created to aid guitarists was books. The first book on guitar playing was published in 1551 by Adrian Le Roy. It contained tablature for the guitar, which was still a five-string instrument at this time. Fifty years later, in the seventeenth century, many books were in print containing guitar tablature. The guitar started to rival the lute in popularity. The guitar increased in popularity throughout the next few centuries and many more books were published containing guitar tablature. In the present day, there are still many books in print on the subject of guitar. They are much more comprehensive than books in the past.

There are entire instructional and reference manuals on guitar, starting from the very basics of
guitar playing and moving on up to advanced techniques. They also often contain guitar tablature for many popular songs and folk songs, and, to a lesser extent, contain some traditional sheet music notation.

In the past century, with the advent of video cameras, a new tool has been developed to help teach guitarists – the instructional video. Aspiring guitarists can purchase instructional videos from stores, rent them from libraries, or, more recently, watch them online. Instructional videos typically contain multiple lessons from a professional guitar instructor. Similar to books, these videos typically start with the very basic fundamentals of playing the guitar and work on up to advanced techniques. They have the added advantage over books of being able to show footage and play sound. Footage can make lessons easier to understand as the instructor in the video can demonstrate techniques whereas books resort to still image diagrams with explanatory text. Being able to play sound is also a tremendous advantage for videos. When learning through a book, one cannot be certain that what he or she is doing is correct. However, with videos, one can listen to the sounds that the instructor is generating and compare his/her playing to that of the instructor.

2.2 Learning with an Instructor

Taking lessons with a guitar instructor is the only widespread method that provides feedback while learning guitar. This is widely regarded as the best method of learning guitar. Instructors can demonstrate techniques in-person and instantly critique and correct the technique of pupils. They can create and change lesson plans depending on their expert judgment and the needs of their pupils. They can also answer questions that a pupil has, whereas with something like a book or a video, it is up to the student to seek out the answer.
2.3 New Developments

In the present day, new technologies have allowed for the development of new aides to facilitate the learning of guitar. Hardware and software solutions have the possibility to provide new ways of interacting with the student and also can have the possibility of providing feedback on the student’s playing ability.

2.3.1 Tablature Readers

The first new development in this field was computer tablature editors. Programs such as Guitar Pro and Tux Guitar take the basic guitar tablature but expand upon it by adding timing information (Guitar Pro) (Tux Guitar). A screenshot of Guitar Pro is shown below in Figure 3.

![Guitar Pro screenshot](image)
Guitar Pro can display guitar tablature, traditional sheet music notation, or both at the same time. The notation on screen is the exact same format as notation printed on paper. The innovation comes in the form of audio and visual elements. A yellow box, the “position marker,” tracks the song’s progress and indicates the current position. This helps bring timing information to guitar tabs. The lack of timing information was one of tablature’s biggest weaknesses. Whenever the position marker moves across a new series of notes, those notes are output in the MIDI format to the computer synthesizer, and the appropriate guitar sounds are played. This helps the player get a sense of the rhythm.

2.3.2 Guitar Modifications

New guitar innovations have also appeared on the market. Guitar manufacturers are searching for ways to create modified guitars that simplify the task of learning the guitar. Yamaha and Optek Music Systems have both very recently released new guitars that use visual aids on the actual guitar fretboard to indicate to the player where to position his/her fingers.

2.3.2.1 Fretlight

Optek Music System’s Fretlight guitar is a standard electric guitar, with one exception – it contains LEDs along the fretboard (Fretlight). There is one LED under each string on each fret, so there are six LEDs per each fret. The LEDs light up whenever the guitarist is supposed to hold that particular string against that particular fret. A picture of the Fretlight is shown below in Figure 4.
In order to do this, the guitar needs to be plugged it into the computer’s universal serial bus (USB) port. While the guitar is plugged into the computer, MIDI songs can be played and the appropriate corresponding frets will light up on the Fretlight in accordance with the song. The basic Fretlight models have a manufacturer’s suggested retail price of $400 (Fretlight Store).

2.3.2.2 Yamaha EZ-AG

Like the Fretlight, the Yamaha EZ-AG employs lights on the fretboard to instruct the guitarist when and where to place his/her fingers (Yamaha EZ-AG). However, unlike the Fretlight, the Yamaha EZ-AG does not have any strings. It employs buttons on the fretboard and strum sensors on the body of the guitar.

The Yamaha EZ-AG is a stand-alone hardware device designed to teach users how to play the guitar more easily and at their own pace. It has the physical shape of a guitar, however the neck is covered with an array of push-buttons instead of strings. The bottom of the guitar
has a set of six strings used to strum while holding down the appropriate button on the neck.
The buttons on the neck light up when they should be pressed, depending on the song being played. An image of the EZ-AG during use is shown below in Figure 5.

![Yamaha EZ-AG (Jamorama)](image)

**Figure 5: Yamaha EZ-AG (Jamorama)**

This device has a speaker where it can output digital sound, as well as a MIDI output where it can connect with a computer and be used with a composing or tablature program. It comes with a variety of MIDI songs pre-programmed into it and also has the ability to download MIDI songs from any computer.

The unique construction of the guitar in addition to its abundant use of LEDs drives up the cost of this product significantly. It has a baseline price of about $220 and comes with no software; its only visual aid lies in the LEDs which light up when frets should be held down.

### 2.3.2.3 Comparison

The previous two guitar modifications are compared below in Table 2.1.
Table 2.1 – Guitar Modification Comparison

<table>
<thead>
<tr>
<th>Guitar</th>
<th>Price</th>
<th>Similarity to real guitar</th>
<th>Guitar Learning Aids</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Fretlight</em></td>
<td>$400</td>
<td>Same – it is a real guitar</td>
<td>Lights on fretboard – player must look at frets while playing</td>
</tr>
<tr>
<td><em>Yamaha EZ-AG</em></td>
<td>$220</td>
<td>Not very similar – buttons instead of strings on fretboard</td>
<td>Lights on fretboard – player must look at frets while playing</td>
</tr>
</tbody>
</table>

2.3.3 Rhythm-Action Games

A number of rhythm-action games currently exist which attempt to teach users about playing guitar, or at least impart mechanics related to guitar-playing. Some products are marketed as such, with companies claiming that players can improve their proficiency at playing guitar through the use of their software. Other products such as Guitar Hero do not claim to teach users how to play the guitar, but are still worthy of mention since they attract many people who are interested in guitar-playing (Quillen). A summary of the current products is listed below in chronological order from the time of their announcement.

2.3.3.1 Guitar Hero / Rock Band

From its initial creation as a small concept game created by Activision Software Studios, Guitar Hero has become outrageously popular and has evolved quite literally into a household name (Guitar Hero). The game offers players the appeal of playing guitar along to their favorite songs by using a simplified controller which is easy to pick up and accessible to almost anyone. The controller is shaped like a guitar and features five colored buttons across the top of the neck. It has a single three-state switch across the body of guitar which users push up and down to simulate strumming a guitar. The guitar and game typically retails for around $100 (Guitar Hero). An image of a typical Guitar Hero controller is displayed below in Figure 6.
Guitar Hero was designed for video game consoles and hence the controller plugs into a game console and is used with an accompanying software disc. Typically, Guitar Hero gameplay requires users to hold down the correct fret button on the neck and strum the switch in rhythm with notes which scroll towards the user in 3D. An image of Guitar Hero gameplay is shown below in Figure 7.

![Guitar Hero controller](image-url)
Guitar Hero has evolved into a global phenomenon, with more than 25 million units sold during its brief lifespan so far. The simplicity of the controller makes it easy for beginners and non-musicians to pick up and enjoy playing. Also, the easy-to-read scrolling interface makes it easy to tell which frets need to be held down at what times.

However, the fact that the Guitar Hero controller deviates so far from a standard guitar means that little guitar-playing skill is actually imparted on the user. Players can spend years playing Guitar Hero and become a master of the game, but they will still not be any better equipped to play music on a real guitar.

2.3.3.2 LittleBigStar

LittleBigStar is a software program for the PC which uses 3D graphics to display real guitar tablature in a style of gameplay similar to Guitar Hero (Little Big Star). Users make their own controllers by attaching a microphone to a real guitar. The game uses signal processing techniques to analyze the sound produced by the guitar in order to detect which notes are played.
being played. The graphical interface is very similar to that of Guitar Hero and Rock Band. It represents which frets should be held by adding the fret number on top of the note. The software interface for LittleBigStar is displayed below in Figure 8.

![Figure 8: LittleBigStar gameplay (Little Big Star)](image)

The method of note detection by using a microphone and signal analysis proved too difficult to perform quickly and accurately enough for a game. LittleBigStar was delayed numerous times because it had problems with note detection. These problems were amplified when there is a quick succession of notes or a chord being played. The project was finally cancelled in 2008 (Little Big Star).

### 2.3.3.3 Guitar Rising

Guitar Rising is a software and hardware system developed for the PC which is intended to teach players how to play the guitar (Guitar Rising). It uses a real guitar for a controller, and uses a microphone and digital signal processing to detect which note is played when the user
strums. Guitar Rising uses a very interesting visual interface to describe which notes should be played at what time. Notes scroll sideways across the screen on one of six strings, with each note labeled with the fret number that should be held down on that string. The image Figure 9 in below details the Guitar Rising software interface.

![Figure 9: Guitar Rising user interface (Slash Gear)](image)

The Guitar Rising project showed promise but had several issues. One major problem is that it is not immediately intuitive for people to play the notes which scroll sideways across the screen. Since they are labeled numerically, players need to stop and read each note as it comes down which is a very clumsy and difficult way of telling which frets should be held down. Additionally, the use of signal processing to determine which notes were played has a very high latency due to the complexity of the calculations. This major factor is ultimately why the Guitar Rising project was cancelled (Kosmix).
### 2.3.3.4 Disney Star Guitar

Disney Star Guitar was a software and hardware suite made by Disney which was intended to teach teens and younger children how to play guitar (Gizmodo). It uses a real guitar as its input controller, which uses a microphone and performs signal processing to perform note detection. It comes with an accompanying software game where users can play along to songs from Disney series such as Hannah Montana and High School Musical while learning how to accurately play the guitar. The software game uses a setup where the entire fretboard is mapped out across the bottom of the screen. Notes fall from the top of the screen and land on the appropriate fret which should be held down at that point in the song. An image of the software program is displayed below in Figure 10.

![Disney Star Guitar user interface](image-url)
The main issue with Disney Star Guitar was its use of microphone recording and signal processing to detect which notes are played. This method of note detection has a very high latency and creates a great delay from what is played in real-life to what is seen on-screen. Additionally, the cost of the entire system was estimated to be $200, which is very expensive and nearly the price of a game console itself. The game was expected to be released during the summer of 2009, but was pushed back indefinitely due to unknown issues.

2.3.3.5 Power Gig: Rise of the Six-String

Power Gig is a software game in production for the Xbox 360 and PS3 that is being developed by Seven45 Studios and aimed for release during Fall of 2010 (Power Gig). The game uses a real electric guitar for a controller, which can be plugged into either an amplifier or a video game console in order to produce music. When plugged into a console, the accompanying software game will allow users to play along to several licensed songs and play actual notes and chords in order to improve their guitar-playing skill. Little is currently known about the software portion of the project, but the controller specifications have been revealed. An image of the electric guitar controller is shown below in Figure 11.
The game is expected to come in a complete package with an electronic drum set, bass, and microphone for vocals.

While the product is not yet released, there are a few flaws that may affect its marketability. First of all, the controller can only detect when a maximum of two frets are held down simultaneously (Ackerman). This seriously limits the number of chords and actual songs that can be played with the guitar. Secondly, the cost of the game bundled with the guitar is $230 (IGN). This is more expensive than most video game consoles themselves. Finally, the software portion of the game has not been seen yet, and with Seven45 Studios being a new company that has never produced a game before the market is unsure of the quality of the software that will be provided.

2.3.3.6 Comparison

The previous five rhythm-action games are compared below in Table 2.2.
Table 2.2 – Comparison of Rhythm-Action Games

<table>
<thead>
<tr>
<th>Guitar</th>
<th>Price</th>
<th>Similarity to real guitar</th>
<th>Guitar Learning Aids</th>
<th>Current Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Guitar Hero / Rock Band</em></td>
<td>$100</td>
<td>Not very similar – buttons and strum bar instead of strings</td>
<td>N/A</td>
<td>Millions of units sold worldwide</td>
</tr>
<tr>
<td><em>LittleBigStar</em></td>
<td>N/A</td>
<td>Same – uses a real guitar</td>
<td>Note tablature scrolls by as song plays</td>
<td>Cancelled</td>
</tr>
<tr>
<td><em>Guitar Rising</em></td>
<td>N/A</td>
<td>Same – uses a real guitar</td>
<td>Note tablature scrolls by as song plays</td>
<td>Cancelled</td>
</tr>
<tr>
<td><em>Disney Star Guitar</em></td>
<td>N/A</td>
<td>Same – uses a real guitar</td>
<td>Notes fall down on an top-down view of the guitar</td>
<td>Cancelled</td>
</tr>
<tr>
<td><em>PowerGig</em></td>
<td>$230</td>
<td>Quite similar – uses a real guitar, but only 2 frets can be held simultaneously</td>
<td>Note tablature scrolls by as song plays</td>
<td>Unreleased</td>
</tr>
</tbody>
</table>
Chapter 3: Proposed Approach

3.1 Introduction

A device was postulated that could combine aspects of rhythm-action games and real guitar tablature. This device would be capable of performing similar functions of a real guitar while sending data on how it is being played to a Guitar Hero-style game. This device would find uses among two difference audiences, rhythm-action gamers and guitar players. A rhythm-action gamer will find the game familiar, but it will have the added capability of providing the user with real guitar skills. The veteran guitar player will also find the device to be useful as a tool for learning new songs.

From researching prior art, it is clear that there have been attempts at creating a system similar to Digitar. However, all of these devices have either not met their goals or failed to achieve market success. Currently no other systems that teach guitar in the rhythm-action manner have risen to popularity, but quite a few companies have tried. This shows that some type of feasibility restriction has kept these other products from succeeding. Therefore, a different approach must be taken to achieve success.

The following is a set of requirements put forth for a hardware-software suite that is capable of teaching a user how to play guitar.

3.2 Hardware

The proposed hardware is a controller for a system which will aid in teaching a user how to play the guitar. It is meant to emulate the look and feel of a normal electric or acoustic guitar, while also providing the specialized software with the musical data necessary to deduce
the note currently being played on the guitar. A press upon the fret board must be quickly and accurately translated to the data needed for the game.

It also needs to be capable of detecting strumming activity. The strumming mechanism will feature a method to strum each of 6 six strings separately. To properly recreate the playing of a real guitar the strumming will need to hold similar dimensions to that of the strumming portion of a guitar. It is important that the strumming provide resistive feedback to feel more natural in the hands of a guitar player.

The data which will be collected from the guitar controller will include note and strum data. The obvious protocol to send this data under is MIDI. The guitar should be capable of acting as an independent MIDI controller. Acting under the MIDI protocol (or a modification of such) will provide a starting point in which to work. The MIDI protocol is heavily documented and firmware and software libraries exist to ease the implementation stage.

It is also important that the If any aspect of the proposed guitar controller does not behave in a similar manner to a real guitar it will lose its usefulness as a teaching tool. The skill acquired from playing the game should directly correlate to skill playing a real guitar.

The number of frets capable of being played on the proposed system is also of concern. The number of frets on a real guitar can vary quite a bit. An average guitar has 22 frets, but since the guitar is a transposing instrument, not all of these frets are necessary. It was determined that the absolute minimum number of frets that a guitar can have while still being usable is 12. This is because the difference in pitch from one fret to the next is one semi-tone and 12 frets makes it able to produce one full octave on each string.
3.3 Software

An integral part of any teaching device is the software provided to the user. The style of teaching desired is one that mimics Guitar Hero while conveying a form of musical notation. The software should be capable of showing the user the correct chord or note to be played and also the correct timing in which these chords or notes are to be played.

The Guitar Hero games have a unique method of showing the user the rhythm and button information needed to play the game. In any way that the software can be made similar to the Guitar Hero’s method of relaying playing information will increase appeal among a larger audience. While the device is meant to be a learning tool, its secondary goal is bring rhythm-action gamers into a creative environment that is familiar and easy to understand.

The proposed device will feature much more complex functions than the Guitar Hero controller. Because of this the accompanying game will need to have a simple, but effective method of conveying this more complex information. Using the different rhythm-action games as platforms, a new more effective method can be created. Three methods of conveying the guitar playing cues were explored. Usability was considered to find potential problems or drawbacks to any particular system. Existing products were examined to assess the advantages and disadvantages of different interfaces.

A side-scrolling method provides the look and feel of real guitar tabs, making it easy to understand for those users who already play guitar. The notes appear from the right of the screen and scroll towards one of the six endpoints on the left, which represent the six strings of the guitar. The number on the note indicates the number of the fret which should be held down
when the user strums. For example, a seven in the second row in the screen indicates that the seventh fret should be held down and the second string should be strummed.

Figure 12: Side-Scrolling Gameplay (Guitar Rising)

This method of displaying songs is understandable, but not immediately sensible to those unfamiliar with music. It requires not only a familiarity with guitar tablature, but the ability to read them quickly while simultaneously playing. Because of this relatively steep learning curve, beginners may find this system too imposing. However, advanced guitarists may prefer this interface due to its similarity to scrolling guitar tablature.

A top down styled interface graphically represents the position of each note to the neck of a guitar image. This approach has several advantages. It is easily understood so that even non-musicians can see where they should position their fingers and what frets they should hold down. The notes fall from the top of the screen onto the fret that should be held down when they are played. It is easy to see not only the next note that needs to be played, but also the location of the notes which follow it.
This interface is very easy to read, but isn’t very similar to any rhythm-action game. If the game is supposed to appeal to those who are already users of Guitar Hero, they may be deterred due to a slight unfamiliarity.
Guitar Hero has become a popular sensation partly through its innovative method of scrolling notes towards the user in an isometric 3D fashion. However, this method does not necessarily translate well to a more complicated game. The Guitar Hero controller only has 5 fret buttons and one strum bar, which makes it considerably more easy to play and able to support such a simple scrolling interface. The interface becomes cluttered with the fret numbers above the incoming notes. Also, fret numbers are not as intuitive as the top-down guitar interface. Users must translate fret numbers into finger positions before they can play the note.
Chapter 4: Implementation

4.1 Introduction

A large portion of this project goes beyond planning and speculation. Beyond basic research, it is impossible to know the true feasibility of such a device. In the proposal section a set of requirements were made for a guitar device and the accompanying game. Research was performed to find the appropriate approach to an implementation. The requirements intend to create an effective method of learning to play guitar, but a question of feasibility lies in the implementation. For this project to have any impact upon society it would need to be a working product or have the capability to be made into a working product.

The following is a documentation of the implementation. This particular iteration of the intended device was simply meant to be a proof of concept. It came together to eventually become a working system, dubbed “Digitar.” The Digitar can perform all of the basic tasks set in place in the proposal section, but a more finished product would be necessary to move onto production. For the purposes of conceptualization and information gathering, this initial proof of concept would suffice.

Similar technologies already exist that use signal analysis to detect the note being played. However, all attempts have failed to work as a commercial product. The note recognition system implemented is faster and more reliable than these previous attempts, hereby meeting a proposed requirement. Digitar utilizes a matrix system for a fret detection rather than note recognition.
4.2 Software

After evaluating all the methods listed previously and performing various tests, the finalized concept for the game was decided upon. A top-down interface was selected for its ease of use and readability for non-musicians. This method also provided the most information “at-a-glance” due to how it shows a guitar graphic and how the notes will be positioned on the neck.

Some minor details were added to aid the user in figuring out the note to be played. Each string and the note corresponding to each particular string is color-coded. Small floating circles on the fretboard were added to indicate which fret is to be played next. Finally, because of the complexity that chords introduce, lines connecting the notes of a chord were added. An image of the finalized interface is displayed in Figure 15.

![Image of the finalized interface](image_url)

**Figure 15: Gameplay screenshot from Digitar software**

Notes fall from the top of the screen and scroll downwards until they land on the string which matches their color. At this point, the fret which matches the position of the note should
be held down on the controller and the matching string should be strummed. When the note arrives and is centered on the string, the player must be holding the appropriate fret and strum the guitar to play the next note in the song.

4.3 Data Protocol

Musical Instrument Digital Interface (MIDI) is a format for encoding digital music on electronic devices. It uses a series of succinct commands called “events” in order to construct music using a bank of existing sound effects that are stored outside of the file. In this way, it allows for extremely small file sizes since the files themselves contain no sound waveforms. MIDI files are made up of “chunks” of data, and may be separated in multiple tracks for any given song. The standard layout for a MIDI file is displayed below:

```
<header chunk>
<track chunk>
<MIDI event>
<end track chunk>
<additional track chunks>
...
```

The header chunk of a MIDI file contains tags specifying the title and artist of the music, as well as any additional information the user would like to be encoded with the file. Following this is the track chunk, which specifies a track number and information for the MIDI events it encloses. After each track chunk come a series of MIDI events that define the progression of the music in the song. For example, in order to play a certain note the “Note On” MIDI event is
used to play a note on a specific key and velocity (volume). A note can be turned off using a “Note Off” event, or by using a “Note On” event with a velocity of 0. A variety of other events exist, such as “Program Change” events which can alter the instruments in use.

The MIDI data that is transferred from our guitar and from most instruments that support MIDI is not a complete file however; instruments generally only send specific event messages describing which notes to begin and end playing, as well as program changes and some additional formatting data. Our instrument uses only a fraction of the MIDI commands available, only making use of “Note On” and “Note Off” events at different pitches to create music. However, this also decreases the latency in processing each note and isolates it into a simple and recognizable event.

4.4 Hardware

4.4.1 Circuitry

The requirements set forth in the proposal state that the method of fret detection must be faster and more accurate than using signal analysis. This leads to a system which is simpler electronically, but quite a bit more complex physically. An addressing matrix met the requirements and presented a method which was well established in the electrical engineering field. An immense amount of documentation exists on the subject and made for an excellent starting point.

A matrix is a mesh of control or data lines used to individually address or receive from one of many electrical locations. This method allows a tremendous amount of switches to be read using only a few data lines. This method of data collection is used in a number of
applications, but it is most commonly seen in computer keyboards. An example of a simple 2x2 matrix can be seen in Figure 16.

![2x2 matrix](image)

The advantage to using this technology is readily apparent when considering the following: A normal guitar has 6 strings. On the proposed device each string has 15 different positions. If each position on each string were to be a discrete data line going to the microcontroller, 90 I/O ports would be necessary. With the use of a 6x15 matrix only 21 lines would be necessary, and various methods exist to cut this down even farther.

Each SELECT line has a logic high applied one at a time and the DATA lines are read-in and stored. A logic low at a DATA line 0 during the first cycle would indicate that switch 0 is open. Cycling the SELECT lines can be done fast enough so that a human could never possibly move faster than the time it takes to read-in on each DATA line.

Despite the fact that the matrix reduces the number of DATA lines required to collect the fret information, it still exceeded the number of I/O ports available upon the microcontroller selected (outlined later in this chapter). By the selection of the particular
microcontroller an implicit requirement not previously mentioned was added to the controller. So to remedy this, the data would need to be further encoded.

An encoder works by taking many bits of data and encoding them in such a way as to reduce the number of lines required to represent the bits.

The first approach to prototyping the matrix system was to use a material known as “liquid wire” to electrically connect the frets to copper wires which run down the back of the neck to the circuitry. After testing it was determined that liquid wire, being a carbon alloy, would have a considerable resistance, but soldering directly to the frets was impossible due to the glue that holds them in place. Since no other solution was evident at the time, it was decided that the resistance would be workable for the purposes of the neck. 14 gauge wire was glued down the back of the neck and the ends were left bare and staggered so each wire ended at a fret. Grooves were milled out of the wood of the neck from the bare ends of the wires around to the fret and liquid wire was filled into the groove to provide a connection from fret to wire. The final product can be seen in Figure 17.

Figure 17: First Digitar neck
After a time, it was evident that only 7 frets could be connected due to limited space on the back of the neck. This did not meet the requirements set during the proposal phase of the project, so unfortunately this particular iteration of the neck was abandoned. But, this attempt provided valuable information about what kind of construction does not work.

It was clear that the method of electrically connecting frets to wire could be improved, so this opportunity was used to try repurposing another material. Copper foil tape is a material usually used for stained glass work. The tape is a thin layer of copper with an adhesive backing. The foil provides excellent conduction and can wrap around uneven surfaces that normally would be difficult to neatly get a conductor around.

![Figure 18: Copper Foil Tape](image)

The foil tape was wrapped around each fret on a newly acquired guitar neck and then a strip was run down from each fret to the bottom of the neck. The wax backing was kept on the tape at any point that the foil had to cross or overlap. This kept everything electrically isolated. To avoid damage to the copper tape when being handled another material was repurposed. A rubber-like material named Plasti Dip was applied to the back of the guitar neck in order to protect the copper tape and improve the user’s grip around the neck.
4.4.2 Guitar Body

The preferred body for the guitar would be the body of an electric guitar, but concerns about price for the proof of concept arose and it was decided that making a simple wooden body would work much better. Using ¾” plywood and a nail gun, a box was fabricated, roughly the size of a guitar that was capable of housing circuitry. A jigsaw was used to cut a face and a back cover out of the same ¾” plywood. The face and back cover are shaped similarly to a guitar so it will rest comfortably in the hands of a user.
4.4.3 Strumming

The strumming mechanism is one that provides more of a manufacturing challenge than an engineering challenge. The device was simply meant to be a proof of concept, so compromises were made in the construction of this system. Under ideal conditions a specialized type of sensor called a “tension sensor” would be used. Due to cost limitations another method was pursued.

![Linear Tension Sensor](image_url)

*Figure 21: Linear Tension Sensor (Measurement Specialties)*

In accordance with the requirements gathered from the proposal section, the strumming mechanism must be able to create gatherable data that conveys the speed and strength in which a user picks each string. A force sensor mounted in such a way as to allow the user to pick or strum it certainly meets these requirements. A number of these sensors exist of all shapes, sizes and electrical properties.

A force sensor is a type of sensor which detects pressure upon its surface and translates that pressure into a change in resistance over its leads. The sensor can have either a positive force coefficient, meaning as force increases as does resistance, or a negative force coefficient meaning as force increases, resistance decreases. An example of a force sensor can be seen in Figure 22.
The sensor itself cannot be simply connected to the system proposed. The sensor simply changes resistance and because a microcontroller does not have current measuring capabilities, it isn’t able to directly measure resistance. To provide a usable type of data for the microcontroller the sensor must be properly voltage biased. Since the analog-to-digital converter of the MSP430 operates at a 2.5V reference voltage, the output of the divider will need to be normalized to 2.5V and only swing downward. An example of how such a circuit might work can be seen in Figure 23.
Each sensor has a resting resistance of approximately 6 Kilohms. When pressured their resistance only goes down due to their negative pressure coefficient. It must also be noted that the supply voltage (+V in Figure 23) being used is 3.3V. Following the rules of voltage dividers and Ohm’s Law, it can be surmised that the biasing resistor must be approximately 1.92 Kilohms.

In order to increase the area in which the user can strum, each force sensor was layered between semi-rigid materials. An array of six force sensors represents the six strings. Each sensor is sandwiched between two rectangular cutouts made from the semi-rigid material. Pieces of balsa wood were used to space the sensors. An image of the construction of the sensor array is displayed in Figure 24.
After binding the entire sensor array together using lag bolts, the strumming module was complete. The final array of sensors is displayed in Figure 25 and Figure 26 from the top (with the strummmable area shown) and from the bottom (with the electrical connections to the force sensors shown):
4.4.4 Microcontroller

With the recent advancements in microcontrollers it has become more feasible to use them in smaller applications. They can perform relatively complicated tasks that normally would take a number of integrated circuits and other components to accomplish. A number of the largest electronic component manufacturers have create their own lines of microcontrollers providing engineers with numerous options to solve any engineering challenge imaginable, including the one set forth in this very project.

A microcontroller works by executing *Machine Code*, a low level programming language that deals directly with registers and memory addresses. The controller is usually programmed in a higher level language like C or Java and then compiled into machine code. The flexibility of the code allows for execution of loops and conditional statements. This makes implementation of a project much faster and easier.

Texas Instruments (TI) has a line of microcontrollers called the MSP430. It comes in several variations for any application. The one particularly relevant to this paper is the MSP430F2274. This model has 16 I/O ports, onboard ADC, 2.4GHz wireless transmission capabilities, and comes in an incredibly small form factor.
This microcontroller was used to store and transmit the data generated in the guitar controller. The ADC was used to translate the analog data generated by the strumming mechanism into digital data that can be much more easily manipulated. The strum data is converted into the “velocity” of a MIDI packet and sent to the software.

4.4.5 Universal Serial Bus

The Universal Serial Bus (USB) is a communication standard that provides data transmission from a device to a computer. It typically has four pins: positive and negative power supply pins, a positive data pin, and a negative data pin. Most computers and many portable devices possess USB ports for transferring data. The most popular USB standard is USB “A,” which is detailed in the diagram below:

![Universal Serial Bus A Standard Port](image)

Data is streamed by sampling the potential difference between the positive and negative data pins. The positive and negative rails provide power to devices at a supply voltage of 5 Volts, with a maximum supply current of 500 mA. This structure provides a simple, yet consistent serial interface for manufacturers to adhere to when considering wired communications between devices. Additionally, due to the reasonable supply current allowed by the USB standard it is also frequently used to charge batteries and directly power devices which are connected to it.
4.5 System Integration

The final step in implementation was to combine these hardware and software components together into a music education tool. User input was detected on the hardware layer, interpreted through software, and transmitted over USB to the software running on a computer. Whenever the player held down a string against a fret, a change in voltage from a logical “high” to a logical “low” takes place on the fret. This fret is electrically connected to one of the input pins of the microcontroller. The microcontroller can detect this change in voltage. Depending on which input pins are logical voltage “high” and “low,” the microcontroller determines which fret was held down.

Whenever the player strums one of the strum sensors, the resistance of the sensor increases. This causes a change in voltage across the sensor. Similarly to the frets, the strum sensors are electrically connected to input pins on the microcontroller. However, these input pins are part of the microcontroller’s analog-to-digital converter (ADC). Instead of registering logical “highs” and “lows,” the ADC is able to approximate the actual voltage on its input pins. The greater the change in voltage, the harder the player strummed the strum sensor.

The microcontroller packages the information it receives from the fret and the strum sensor inputs and sends this data via USB to the attached computer. The computer software reads in the data and passes it on to a MIDI parser. The MIDI parser translates the received packets into the physical guitar events they represent, such as strumming the first string while it is held down on the fifth fret. The software then compares the player’s actions to that of the song that is currently being played. If the player’s actions fall within a certain threshold of the
song’s note, then the player is said to have played that note successfully. If not, then the player is said to have missed that note.
Chapter 5: Performance

Following the final stages of the implementation phase, both a working guitar controller and an accompanying software game had been successfully created. A set of metrics was created to judge the performance of the design relative to market competitors and prior art within the field. A confidential survey was distributed among one hundred people from many different demographics in order to formulate a public opinion of the guitar interface and the animated software music notation. A copy of the survey can be found in Appendix A.

The initial questions in the survey queried the public regarding their music education: Did the user have music education in the past? Are they capable of reading sheet music or playing an instrument? This information was used to separate those who took the survey into different demographics based on interest and skill level. For those who were not musically inclined, they were asked what their main deterrents were to playing an instrument and learning about music notation. Each user was also asked whether or not they had ever played the rhythm-action game Guitar Hero or any of its related franchises. This was used to compare the size of the rhythm-action gaming market with the relative number of actual musicians in our sample population.

Finally, after asking these initial questions the user was given a series of tests that would serve as direct metrics to how useful and ultimately successful the implementation of the project was. Each user taking the survey was first given a piece of sheet music and asked to demonstrate how it would be played on a guitar. Then they were given a short series of notes in guitar tablature and asked if they could demonstrate how it was played on a guitar. Finally,
without any explanation of the animated music notation used in this project, each user was shown a short segment from the software game and asked to demonstrate how it would be played on a guitar. The test was designed as a direct metric to compare the readability and intuitiveness of conventional music notation compared to the animated notation used in this project.

After this test, the user was then asked to play along to a simple song by using the constructed guitar controller to play several incoming notes that were displayed in the software game. They were asked to rate how easy it was to determine what frets and strings to hold down on a numerical scale, with 1 being extremely difficult and 10 being extremely intuitive. They were then asked directly whether or not the animated software notation was easier to read than sheet music and guitar tablature. Next, the user was asked whether they would be encouraged to play the guitar using the system developed in this project. Finally, each person was asked if they would play a polished version of the game with all the same features and graphics of Guitar Hero, but using the guitar interface and notation developed in this project. Following this question the user was then invited to share any comments regarding the system in general, comparisons to other games, and possible improvements.

An attempt was made to survey as varied a group as possible, including musicians, rhythm-action gamers, and those with little to no musical skill. The table below summarizes the data obtained from the first set of questions in the survey, which can be used to characterize the population used in this study.
Table 5.1- Statistics for the population surveyed.

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Percentage of Population Surveyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Had formal music training</td>
<td>32%</td>
</tr>
<tr>
<td>Able to read sheet music</td>
<td>27%</td>
</tr>
<tr>
<td>Had played an instrument</td>
<td>35%</td>
</tr>
<tr>
<td>Able to read Guitar tabs</td>
<td>30%</td>
</tr>
<tr>
<td>Had played Guitar Hero/Rock Band</td>
<td>96%</td>
</tr>
</tbody>
</table>

The response received from the population surveyed was extremely encouraging. Out of the population surveyed, only 27% percent of people were able to play the guitar by reading sheet music, and only 30% percent of people could play the guitar by reading off of tablature. However, 100% percent of the people surveyed were able to figure out how to play the guitar when viewing the animated software notation for a short period of time. One user specifically commented “It can’t get much simpler than that. You’re literally showing me exactly what fret on what string needs to be held down.” This sentiment held true through all demographics surveyed, with both musicians and non-musicians being able to clearly understand the music notation described by the software.

The results of the second test in the survey provided some numerical data to back up these notions. When asked how easy it was to tell what fret to hold down (on a scale of 1 to 10), the average user response was a 9.3 out of 10, with 10 being very easy and 1 being very difficult. A graph of the user responses is shown in Figure 28. On the same scale, the user was asked how easy it was to tell what string to hold down, with an average user response of 9.2 out of 10. A graph of these responses is shown in Figure 29. In general, the audience found the
system to be very intuitive and simple, with room for some minor improvements. One user commented “It is very easy to see what’s going on, which is great. The only thing I could suggest is some way to separate some notes which fall very closely together, but other than that it was awesome.”

Figure 28: User Ranking of the Ease of Identifying Which Fret to Hold Down

Figure 29: User Ranking of the Ease of Identifying Which String to Pluck
In the following questions, 96% percent of users thought the interface was easier to understand than sheet music and 94% percent of users thought the interface was easier to understand than guitar tabs. Charts showing these responses are shown in Figures 30 and 31, respectively. As final metrics of our implementation, 94% percent of the people surveyed said that they would be inclined to play the guitar using the system developed in this project and an encouraging 84% percent said that they would play a polished game with all the same features as Guitar Hero that used the guitar interface developed in this project. Charts diagramming these responses are shown in Figures 32 and 33, respectively.

![Survey Results of Intuitiveness of Digitar vs. Sheet Music](Figure 31)

![Survey Results of Intuitiveness of Digitar vs. Guitar Tablature](Figure 30)
Not all comments were totally positive regarding the system. Many users who were surveyed noted the tradeoff between the learning involved in the game and the added complexity of the system relative to rhythm-action games. One user specifically commented: “I
think I’d be much worse at it than [I am] at *Guitar Hero*, but I’d actually be on the track to learn something so that would make me want to play.” Still, relative to sheet music and guitar tablature the notation system received abundant praise from users regarding its readability and intuitive appearance.

In general, when the software was viewed as a learning instrument with the goal of helping users learn to play the guitar, the feedback was very positive. When the software was viewed as a video game that’s sole purpose was to give players the opportunity to have fun playing along to their favorite songs, the results were more split. Some users who identified themselves as avid video game players commented that they prefer the simplicity of the traditional *Guitar Hero* interface for competitive video-game playing. However, as a whole, the public feedback to the overall system was overwhelmingly positive.

In general, the Digitar system of music notation was rated as much more intuitive and easy to read than both sheet music and guitar tablature. 94% of users reported Digitar’s system to be easier to understand than guitar tablature, and similarly, 96% of users reported Digitar’s system as more intuitive than sheet music. When asked about specific elements of the system, the results still were very positive for Digitar. The user ease in understanding what fret to hold down and what string to pluck scored an average 9.3 and 9.2 out of 10, respectively. These results are very encouraging considering the software game was just in a prototype stage. With more time, the graphics could be improved upon to enhance the readability of notes and make it even easier for users to understand.
Chapter 6: Conclusions

The creation of a working electronic music interface was a tremendous undertaking, but a necessary one to gauge the true interest and impact that such a device could have on various groups in society. By actually constructing the device and collecting data in the field, the team was able to infer the potential impact of the system upon society and draw several strong conclusions from the study.

The potential impact of the project is large due to the inherently large sizes of the audiences being targeted. Between rhythm-action gamers, actual musicians, and those with little or no musical experience there are numerous positive impacts that the project would have on society.

6.1 Making Instruments More Accessible and Easy to Learn

For the average person, it takes years of practice to truly become a skilled musician. Even learning to play a single song takes a great investment of time, will, and repeated practice. There is no positive reinforcement provided when initially learning an instrument and it takes an extended period of time to truly be able to produce good sounding music. All of these are factors which discourage potential musicians and make it difficult to progress when getting started with an instrument.

The concept of a game to teach musical ability is refreshing for multiple reasons. It reduces the monotony of spending hours playing an instrument by one’s self and replaces it with a system which is encouraging and interactive. It provides an engaging environment which presents active feedback to the player and turns practice into entertainment as opposed to a
chore. Players can immediately start playing parts of songs that they enjoy listening to, learning about music and practicing timing and muscle memory. The increase of their performance, or “score” in the game parallels an increase in real musical ability in their actual lives.

Many aspiring musicians choose to pay for lessons and expensive classes which still do not overcome the fundamental flaws of why it is discouraging to take up an instrument with little experience. They may become disheartened by the lack of immediate returns on their investment or unable to keep up with the pace of rigid lessons and tutorials. An electronic music interface would allow users to learn at their own rate and progress at a speed which is comfortable to them. If a user is busy and unable to devote a large amount of time to practice, they can put in a few hours of gaming and see modest improvements in skill. For users with more time, they can put in larger amounts of practice time and reap larger gains in skill while still having fun all the while. Unlike a tutor, the device is always there whenever the user wants to practice and is totally centered on the player’s schedule.

6.2 A Low-Cost MIDI Instrument

Unlike a conventional instrument, MIDI instruments are designed to produce data, not sound. This allows them to be used in a variety of different applications, such as composing music or as software controllers.

For the particular implementation of this project a very low-cost MIDI guitar was created, costing under $50 in parts. A typical MIDI guitar costs in the range of $600 or more, with most synthesizer-guitars costing around $800 (Sweetwater Music Instruments). Knockoff MIDI guitars such as the Yamaha EZ-AG exist, but they lack the actual frets and strings that are essential to the actual experience of playing.
Due to the construction of our implementation, we were able to significantly drive down costs and create a MIDI instrument that can be used by newcomers and experienced musicians alike. While it may not possess some of the more advanced transformation features of a high-end MIDI guitar, the interface is significant due to its accessibility in both price and ease of use.

6.3 A New Type of Music Notation

There are currently two main standards in use today for representing music in a visual form. There is traditional sheet music, which can be applied to all instruments, and there is tablature which is usually created for a specific instrument or class of instruments. However, these two prominent forms of notation are not the only ways to describe a musical composition. A visual display of incoming notes on a computer screen is as much a viable form of notation as any other method. In the implementation of this project, a visual system of describing the notes and timing of a musical piece is used as an intuitive way to express music. It takes advantage of technology to create a scrolling visual image that represents the current and near-future states of the song being played. This is simpler to understand than reading sheet music or tablature off of a page, because the visuals play in time with the music and provide specific information about how the instrument should be held or played.

By using technology as an enabling factor, a virtual notation system would provide a benefit to society by allowing the reading and understanding of music to become easier and more intuitive. The software program created in the implementation of the project shows the benefits of such an “animated tablature” due its simplicity and readability.
6.4 Turning Rhythm-Action Gamers into Actual Musicians

Over the past 5 years, the name Guitar Hero has gone from a simple videogame reference to a household name. The Guitar Hero franchise has sold more than 25 million copies during its brief time on the gaming market and sales numbers show no signs of the series backing down any time soon. People everywhere, especially children, teens, and young adults have subscribed to the addicting gameplay of the series and the chance to finally be like their favorite artists and popular musicians.

Many gamers put hours of time on end into playing rhythm-action games such as Guitar Hero. They play every song, get the highest scores possible, and perfect their playing to an incredible degree. However, at the end of the day they walk away with no tangible music experience and are not better musicians; they are simply better Guitar Hero players.

With such a massive installation base for rhythm-action games like Guitar Hero, it is easy to see that there is already an incredible demand for innovative, music-centered games. By taking the engaging and addictive nature of rhythm-action games and applying them to an educational interface, there is an immediate positive benefit noted to society. A massive group of people are now able to both have fun and learn a useful skill simultaneously; society benefits from the added learning and incorporation of musical concepts into the gameplay.

Depending on the success of the interface, an entirely new generation of musicians could be bred from an electronic music interface. The device could serve as a tool that would encourage gamers and other non-musicians to learn more about playing an instrument and ultimately become musicians themselves. Children and teenagers playing the game would be more disposed to playing and learning about music given the knowledge and skills they acquire.
from the game. A huge user base of rhythm-action gamers could be converted to actual musicians, with the gaming interface used to bridge the gap between the two groups.

6.5 Summary

The first item that the team was able to conclude is that there is an undeniable interest in the use of electronic music interfaces within the audience of musicians, non-musicians, and rhythm-action gamers alike. The results of the surveys that were taken were resounding and clear in the support of this claim: approximately 94 percent of the people surveyed said that they would be more inclined to play the guitar using the system in this project, and 84 percent would be inclined to play a polished rhythm-action game based off of it. This established interest across a wide range of demographics is indicative of the desire for such a device by society, and a definite potential market for future products.

After concluding the interest of the market, the team was also able to use the collected data to draw a conclusion on the success of the implementation of the project. Given that 100% percent of the people surveyed could figure out how to play the guitar simply by looking at the project’s animated software notation (compared with 27% and 30% for sheet music and guitar tabs respectively), it is safe to say that the project was extremely successful in effectively conveying musical information to users. A large amount of positive feedback was also received regarding the feel of the controller; the use of real strings on the neck of the guitar was appealing to most people who played, allowing for a more accurate and educational playing experience. Users who were surveyed reported an average 9.3/10 satisfaction rate with how intuitive the fret controls were, with the overwhelming majority saying they found the experience of the developed interface to be easier than both sheet music and guitar tablature.
While the project has some room for improvements, these statistics allow us to conclude that the developed implementation was successful in meeting the initial needs of the market and a strong building block for future development.

Technology is an enabling factor in changing the way the people learn. Conventions that have been in use for years, such as learning from sheet music and guitar tablature, are based off of resources and standards that can be traced back centuries before the advent of electronic computing and many of the advanced technologies that we enjoy today. By making use of these advanced technologies in a way that is both educational and engaging, it is possible to create systems for learning that are more simple, effective, and intuitive than those of the past. The research entailed in this project report has demonstrated the tremendous interest for such a system, as well as its feasibility in being applied to both educational and entertainment purposes.
Chapter 7: Future Work

Throughout the implementation process of constructing the guitar interface and software, there were many ideas which went unrealized due to restrictions in time and resources. These ideas are summarized below and are in consideration for use as improvements in future revisions of the interface.

7.1 Guitar Improvements

Several improvements could be made in future implementations of the guitar controller. They are detailed below:

7.1.1 Guitar Body

The guitar could have a sleeker, more realistic and aesthetically appealing body. Ideally, we could manufacture a plastic body upon licensing the product out to a larger company. This would raise consumer interest and would be essential to effectively marketing our product.

7.1.2 Strumming Mechanism

One aspect of the guitar which was under-realized upon construction was the strumming mechanism, which uses force sensors wedged between an external material to detect strumming. The use of small force sensors severely limits the area that can effectively be used when strumming the guitar; only about one inch of space is afforded where players can strum in order for it to be detected. After doing more research as the project continued, we encountered a number of other ways to improve our strumming mechanism, including the use of tactile switches and different materials that would be better suited to serve as a way to
detect strumming. We may replace the current strumming mechanism in future implementations if we can find a method that is more reliable and can detect across a greater area.

7.1.3 More Accessible Frets

Our guitar neck did not utilize all of the available frets – some were left unconnected. While 15 frets are enough to play most popular songs, the guitar neck could have more accessible frets to make it more realistic. This would also raise the range of attainable notes, making electric and metal guitar music more accessible to our interface.

7.1.4 Wireless

The guitar could be modified to transmit data wirelessly rather than through our current method of using a USB cable. The microcontroller board used has a CC2500 2.4GHz wireless transceiver included on its circuit board. It could have a wireless receiver that plugs into the USB port of a computer; with an appropriate driving voltage and antennae we could attain a feasible operating range of more than 10 meters between the guitar and the receiver. This is a convenience we are highly considering for future implementations of the guitar.

7.1.5 MIDI Out

The guitar could have a MIDI-out port to allow it to be used with any MIDI synthesizer by connecting them via a MIDI cable. This would increase the versatility of our product and turn it into an actual instrument that could be used for composing and actual musical performances. We could also include a synthesizer inside the guitar with internal speakers in order to make the instrument capable of producing sound entirely on its own.
7.1.6 Ability to change tuning

The ability to change the tuning of individual strings is being considered as a possible improvement for future versions of the Guitar controller. This would allow users to realize a variety of different songs that lay beyond the threshold of standard tuning, such as lower bass songs or high-pitched songs for an electric guitar. We could also implement a type of “software tuning,” where we programmatically change the tuning of the guitar without physically changing any aspects of the controller.

7.1.7 More Guitar Controls

A variety of additional controls could be added to increase the functionality of our product. For example, a distortion bar could be added to attain different frequencies other than the notes provided in standard tuning. Switches and knobs could be added to provide other filtering effects to the sound produced by the guitar; these features come standard on most electric guitars.

7.2 Software Improvements

Though the game possesses a number of features already, there are additional improvements that could be made to make our software more appealing.

7.2.1 Graphical Improvements

Additional skins, backgrounds, and images could be created in order to make our interface more aesthetically pleasing and attractive. We could also consider rendering the game in three dimensions to simulate performances with 3D modeled characters. This would make performances more exciting and enjoyable for players.
7.2.2 Guitar Pro/Additional Music Files

The game currently only can import and read tracks from MIDI files. While this still gives it access to a large library of songs, many musicians have Guitar Pro Tabs for their favorite songs that could be incorporated into our software. In general, increasing the types of files that can be read by our software will make the end product more versatile and more appealing to consumers.

7.2.3 Multiplayer/Online Play

Our current implementation of the software has a basic single-player mode; however, adding a multiplayer mode where users can play online would be relatively simple. By using the INDY wrapper for internet socket controls, we could have a peer-to-peer multiplayer mode where one person acts as a TCP server and one or more players act as clients and play competitively against each other. We could also set up our own online servers depending on the popularity of the game. These could provide extra tasks or “missions” that players could accomplish collaboratively or competitively.

7.2.4 Personal Customization Options and Unlockables

Video gamers tend to be more encouraged to keep playing a game when they are provided with a virtual incentive to do so. For example, by using a system where players earn virtual “money” for songs that are played well, gamers will be encouraged to improve their skill level in order to take advantage of this incentive. This money could be used to unlock special songs associated with the game or to customize virtual characters or change special settings in the game. Providing a greater structure around the game will create more addictive game play for users and make their experience more enjoyable overall.
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Appendix A- Performance Survey

CONSENT FORM
WPI Electronic Music Interfaces IQP

Thank you for considering participating in this study. Research is being conducted to study the effectiveness and intuitiveness of different music notation systems. This research is being conducted by Patrick DeSantis, Sean Levesque, and James Montgomery from WPI.

There are no known risks associated with participating in this study.

Please remember that your participation in this research is voluntary, confidential and anonymous. Only the researcher will have access to the data collected. You may withdraw your consent to participate at any time without any penalty. This is a completely voluntary research project so you may stop at anytime.

By signing below you acknowledge that you may not gain anything personally by participating in the experiment.

If you wish to obtain further information about this study you may obtain a more detailed explanation of its goals after your participation has finished.

YOUR SIGNATURE BELOW INDICATES THAT YOU HAVE READ THE INFORMATION ABOVE AND YOU ARE CONSENTING TO PARTICIPATE IN THE EXPERIMENT DESCRIBED ABOVE.

___________________________________________________________________________  ____ / ____ / ___
Participant's Signature                                         Date

___________________________________________________________________________
Participant's email address

I have explained in detail the procedure for this experiment to the participant and, if asked, have made a copy available for the participant to keep. The participant has agreed to participate by signing above. My signature also confirms that the experiment was carried out as described.

___________________________________________________________________________  ____ / ____ / ___
Researcher Signature                                          Date
1. Have you had any formal music training?

2. Do you know how to read sheet music?
   a. If no, then why not (check all that apply)?
      i. Lack of interest
      ii. Never given the opportunity
      iii. It seems too difficult / intimidating
      iv. Other (specify) ______________

3. Do you or have you ever played any instruments?
   a. If no, then why not (check all that apply)?
      i. Lack of interest
      ii. Never given the opportunity
      iii. It seems too difficult / intimidating
      iv. Other (specify) ______________

4. Do you know how to read guitar tabs?

5. Have you played Guitar Hero / Rock Band?

Tests:

1. Test the intuitiveness of different notation systems
   a. Show a piece of sheet music. Can the subject figure out what to do on the
      instrument?*
   b. Show a piece of guitar tablature. Can the subject figure out what to do on the
      instrument?*
c. Show a clip of our system (i.e. the game). Can the subject figure out what to do on the instrument?*

2. Play-test – Have them play along with the song and try to keep up with the notes.
   a. Rate on a scale of one to ten how easy it was to tell what fret to hold down
   b. Rate on a scale of one to ten how easy it was to tell what string to hold down
   c. Is this easier to understand than sheet music?
   d. Is this easier to understand than guitar tabs?
   e. Would you be more inclined/encouraged to play guitar with a system like this?
   f. Would you like to play a polished version of this game with all the same features as Guitar Hero?
Appendix B- Business Plan

WORCESTER POLYTECHNIC INSTITUTE

Digitar, Inc.

Patrick DeSantis
James Montgomery
Confidentiality Agreement

The reader acknowledges that the information provided by Digitar, Inc. in this business plan is confidential. The reader agrees not to disclose it without the expressed written permission of Digitar, Inc. It is acknowledged by reader that information in this business plan is confidential in nature, other than information which is in the public domain through other means; and that any disclosure or use of the confidential information by reader, may cause serious damage to Digitar, Inc. Upon request, this document is to be immediately returned to Patrick DeSantis.

Signature ___________________

Name (please print) ________________

Date ________________
Executive Summary

Digitar, Inc. is a music hardware company providing solutions to lower the tremendous cost in Musical Instrument Digital Interface (MIDI) guitars. A major application of low-cost MIDI guitars is helping to remedy the considerable difficulty in learning to play guitar and to enhance the immersion and reality of video games and training tools. Digitar, Inc. differentiates itself from the competition by using our (patent pending) fretboard sensors to determine exactly what frets are being held down. This approach eliminates the need to use a microphone and signal processor to resolve the notes and chords being played, resulting in a faster, more accurate, and more cost effective solution.

There is a vast and growing market opportunity for our technology. Guitar manufacturers have recently been exploring new guitars that use a combination of hardware and computer software to act as a teaching assistant to beginner players. Guitar rhythm-action games have proven to be very successful and are only increasing in popularity. In less than five years, Guitar Hero, the most popular guitar rhythm-action game, has sold over 25 million units worldwide, making it the third largest video game franchise behind such long established franchises as Mario and Madden NFL. The Guitar Hero franchise alone has earned over two billion dollars in
retail sales. The second most popular franchise, *Rock Band*, has sold over 13 million units worldwide and earned over one billion dollars in retail sales.

Potential competitors include Harmonix and RedOctane, the manufacturers of the guitar controllers for the aforementioned *Guitar Hero* and *Rock Band* series of video games. Other competitors include newcomer Seven45 Studios with their game *Power Gig: Rise of the Six-String* and the self-teaching Yamaha EZ-AG Guitar. Finally, several competing products including *Guitar Rising*, *LittleBigStar*, and *Disney Star Guitar* have recently exited from the market. Their failure was largely attributable to their overreliance on signal processing methods to determine what notes and chords were being played.

Digitar, Inc. has many essential competitive advantages over the competition, including:

1. Fretboard sensor technology to determine what notes are being played, eliminating the need for inaccurate, expensive and time-consuming signal analysis.

2. Engaging gameplay, with an intuitive method of displaying what notes should be played at what time.

3. Positive feedback and an encouraging scoring system to keep players motivated even at early stages of the game.

4. The ability to change the tempo of the song on the fly while playing, as well as the ability to play back notes in any instrument supported by the MIDI standard.

5. The ability to play along to any MIDI song or guitar tab file supplied by the user, creating an instant library of millions of songs.

6. Realistic representation of the guitar through the physical controller, so that skills acquired can be directly applied to playing a real guitar.
Digitar, Inc. is in the process of applying for a patent. Once the patent application has been filed, Digitar, Inc. can begin marketing the product to guitar manufacturers and video game peripheral manufacturers. Digitar, Inc. plans to license the manufacturing rights out to various companies and collect royalties on units sold.

**The Need**

Learning to play guitar is a difficult endeavor and can be very overwhelming. Popular rhythm-action games like *Guitar Hero* and *Rock Band* try and simulate the feeling of playing the guitar, but any skills attained in the game are not transferable to playing the actual instrument. Digitar, Inc. seeks to solve these problems through the use of a hardware and software suite simply referred to as the Digitar.

Many people have aspirations to be able to play music, but are discouraged by the amount of time they would have to invest and the lack of reinforcement they would get by trying to learn to play on their own. Guitar lessons are frequently expensive and the player may also not find them engaging enough at early stages to maintain their interest. The Digitar software and hardware suite aims to satisfy the need of these newcomers by quite literally turning guitar-playing into a game. With the same engaging and entertaining qualities such as *Guitar Hero*, the Digitar hopes to gratify players with little musical experience as well as those who have been discouraged to play the guitar due to the difficulties mentioned before.

The Digitar is certainly not a product purely for beginners, however. It features the ability to play a massive variety of songs and pause and adjust the tempo of a song in real-time as the user plays along. This allows any user to custom-fit the difficulty to their specific skill level by choosing harder or easier songs to play, in addition to making the song faster or slower if they
are looking for a greater or lesser challenge. In this way, it serves the purpose of a general
guitar trainer that provides a fun and entertaining way to learn how to play new songs without
sifting through sheet music or guitar tabs. It addresses an important need of making music,
specifically guitar-playing, more accessible to the general public.

The Market

The primary market is rhythm-action gamers. The market has pleaded for more realistic
simulations and *Guitar Hero* and *Rock Band* have been racing to one-up each other. Similar
projects involving using real guitars as controllers have generated much excitement at trade
shows, however none have been able to successfully release a product.

The secondary market is aspiring guitarists. Learning to play the guitar can be quite expensive.
People who are unsure of their commitment to it might be hesitant to pay hundreds of dollars
on an instrument and equipment. If the aspiring guitarist desires lessons, then that will add
even more to the total cost. While not a perfect substitute for lessons from an experienced
teacher, a Digitar and accompanying software can help players learn how to play guitar. It
presents guitar playing in a fun and engaging atmosphere that rewards good playing through
positive reinforcement.

Players are often discouraged by their inability to produce good sounding music when first
starting to play guitar. Digitar and its accompanying game can help players learn finger
positioning and hand movements as well as the picking and strumming motions without letting
them get too discouraged. The game will not punish the player with out-of-tune notes when
playing missed or incorrect notes. However, the game will reward the player for playing correct
notes by playing the correct, in-tune notes in the song.
Current guitarists may also find a use in Digitar. It offers a cheap alternative to very expensive MIDI guitars. The game offers players the ability to learn how to play new songs in an exciting new atmosphere and provides an immersive alternative to reading sheet music or guitar tablature.

**Competitive Landscape/Prior Art**

See Section III of main report.

**Benefit to Society**

The Digitar would have a notable benefit to society upon entering the market. There are currently millions of people who play video games and spend hours of their time playing rhythm-action games such as *Guitar Hero*. Many of them master the game to an unbelievable level, but walk away from their virtual experience with no skills that can be applied in real life. By introducing a similarly engaging game that very closely mirrors playing an actual instrument, we can see that there would be very positive societal implications. Gamers who spend hours of time trying to get higher scores and become experts of the game would walk away from the Digitar with real experience that can be directly applied to playing an actual guitar. In this way, the Digitar would help breed an entire generation of musicians out of rhythm-action gamers and those who may have never tried their hand at music in the first place. With millions of such gamers in existence, we can see that the successful introduction of a product such as the Digitar would have profound effects. The Digitar would serve as a bridge for making the guitar accessible to almost anyone.
Implementation

See Section IV: Implementation of main report.

Financial Analysis

The Digitar has two main markets: a realistic guitar video game controller and a cost-effective alternative to expensive MIDI guitars. Since both of these industries already have many large companies that have strong footholds, starting a new company to compete would require a lot of capital. A more lucrative plan would be to license out the rights to manufacture the Digitar to these companies. They would handle the expenses and fine details of design, manufacturing, and marketing towards consumers while Digitar, Inc. would collect royalties on units sold.

Cost of Production Estimate

All points aside, it is still important to estimate the cost of manufacturing a Digitar. Ignoring the cost of setting up and tooling a manufacturing line, the cost of mass producing a Digitar would range from $15-$50 per unit, depending on the materials used to construct it. When ordered in bulk, the electronic components could be purchased for less than $10. Creating a low-cost plastic mold and assembling the entire unit would cost no more than $5. However, if the manufacturer wanted to create a higher-quality, more realistic guitar body out of a material such as wood, then the cost will increase. The cost to manufacture a wood body will be slightly less than the cost to produce a traditional guitar out of wood since the acoustic properties of the unit being produced can be ignored. Therefore, the cost would be no more than $40. Assuming a markup of three times from manufacture cost to retail price, the Digitar could be priced in the range of $45-150 and have an extremely competitive price point while still earning a profit. Guitar Hero and Rock Band controllers retail for around $60. Entry-level guitars cost...
around $150, and entry-level MIDI guitars cost around $800. The price of the Digitar could be marked up even more and it could still remain competitive.

**Marketing**

Since Digitar, Inc. will not do manufacturing itself, its primary focus will be to market the manufacturing rights to guitar manufacturers and video game peripheral manufacturers. Some prototype Digitars will have to be produced to demonstrate the functionality and advantages of the product.

**Licensing**

Potential licensees include companies from the guitar manufacturing industry and the video game peripheral manufacturing industry.

There are over one hundred mainstream guitar manufacturing companies that may be interested in licensing manufacturing rights for the Digitar. Examples include Epiphone, Ernie Ball, Fender, Ibanez, C.F. Martin & Company, Squier, and Yamaha.

There are many companies that produce video game peripherals and may be interested in licensing manufacturing rights for the Digitar. Prominent examples include Nintendo, Sony, Microsoft, Mad Catz, RedOctane, Electronic Arts, and Activision.

**Accounting Details**

Estimates of the accounting details are listed below.

**Expenses**

Digitar, Inc. would have few considerable expenses. Additionally, most of the expenses incurred would be one-time fees rather than fees that recur over time.
Research and development is mostly complete already, and would not require anyone other than the founding three person design team. Materials needed to complete additional proofs of concept would not exceed $500.

The patent application process involves hiring a registered patent attorney and could incur anywhere from around $12,000 up to $25,000 worth of expenses. The breakdown is detailed below:

- $1000 Patentability search
- $4000-$7000 Application preparation
- $545 Government filing fee
- $500 Drawings
- $2000 Prosecution fees
- $1050 Issue and Publication fee

A sufficient amount of prototypes for demonstration purposes could be produced for under $20,000.

In total, the expenses incurred from completing research and development, applying for a patent, and procuring prototypes would not exceed $50,000 in the worst-case scenario.

**Revenue**

All revenue would come from royalties collected from licensees. An explanation of possible licensees was given on the previous page. Considering *Guitar Hero* has sold over 25 million units and *Rock Band* has sold over 13 million units, if either game were to adopt a Digitar as its controller, there would be a significant amount of revenue generated from the massive amount
of royalty payments made. Supplementary income would be generated by royalty payments from any guitar manufacturer who decided to produce a Digitar.
Appendix C – Electronic Datasheets
MM74HC148
8-3 Line Priority Encoder

General Description
The MM74HC148 priority encoder utilizes advanced silicon-gate CMOS technology. It has the high noise immunity and low power consumption typical of CMOS circuits, as well as the speeds and output drive similar to LB-TTL. This priority encoder accepts 8 input request lines 0–7 and outputs 3 lines A0–A2. The priority encoding ensures that only the highest order data line is encoded. Cascading circuitry (enable input El and enable output EO) has been provided to allow octal expansion without the need for external circuitry. All data inputs and outputs are active at the low logic level. All inputs are protected from damage due to static discharge by internal diode clamps to VCC and ground.

Features
- Typical propagation delay: 13 ns
- Wide supply voltage range: 2V–6V

Ordering Code:

<table>
<thead>
<tr>
<th>Order Number</th>
<th>Package Number</th>
<th>Package Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM74HC148M</td>
<td>M15A</td>
<td>16-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-012, 0.150” Narrow</td>
</tr>
<tr>
<td>MM74HC148MTC</td>
<td>MTC16</td>
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<tr>
<td>MM74HC148N</td>
<td>N15E</td>
<td>16-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-001, 0.300” Wide</td>
</tr>
</tbody>
</table>

Devices also available in Tape and Reel. Specify by appending the suffix letter “X” to the ordering code.

Connection Diagram

Truth Table

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
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</tbody>
</table>

H = HIGH
L = LOW
X = Irrelevant