Interactive AR Experiences as Training Applications:

Guidelines and Requirements for Piano Pedagogy in Mixed Reality

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Dedications

I dedicate this project to my mother, my father, siblings and my friends who have always supported me in both good times and bad. You are just as inspirational to me as I am to you.

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I would like to thank my advisor Stefan Rank, my committee members Paul Diefenbach and Youngmoo Kim, as well as the Digital Media staff for being so inspirational and supportive throughout this two year program. Thank you for being so incredibly hard to satisfy. It's because of all of you I am able to walk away from this program not only with a master's diploma but with the confidence that I am ready for wherever my career takes me.

Drexel - Where meeting expectations also means surpassing them.

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Abstract

Interactive AR Experiences as Training Applications:
Guidelines and Requirements for Piano Pedagogy in Mixed Reality

Amare Birhanu
Stefan Rank, Ph.D., Youngmoo Kim, Ph.D., and Paul Diefenbach, Ph.D.

In this thesis, we analyze research regarding augmented reality (AR) and its use as an educational and training tool, for piano pedagogy specifically. Several exiting systems involve the use of AR in training and educational scenarios. The effectiveness of any one system varies based on the learning environment and how the technology is being used in a given scenario. Integrating new technology with learning environments is not a simple process and if the technology is used in an ineffective way it can hinder the learning experience. To prevent this, it is important to have a comprehensive understanding of the users' needs as well as an argument as to why the technology will aid in the learning process.

In order to work towards such an understanding and argument with respect to piano pedagogy, focusing on notation literacy, and Augmented Reality, we designed and implemented a series of prototypes of a piano training application called KeynVision (keen-vision) for the Microsoft Hololens. The design goal was to explore the introduction of octave scales, chords, and arpeggios to beginners while also improving their note literacy. The design of the developed prototypes was evaluated by an iterative playtesting process with a panel of experts and practitioners in piano pedagogy. By utilizing the benefits of augmented contextualization that mixed reality experiences provide, we created prototypes of an application that can meet the requirements needed to effectively aid students in the process of learning with beginner's exercises. Based on our research and the results of the expert panel, we believe that AR can be an effective tool for aiding students in the process of learning new tasks such as playing piano.

Chapter 1: INTRODUCTION

The process of learning is an active area of study and researchers are always investigating new ways of improving methods for teaching students in all levels of education. From the perspective of Digital Media, the question is usually how can novel technology contribute to the practice of learning and teaching. This thesis, partly, contributes to this effort by documenting the design and implementation of a series of prototypes of a piano training application called KeynVision (keen-vision, see Fig. 1.1). The application is built as a Mixed Reality experience for the Microsoft Hololens and the specific focus for evaluating this application is the subject of notation literacy in piano practice.

An in-depth study of the learning process is out of scope for the purpose of this paper. However, we will be discussing principles of multimedia learning and its application towards interactive training systems. We will also be framing a basic understanding of piano practice including player motives, the role of the instructor, common challenges beginners face, improving skills, and memorization. To increase the likelihood of making an Augmented Reality (AR) application that is effective at aiding students develop skills at playing the piano, we consulted an expert panel of piano instructors for finding an effective approach to integrating AR technology with piano practice.

In the following, we introduce the above mentioned problem setting in more detail as well as the guiding framework of participatory design research, followed by a chapter on the background and related work in both piano practice, multimedia learning, and Augmented Reality. The later chapter provide details on the research question and our approach, as well as the implementation and evaluation of the developed prototypes.

1.1 Education and Technology

While developing an application intended for education and training, it is important to understand the users' interests and level of acceptance of the technology that is being proposed to be integrated into the learning environment. If the technology that is being used offers an advantage over traditional learning methods

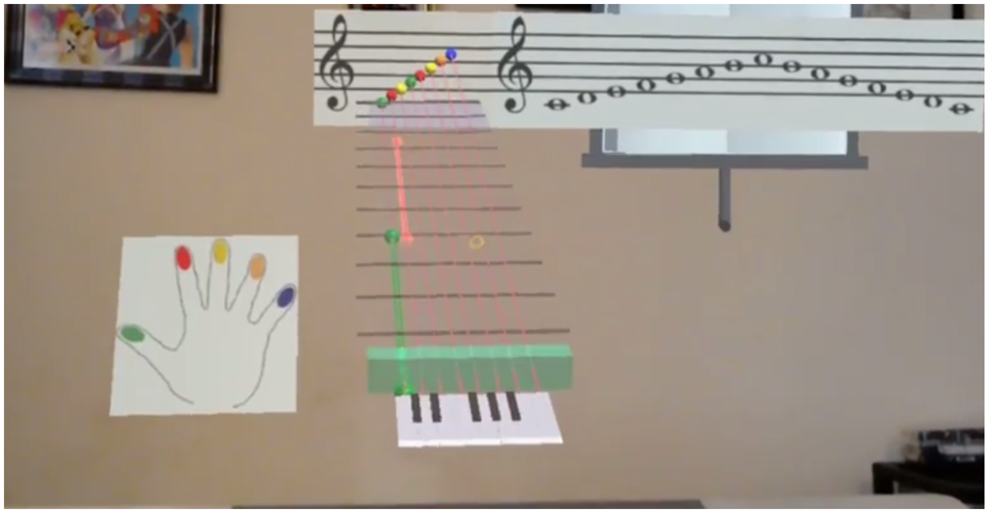

Figure 1.1: Final prototype of KeynVision.

and an application has been developed to utilize those features, a user will likely perceive the technology to be highly useful. If a user believes that the use of the technology would result in an enjoyable experience, while being perceived as useful, this will increase the likeliness of the user integrating the technology in their learning. There is also an aspect of gamifying a learning experience to make it more appealing for users, especially younger students, potentially increasing attitudes towards learning [Long and Aleven 2014]. However, it is unclear how effectively a gamified learning experience can transfer knowledge towards the desired task. This is because in most cases where students engage in a gamified educational experience they often develop in-game skills but rarely show significant improvement for the desired skills outside of the game.

1.1.1 Multimedia Learning, Learning Systems, and Games

Multimedia learning studies mental representations of words and pictures and has been strongly influenced by Richard Mayer's cognitive theory of multimedia learning [Mayer 2012]. All that is required for multimedia learning to take place is a dual-channel setup for visual and auditory information. The learning system should be structured as to limit the cognitive load of the user by understanding the demand being put on the three memory stores (sensory, working, long-term) as well as the five cognitive processes (selecting words, selecting images, organizing work, organizing images, and integrating new knowledge with prior knowledge) [Sorden 2012]. What makes multimedia learning effective is that the user can make meaningful connections between the images and audio information that is provided to them through the learning system. When a user can make these meaningful connections, it leads to them having a deeper learning experience than they could have with words or pictures alone [Sorden 2012].

Learning systems can be defined as an environment that contextualizes a specific educational goal or predefined learning task. Video games are capable of teaching in powerful ways, however teaching methods that are found in effective educational games can be implemented into non-gaming learning system. "The best game learning, whether in or out of school, offers guidance, mentoring, smart tools, well-designed and well-organized problems, feedback, and language just-in-time and on demand" [Gee 2013 p.148]. Because learning is so deeply tied with experience, students tend to process information more efficiently when they can take newly acquired information and use it as a tool to solve a new but similar problem. Teaching that focuses on the retention of facts may lead to passing paper-and-pencil tests but will not lead to the development of problem solving skills. "Teaching that focuses on problem solving and that uses facts as tools to solve problems leads both to fact retention and problem solving" [Shaffer 2008].

The gamification of intelligent tutoring systems will often result in providing students with a beneficial and engaging learning experience. This is possible when students can be entertained while engaging with an experience that contextualizes relevant information that can continue to be generalized and used as a platform for new knowledge to further be built upon. Video games allow for the opportunity to improve learning because they are a good medium for taking advantage of sensory stimulation that will allow for more effective learning. Despite gamification of tutoring systems having a potentially positive effect on the learning experience they don't always result in a successful transfer of learning. [Balog and Pribeanu 2010] found that tutor-like assistance can lead to better learning and interest, compared to game-like assistance in an educational game of policy argument. Intelligent tutoring systems are designed based on teaching methods that are supported by literature review and have been tested in qualitative studies to be effective at aiding students in the learning process. What they lack is providing students with the level of engagement that can be found in an interactive gaming experience. The problem comes from the fact that many educational games fail to improve the student at the skill they are trying to learn outside of the game.

1.1.2 AR in Education and Training

Augmented reality has a strong potential in education because it allows for contextual on-site learning and it can provide a sense of exploration. Users tend to have a sense of discovery as they begin to see the relationship between the augmented digital content and how it relates to the physical environment [Johnson et al. 2010]. Lee [2012] have suggested that learners can strengthen their understanding of a topic with the use of virtual and augmented reality. This is because these technologies provide more opportunities to relate different aspects of a task or skill in ways that are convenient and easier for people to process mentally.

Interactive, situated, and collaborative problem solving affordances of AR simulations tend to be highly engaging. Although AR simulations provide added value to the learning experience, it simultaneously presents unique technological, managerial, and cognitive challenges to teaching and learning. Despite the overall expansion of sophisticated technology, typical classrooms rarely leverage AR interfaces for teaching and learning immersive participatory simulations [Dunleavy et al. 2008].

Multimedia can be used to enhance present guidelines for making individual practice more beneficial by disguising laborious tasks as games. Augmented reality can be used to create a more direct interaction between students and the system. Azuma [1997] describes augmented reality as creating an environment in which the user sees the real world with virtual objects superimposed upon it. The main advantage of augmented reality is that a perceptual and cognitive overlap can be created between physical objects and instruments and how we use them. To make an effective AR application for piano learning, it is important to determine what the minimum requirements for the system will be. One of the major difficulties that beginners run into is mentally translating a note from the written score to the physical key on the keyboard [Shacklock 2011].

1.2 Piano Practice

The piano is an instrument that is enjoyed by people all around the world and is used in just about any genre of music. Playing the piano, like any instrument, is a skill that takes years to develop and is often a lifelong commitment. As people get older, scheduling time to learn how to play an instrument does not typically fit into their daily life. This feeling of not being able to develop skills to play piano can be amplified when a person considers that well-trained pianist often practice for three or more hours a day. Learning how to play the piano is difficult for several reasons, despite the many challenges that come with learning to play piano, with dedication, effective learning tools, and the guidance of an instructor, anyone can learn to play the piano.

1.2.1 Motives for Playing

There are several reasons why people tend to want to be able to play the piano or keyboard, such as to play in a band or choir, to express themselves, or for the pleasure that it brings them [Uszler 2000]. Even though there may be people who have an interest for playing an instrument like the piano, they may never come around to doing so. There are several reasons that could potentially explain why someone who has an interest for playing piano never ends up doing so. It can be very costly for someone who has an interest in playing the piano to start if they do not already have a keyboard, not to mention paying for a piano instructor. Although some may have financial issues, others may have problems believing that they can play the piano or any musical instrument. This type of thinking can lead to a feeling of intimidation which is common among first time piano players because beginners tend to have unrealistic goals for themselves. When a student has unrealistic expectations of learning to play the piano, they may become disappointed with their current skill level or their inability to play the way they want to and the frustration that this brings can cause some students to want to quit. What most beginners do not realize is that developing skills to play the piano takes days, weeks, months, and years of practice before results can be clearly seen. That is why it is important for someone interested in learning to play the piano to know how to set realistic goals for themselves or have someone who will help them stay focused on goals that are within the student's skill range.

1.2.2 The Role of the Instructor

Many beginners may be eager to start playing the piano but how they do will often differ. Some would rather try to learn on their own by using external sources such as books, musical training apps or watching tutorials online than to pay for a personal instructor. However, often when someone plays piano without the help of an instructor, especially during the early stages, they are likely to develop bad habits in technique and posture that will hinder their overall ability to play the piano at a proficient level. If for example a beginner has access to learning tools that effectively convey to them fingering patterns and pictures they may be able to make progress playing on their own while avoiding bad habits. However, the biggest problem people will face when they first start learning to play the piano is that when they sit in front of the keyboard for the first time they are likely to be making ten or twenty mistakes the instant they rest their hands on the keyboard. If they remain oblivious to their mistakes, they may be able to push through and learn a few simple songs but in the long run, they will deal with the challenge of having to unlearn their bad habits or overcoming later learning curves will be impossible. The best way for an absolute beginner to learn proper technique and posture is in the presence of someone with a great deal of experience at their side who can guide them along the way [Chang 2016].

1.3 Transfer of Learning between Tasks

Transfer learning, also known as inductive learning, is a research problem that focuses on storing knowledge gained while solving one problem then applying that new knowledge to a different yet related problem. Transfer of knowledge can be said to have happened if a task a person partakes in has led to improvements in another task that is new to the user and requires similar skills to complete. Transfer learning is structured in a way where the new skill the user would like to learn is called the target task whereas the task that is being practiced (where transferring takes place) is called the source task. The goal is to improve learning in the target task by leveraging knowledge in the source task. Transfer may be possible if the performances that come from executing a source task can develop similar skills in a target task only using transferred knowledge [Torrey and Shavlik 2009].

One of the major challenges that comes from developing transfer methods is being able to produce positive transfer between two appropriately related tasks while avoiding negative transfer between tasks that are less related. Transfer reinforcement learning speeds up of the learning process because students would most likely spend much of their time doing unnecessary exploration before finding an effective practice method. How effective the transfer of knowledge towards the target task is dependent on the relationship it has with the source task. If this relationship is strong and the transfer method can take advantage of commonalities, the performance in the target task can significantly improve through transfer.

However, it is important to be cautious because the opposite will result in failure to improve in performance and could potentially even decrease it as well. In an ideal situation, transfer methods should produce positive transfer between tasks while avoiding negative transfer.

1.4 Participatory Research

Participatory design can draw on various research methods but the core element of this approach is centered around iteratively constructing the design based on interactions of the designer/researcher and the participants who will use the design. The core of participatory design is to productively examine tacit, invisible aspects of human activity through design partnerships in which researcher-designers and participants cooperatively design artifacts, workflow, and work environments. The partnership must be conducted in an iterative way so that researcher-designers and participants can develop and refine their understanding of the activity. The developers of participatory design believed that tacit knowledge of the participant and the abstract knowledge of the researcher must be bridged, with each party valuing the end goal equally [Spinuzzi 2005].

Participatory design's object of study is the tacit knowledge developed and used by those who work with technologies because tacit knowledge is typically difficult to describe and design for. Tacit knowledge is implicit and holistic because it is what people know without being able to articulate. When using the tool perspective, you allow yourself to recognize how the tool that is being researched can be further developed to support the needs of the user rather than disrupting their natural flow. Something that is very important to using participatory design is being able to describe the users' tacit knowledge and taking it into account when building new systems. The main idea is that the new system that is being created based one the participatory research is that it empowers the user who the product is made for.

Participatory design research tends to be quite flexible and can be put into tree basic stages in almost any situation when conducting this type of study. The first stage is the initial exploration of the work where designers meet the users and familiarize themselves with the users and their way of working. The second stage is the discovery processes where designers and users employ various techniques to understand and prioritize work organization and envision how things can potentially work. This is the time where both designer and participants get the chance to clarify goals and to agree on the desired outcome of the project.

The final stage is prototyping which is when designers and users iteratively shape technological strategies to fit into the work flow.

Methods can also be grouped into three stages as well where the first stage is the initial exploration of the work. This stage draws on observations, interviews, walkthroughs, and examinations of artifacts. The second stage of developing a method for participatory design research is the discovery processes. This is the stage where researchers and users interact with each other the most. Techniques that have been used in the past to generate a deeper understanding of tacit knowledge are things like organizational games, role playing games, organizational toolkits, storyboarding, and workflow models. The final stage is to prototype where a variety of techniques for iteratively shaping artifact can be applied. Mockups and paper prototyping are examples of ways to start the prototyping process but what's most important is that results are disseminated in forms that users can understand.

Some say that limitations of methodology for participatory design exist because it mainly focuses on empowering workers and does not lend itself to radical change. Sometimes participatory designers can tend to focus too narrowly on artifacts rather than the overall workflow which does not lead to empowerment for the overall user activity. The method of participatory design studies can be described as exploring, approximating, then refining. The participatory designer plays the role of initiating and sustaining significant change at the research site. For some people this can be problematic because they think that it is possible that the researcher and the participant may assume to understand what the other is thinking and may "discover" what they wanted to discover. This can be less likely to happen if working in groups and building off one another [Wilkinson and Angeli 2014].

1.5 Purpose of Study

By working closely with piano instructors, I aimed to uncover what types of visual references and practices best aid in the transfer of learning when developing a piano training application for the HoloLens. I presented a panel of experts, i.e. professional piano instructors, with a variety of AR and non-AR piano training applications that have been created or are in the process of being developed. Once the panel had an idea of what the technology does, they provided their insight towards important aspects of teaching and learning to play the piano that they saw as important to consider while developing an AR piano training application. I used the information gathered from my panel after a series of iterative playtest sessions, considering feedback relating towards the design of the application and how the technology is being implemented to the learning experience. By doing this, we hope to discuss ways that the HoloLens and the application that was created can further be tested to be able to better determine how effective of a learning tool it is for learning piano. We hope to create a framework for applications that want to demonstrate features and learning support that professional music instructors can get excited about and believe are most useful for the teaching and learning processes.

Chapter 2: BACKGROUND AND RELATED WORK

The sources discussed in the following were used to strengthen my understanding of the explored technology, research principles, and music-related augmented reality applications that have been made or are in production at the time of writing. The sources describe the basics of AR application, history, and various ways the technology can be used in research and business. Articles relating to participatory research are also discussed that well be used to determine how I will engage my panel of experts in my project. Furthermore, I have included research on mental practice as a reference for discussing how the panel of experts regards the importance of this topic, in order to determine if AR could potentially be helpful in the development of mental imagery exercises.

2.1 Piano Pedagogy

In this section, we take a look at sources that helped us gain a stronger sense of basic principles that relate to piano development as well as the influences of mental practices and multimedia learning. By increasing our understanding of how piano development is approached and how pianists develop their technique over time, we will be able to analyze the current user experience and potentially find new ways to aid in that process. While researching the influences of mental practice as it pertains to music learning, we were able to validate the importance of visualizing music and how a strong mental picture of a task will result in a longer lasting memory of how that task is executed. It is because of what we learned about mental practice and the potential influences AR may have on how students visualize music, that causes us to question if the use of AR can potentially lead to a stronger retention of exercises practiced. We conclude this section with an article that discusses principles of cognitive learning through multimedia elements. This paper serves as the foundation of our research because it explains that people do learn more effectively when they are provided both visual and audio sources at the same time, compared to just one. We also learn the limitations of the human mind and how we can make it easier for students who learn from a multimedia application.

2.1.1 Fundamentals of Piano Practice

For a student to develop effective methods for practicing the piano, they must understand proper techniques associated with playing the piano. One common misconception relating to technique is the importance attributed to the dexterity of the fingers. The acquisition of technique is a process of nerve development that takes place mostly in the brain and is not based on the development of finger strength. Technique is enhanced when someone has played a large variety of piano passages over a long period. The ability to play piano passages with proper technique is not a result of dexterity, but an aggregate of many skills that were developed over time. "These skills are acquired in two stages: (1) discovering how the fingers, hands, arms, etc., are to be moved, and (2) conditioning the brain, nerves, and muscles to execute these with ease and control" [Chang 2016 ch.1.I.2].

A student's ability to accurately play a piece on the piano will correspond to their overall technique. This can be divided into three components: intrinsic, limber, and conditioning. Intrinsic relates to the student's skill level and limber refers to the warming up of the hands before the student can play efficiently. The conditioning component relates to what the player has conditioned their hands to do over last few days or weeks. If the hands have adapted to a different job, then it could result in the player not being in the right condition to play the piano. "Defining the components of technique is important because these definitions enable the identification of the exercises that are needed" [Chang 2016 ch.1.III.7.1]. It is important for a student to be careful not to fall into the habit of practicing mindlessly because the results can be harmful to their development and overall performance. The purpose of an exercise is to increase stamina; however, most students have plenty of physical stamina but not enough mental stamina. Therefore, mindless mechanical repetition is not beneficial to performance and often will hinder the learning experience. Scales and arpeggios do not fall under the category of mindless repetition and should be practiced diligently because of the numerous necessary techniques that are acquired through using them (including thumb over, flat finger positions, feeling the keys, velocity, parallel sets, glissando motion, tone/color, how to reverse directions, supple wrist, etc.) [Chang 2016].

2.1.2 Mental Practice in Music Memorization

This study describes mental practice (MP) in music memorization, regarding individual differences in other MP strategies used in other studies. Mental Practice is defined as a technique by which someone with the intent to practice creates a mental representation of a preconceived idea or action to enhance performance [van Meer and Theunissen 2009]. MP is shown to have been investigated as a potentially useful practice technique in fields such as athletics, rehabilitation, and music. MP has a moderate to significant impact on performance but is not as effective as physical practice (PP). The effectiveness of MP increases when the task involves a significant amount of cognitive and symbolic skills and when the subject has a lot of experience with that specific task. This makes music performance an excellent model for studying MP because it is made up of complex cognitive elements. MP techniques for musicians include analysis of the score, listening to a recording of the song, auditory imagery of the pitches, imagining movement, and visualizing the score. Overall, MP is more effective than no practice but not as effective as PP.

Types of MP strategies that have been used in previous experiments required that the subject were to only focus on a specific type of MP and to avoid using others. The authors of this study list a few good reasons why these constraints may have significantly altered the MP processes from what a musician is used to doing in their daily life. Experiments that asked their subjects to include or exclude specific MP strategies are guided by the assumptions about which strategies constitute the very core of MP and might not be particularly relevant to the musician. Such experiments do not consider how much the selected strategy meets each subject's personal preferences, habits, or abilities. Also, asking a subject to maintain the same strategy throughout the process of the experiment does not allow the subjects to flexibly change their approach to optimize the learning process. There is also a question of experimental control of a study designed to focus on a specific MP strategy because it is not possible to identify if each participant fully eliminates the use of undesired MP strategies. That is why this study attempts to uncover if certain MP patterns are more effective than others as well as if MP is more effective when it is freely used compared to other studies who used constraints.

The experiment that was conducted consisted of sixteen pianists and gave them two Domenico Scarlatti sonatas of equal length and challenge. Each subject was asked to learn both pieces, one by MP and the other with PP on separate days. After each subject finished their practice sessions they were asked to perform the piece from memory. Data was collected by developing a questionnaire that was divided into six sections: Registry information, MP-abilities, MP-habits, MP strategies, external resources, and solfege (the application of the sol-fa syllables to a musical scale or to a melody). The subjects were provided statements that they had to rate on a 10-point scale ("1" = "never" to "10" = "always") that recorded what aspects of MP the participant was using. During the MP phases subjects were free to use whatever practice method they preferred, except for physically playing a real piano. During the PP sections the participants were asked to focus on physically practicing the piece while ignoring mental images and avoiding any type of analysis of the piece as the practice. During all the practice conditions, after each ten-minute phase subjects were asked to fill out the questionnaire documenting the mental strategies that they had been using. The rating scale was used to determine how often the subject used strategies such as mental hearing of notes, imagining the feeling of moving their fingers, visualizing the movement of fingers, visualizing the score, harmonic analysis, rhythmical analysis, and melodic analysis. Individual differences in mental imagery were tested by using the standardized questionnaires USOIMM77 [Antonietti and Colombo 1996-1997], Motor Imagery Questionnaire-Revised [Hall and Martin 1997], and Verbal-Visual Strategies Questionnaire [Antonietti and Giorgetti 1996]. MIDI data was used to compute objective parameters of performance relating to the number of notes played and the ratio between the number of wrong notes and the total number of notes played. This ratio was used to determine performance accuracy which helped to make sure each subject was being observed equally because each participant did not perform the exact amount of each piece by the end of each session. Participants were then rated on the correctness of notes, articulation, dynamics, and the global score.

The findings reported that mental practice processes were always active during physical practice, although subjects were asked to avoid the use of them and the subjects tried to comply. Questionnaire data shows that PP intrinsically implies MP processes and from a cognitive point of view, MP appears to be an involuntary strategy used when facing a musical task. When comparing post mental practice and post physical performances it is shown that MP alone allowed a level of proficiency between 40 (percent) and 60 (percent) of that achieved by PP. Combining intense mental practice with short physical practice can lead to results that are very similar to continuous physical practice. If a musician optimizes their time for both mental practice and physical practice they can reach almost the same performance level as they would if they were to just physically practice. At the end of five days, the mental practice group's performance was like that of the group who physically practiced the piece on day three. Those who were in the mental practice group could play at the same level as those who were in the physical practice group after a single session of physically practicing the piece with the score available to them. Formal analysis as a MP strategy was expected to lead to better performances because building a formal structure of the music allows the performer to use memory retrieval techniques that are based on hierarchical scheme and organization of both how the player practices the piece as well as how they memorize it. The observations that were made in this study lead to the conclusion that effective memorization of music by mental practice requires a mental representation of how the music sounds and the use of external models can be effective ways to support practice, if they clearly help to build up an auditory/structural mental representation when the model is no longer there.

2.1.3 Cognitive Theory of Multimedia Learning

Multimedia learning is a cognitive theory of learning that was first popularized by Richard Mayer [Sorden 2012]. Multimedia learning is made up of mental representations of words and pictures, these theories have largely been defined by Mayer's cognitive theory of multimedia learning. "The theory can be summarized as having the following components: (a) a dual-channel structure of visual and auditory channels, (b) limited processing capacity in memory, (c) three memory stores (sensory, working, long-term), (d) five cognitive processes of selecting, organizing, and integrating (selecting words, selecting images, organizing work, organizing images, and integrating new knowledge with prior knowledge), and theory-grounded and evidence-based multimedia instructional methods" [Sorden 2012 p. 01].

Multimedia researchers generally define multimedia as a combination of text and pictures. Multimedia learning occurs when mental representations from words and pictures are made. The theory centers the idea that learners build meaningful connections between words and pictures and that this allows them to learn more deeply than they could have with words or pictures alone. "According to CTML [Cognitive Theory of Multimedia Learning], one of the principle aims of multimedia instruction is to encourage the learner to build a coherent mental representation from the presented material" [Sorden 2012 p. 02].

Meaningful learning from words and pictures happens when the learner engages in cognitive processes such as using relevant words or images when processing verbal working memory, organizing selected words or images into a verbal or pictorial model, and integrating representation with each other and prior knowledge. Working memory ultimately determines how information is handled by managing retrieval, integration, and the construction of new knowledge. Knowledge that is created in working memory can be transferred to long-term memory through a process known as encoding. For proper encoding to occur, many hours of rehearsal are required. For multimedia learning to be effective it must be designed to allow for an adequate period of usage. Mayer also describes that effective multimedia learning should require the learner to actively be constructing new knowledge as they are moving forward because meaningful learning is knowledge that can be applied to new situations.

Cognitive load represents a limit to the amount of information that a person can process at one time. When working-memory capacity is exceeded and cognitive overload occurs a person will be likely to have a hindered learning experience. DeLeeuw and Mayer [2008] theorize that there are three types of cognitive processing (essential, extraneous, and generative). Multimedia learning and instruction must manage essential processing, reduce extraneous processing and foster generative processing so that the user can effectively build the necessary mental connections. When making a multimedia lesson the design must be learner-centered and not technology-centered. It is important to look at the learning experience from the perspective of the learner and to understand their limitations as best as possible.

To provide instruction via multimedia, consider the three types of cognitive load as described by Mayer [2009] and their corresponding principles. Reducing extraneous processing can be done when consideration has been given to coherence, signaling, redundancy, spatial, contiguity, and temporal contiguity. To better manage essential processing for a multimedia learning experience, the use of segmenting, pre-training, and modality principles should be considered. Lastly, when fostering generative processing, multimedia, personalization, voice and image principles are most effective in this area. In recent years' boundary conditions, have been included to help determine the effectiveness of some of the principles. One example is the expertise-reversal effect that suggests that techniques that prove to be effective for novice learning can be extraneous towards experts.

2.2 Game-based Learning

In the following section, we will be discussing theories and projects that relating to game-based learning that influenced how we conducted our research. We take a look at an article by Moi [2016] that discusses the positive influences game-based learning experiences provides for its users. This article also helped us to understand common attributes that are attributed to applications that educate its users through a game-like experience. Then we discuss Long and Aleven [2014] on potential adverse effects of game-based learning applications. This article helps us to gain some perspective on the gamifying of tutoring systems so that we can better gauge what we should consider as we develop our training application. In Torrey and Shavlik [2009], we learn about the nature of transfer learning in order to discuss the likelihood that students will be capable of transferring knowledge from the learning application towards piano playing without the aid of AR. We take a look at the work of Balog and Pribeanu [2010] in order to better determine how likely it is that users would find AR to be a useful tool in an educational scenario. This article allowed us to better determine priorities for an application to be appealing not just because of the novelty provided by using new technology but the supportive use of the technology for the learning experience. To complete this discussion of gamification of learning systems, we conclude with an article by Gee [2013] on creating learning systems. Finally, we end with an example of a project conducted by Gaggioli et al. [2004] that demonstrates the use of an interactive learning system that helped to improve the use of peoples' limbs, with the help of computer generated imagery.

2.2.1 Students Algebraic Thinking and Attitudes towards Algebra

In this study, the authors Moi [2016] researched how the android app DragonBox 12+ influences students attitude towards learning algebra. A quasi-experimental approach was used when conducting the experiment and comparisons were made between an experimental group and a control group (n = 30 each). Pre-Post tests were used to track algebraic thinking throughout the experiment and a Fennema-Sherman questionnaire was used to measure the student's attitudes towards algebra. Students who used the DragonBox 12+ game were shown to have significantly higher mean scores in algebraic thinking and attitudes compared to the control group.

Students who build up their skills in algebra develop problem-solving, representation, and reasoning skills. The task of solving an algebra equation consists of manipulating equations by performing the same operation on both sides to form a newly written equation with the same value. Areas where early middle school students tend to struggle the most when they are first being introduced to algebra are the concepts of algebraic notation, variables, functions and properties of numbers. Video games allow for the opportunity to improve learning in these areas because they are a good medium for taking advantage of sensory stimulation which allows for more effective learning. Sensory stimulation can be triggered by using images, sounds, animations, and interactivity.

DragonBox 12+ is a video game app designed to aid students between 12 and 17 years of age learn the basics of algebra such as property of addition and subtraction, expansion, operations of variables, and factorization or substitution. The player earns points by solving algebra problems that have been designed using the *RETAIN model* which is used to support game-based learning. These dimensions are described as Relevance, Embedding, Translation, Adaptation, Immersion and Naturalization. Relevance is obtained when content that is being delivered to the player is relevant to their learning needs and contextualizes the task within the system of the game. Embedding is the extent to which academic content can combine with content of a gaming application but also shows the level of student's potential to appreciate or be distracted while in game. Ultimately, an educational game should make learning a natural feeling experience so that the skill that the player learns is a byproduct of playing. Translation describes problems that require similar skills that the player will need in order to solve. Translation occurs when problems are restated in a different form or other context that requires the player to apply existing information to solve. The process of transfer and application of knowledge to a new situation is a part of learning. Adaption occurs when a student cognitively assimilates and adjusts newly learned knowledge to conform into solving an unfamiliar problem. Assimilation is associated with how students interpret events in terms of what they already know while adjustments are related to the transfer of newly established and constructed knowledge. Immersion is measured based on how much interacting the player can do in the game. Finally, naturalization is defined as usefulness of cognitive domains, which is to say, students can apply the learning information without deep thinking.

The findings in this research shows that DragonBox 12+ helps to enhance algebraic thinking and attitudes toward algebra among students. The research shows us that DragonBox 12+ is a good example of what it looks like to give students a game that makes them actively engage in solving problems by utilizing the six dimensions of effective interactive learning experiences. The effects DragonBox 12+ has on students shows that an educational game is most effective when it can entertain the user while staying contextually relevant.

2.2.2 Gamification of Joint Student-System Control over Problem Selection in a Liner Equation Tutor

Intelligent Tutoring System (ITS) researchers are interested in finding out the best way to integrate game elements within a tutoring environment. Some studies suggest that game-based learning can lead to improved scores and can produce similar results as nongame educational environments. Gamification of ITSs can lead to many positive outcomes but unfortunately it is not always successful. In Using Tutors to Improve Educational Games, Long and Aleven [2014] found that tutor-like assistance can lead to better learning and interest compared to game-like assistance in an educational game.

One aspect of commercial games that provides an added benefit towards their use of gamification is the possibility to re-do problems after they have been completed. This aspect of gamification is usually emphasized by incorporating a scoring system that tells the player their performance. A scoring system can be created to provide rewards for players that complete a level more than once or for beating their best score. This is important because the player re-practicing levels could result in the student developing an efficient acquisition of problem-solving skills. "Although this seems like the obvious answer it has not been established definitively in the cognitive science literature... It is possible that frequent re-practice may reduce problem variability and therefore be detrimental for learning" [Long and Aleven 2014 p. 379].

The experiment the authors conducted consisted of a gamified linear equation tutor that had a scoring system and different rewards for each level. They hypothesized that the ability to repeatedly practice a level would enhance student learning and engagement. Rewards based on students' performance was also expected to lead to better learning and engagement as well.

190 students participated in the study and completed the pre-and post-tests throughout multiple schools, which led to the use of a Hierarchical Linear Modeling method to analyze the test data. All five conditions for Lynnette improved significantly on the shared procedural items as well as students' overall test scores. By comparison, the students who used DragonBox did not show significant improvement on any of the three categories of test items from pre- to post-test. Students who did not see rewards for their performances ended up having better results than students who did get rewards. Students who completed the same problems multiple times were recorded as learning less compared to students who did not re-start problems. Enjoyment was recorded to have been higher for students who had spent their time playing DragonBox, compared to students who were in the group who used Lynnette.

Although gamifying ITSs has become more of a popular theme in ITS development, the beneficial features of gamification are circumstantial based on how well tutoring features have been implemented into the experience and whether the user finds using the learning application enjoyable. "The two gamification features held up well in the class room but did not foster the expected higher enjoyment or learning gains [...] We did not find a significant difference between the experimental (gamified) Lynnette tutors and the control Lynnette with respect to enjoyment or learning." [Long and Aleven 2014 p. 379].

This means that gamifying tutors by incorporating common game design patterns does not automatically result in a more effective means of teaching and learning. An unexpected result that came from this research is that the students who could repeat completed problems to receive rewards performed significantly worse than their counterparts who could re-practice problems that had added rewards for extra completion. "A possible explanation is that the urge to earn more stars pushed the students to re-practice, yet re-practicing previously-seen problems is not an optimal strategy for learning as compared to practicing new problems." [Long and Aleven 2014 p. 385].

It is a common practice in ITSs that students are presented new problems that target the same skills, instead of making the student repeat the same problems that they have already completed. During the RePr+Rwd condition there were significantly more re-starts of problems as well as a large percentage of students having poor results on the post-test. This shows that performance-based rewards can influence students' study choices but it also calls attention to the importance of guiding students towards making optimal choices. “Although the combination of re-practicing with performance-based rewards is a very common design pattern in games, its implementation in tutors should be handled with care” [Long and Aleven 2014 p. 386].

One potential way of showing the student their results that might lead to a more constructive learning experience could be to show them data visualizes that summarize their performance. Finally, this paper illustrated that an ITS can help students learn more effectively than a commercial educational game. Students in the tutor conditions showcased higher learning gains than students who used DragonBox, in spite the fact that students who used DragonBox solved up to four times as many problems. These results further indicate that DragonBox is ineffective in helping students acquire skills in solving algebra equations. Although DragonBox was more engaging than the tutor, the authors believe that the game may be falling short because of the context used to hide equations during much of the game makes it harder to portray the connection these rules have towards standard algebraic notation and transformation rules. “It is not that there is no learning in DragonBox – there is plenty of it, as evidenced by students’ progression through the game levels. However, the learning that happens in the game does not transfer out of the game, at least not to the standard equation solving format. [...] What matter is not within-game learning, but out-of-game transfer of learning, and the two cannot be equated.” [Long and Aleven 2014 p. 386].

2.2.3 Transfer Learning

Transfer learning, also known as inductive learning, is a research problem that focusses on storing knowledge gained while solving one problem then applying that new knowledge to a different yet relatable problem [Torrey and Shavlik 2009]. Transfer of knowledge can be said to have happened if a task a person partakes in has led to improvements in another task that is new to the user and requires similar skills to complete. Transfer learning is structured in a way where the new skill the user would like to learn is called the target task whereas the task that is being practiced (where transferring takes place) is called the source task. The goal is to improve learning in the target task by leveraging knowledge in the source task. Transfer may be possible if the performances that come from executing a source task can develop similar skills in a target task only using transferred knowledge. One of the major challenges that comes from developing transfer methods is being able to produce positive transfer between two appropriately related tasks while avoiding negative transfer between tasks that are less related.

Transfer reinforcement learning speeds up the learning process because students would most likely spend much of their time doing unnecessary exploration before finding an effective practice method. How effective the transfer of knowledge towards the target task is dependent on the relationship it has with the source task. If this relationship is strong and the transfer method can take advantage of commonalities, the performance in the target task can significantly improve through transfer. However, it is important to be cautious because the opposite will result in failure to improve in performance and could potentially even decrease it as well. In an ideal situation, transfer methods should produce positive transfer between tasks while avoiding negative transfer.

2.2.4 The Role of Perceived Enjoyment in the Students Acceptance of an AR teaching platform: A Structural Equation Modelling Approach

This study investigates the interest and engagement students have when using AR technology during learning experiences [Balog and Pribeanu 2010]. A model is designed to capture both extrinsic and intrinsic motivators so that the intention of students who use new technology for learning may be explained. The results discussed in the article show that perceived usefulness and perceived enjoyment have a significant impact on the behavioral intention to use AR teaching platform. This study carries both pragmatic and hedonic characteristics because the application should be easy to use while being useful for learning. By comparing models by Hassenzahl and Tractinsky [2006], and UX evaluations by Cockton [2006] and Roto [2007], the authors hypothesize that the evaluation of interactive systems should be beyond pragmatic and hedonic aspects measured in isolations. Therefore, their goal was to investigate the user's acceptance to understand the various factors that influence a user's intention to use AR technology during learning experiences. They integrated user experience constructs and suspected that a technology acceptance model would bring insights on relationships between UX and other factors that influence intention to use. The relationship between hedonic and pragmatic aspects of incorporating technology to learning environments underlie motivational and educational value of the device that is being used. "A well-known model aiming to explain and predict technology acceptance is TAM (Technology Acceptance Model), developed and validated by Davis [1989], and Davis et al. [1992] ... The TAM model posits that two beliefs, perceived ease of use and perceived usefulness, determine one's behavioral intention to use a technology. In a later study, Davis et al. [1992] introduced perceived enjoyment in the model as an intrinsic motivation and defined perceived usefulness as an extrinsic motivation" [Balog and Pribeanu 2010 p. 319].

Perceived enjoyment was defined as "the extent to which the activity of using the computer is perceived to be enjoyable in its own right, apart from any performance consequences that may be anticipated" [Davis et al. 1992 p. 1127].

Therefore, perceived enjoyment is a form of intrinsic motivation which emphasizes on the pleasure that is a result of a specific activity. Perceived usefulness has a large effect on the user's intention of adopting a technology and the influences are then complemented by any perceived enjoyment. "The purpose of this paper is to evaluate the validity of the measurement model and to explore the casual relationships between the factors influencing the user's acceptance of an augmented reality teaching platform" [Balog and Pribeanu 2010 p. 320].

The authors hypothesized that the intention to use AR as a learning tool is influenced by both perceived ease of use and perceived enjoyment. The impact of perceived ease of use and perceived enjoyment have been documented in numerous studies in TAM research [Bruner and Kumar 2005; Van der Heijden 2004]. A learner's perceived ease of use is likely to be influenced by the devices used to perform specific tasks. Although AR devices tend to be harder to use than more traditional tools, they may provide a greater intrinsic motivation for learners because of the novelty and versatility that new technology is associated with. Based on this reasoning, the authors continue to hypothesize that ergonomics of the AR platform has a positive effect on perceived ease of use as well as a positive effect on perceived enjoyment. The experiment was conducted using two AR-based learning scenarios and a total of 139 students where each student tested the learning platform twice. Each scenario consisted of a demo lesson and a verity of exercises for the students to do. Later they were asked to answer a questionnaire that were used to ascertain the representativeness of the data in both learning scenarios (Biology and Chemistry). The results were compared and showed that there were no significant differences between the two sets of data and were used to justify the remainder of the study.

The findings add further evidence for the adaptability and applicability of TAM explaining students' intention to use technology in learning. The results show that both perceived enjoyment (an intrinsic motivational factor) and perceived usefulness (an extrinsic motivational factor) are important. Perceived enjoyment is a stronger determinant of perceived usefulness than its perceived ease of use, which suggests that an enjoyable learning experience increases the usefulness of an AR teaching platform. The influence of perceived enjoyment was slightly higher than that of perceived usefulness on the intention of use. Thus, perceived enjoyment is just as important as perceived usefulness when determining the behavioral intention to use an AR application as a learning tool.

2.2.5 Learning Systems, Not Games

Textbooks are an example of a learning tool that is crafted and structured with a one-size-fits-all approach, which ultimately makes them ineffective learning tools. Today, digital games are at the center of attention as the tool that people want to use to teach with but just like with textbooks, games have affordances to do some things well and some things less well. Effective learning is made up of a complex system in which the mind, body, time, space, language, and tools all interact with one another. Video games are capable of teaching in powerful ways, however teaching methods that are found in effective games can be implemented into any learning system. “The best game learning, whether in or out of school, offers guidance, mentoring, smart tools, well-designed and well-organized problems, feedback, and language just-in-time and on demand” [Gee 2013].

Students tend to learn primarily from experiences had and shared with others, specifically when they can associate patterns throughout their experiences. With the help of good teachers and enough time the student will eventually be able to generalize from these patterns and form larger generalizations or principles. “Words in a text or textbook gain their meanings from the experiences people have had, not from definitions in terms of other words. The words in a manual for a game are about the actions and images in the game; the words in a biology text are about the actions and images in the world as biologists engage with it. The game or the world of plants, animals, and cells is what gives meaning to the game manual or the biology text. If a student has no experiences (no actions or images) associated with a text, the student cannot understand the text deeply” [Gee 2013]. Because learning is so deeply tied with experience, students tend to process information more efficiently when they can take newly acquired information and use it as a tool to solve a problem. Teaching that focuses on the retention of facts may lead to passing paper-and-pencil tests but will not lead to the development of problem solving skills. "Teaching that focusses on problem solving and that uses facts as tools to solve problems leads both to fact retention and problem solving" [Shaffer 2008].

The problem with learning from experience is that it often takes a long time and students can fail to see what they should be paying attention to. The best learning experiences are the ones that are well designed and are supported with good mentoring from an involved teacher. Properties that are common among effective educational games are: They focus on well-ordered problems, develop crucial non-cognitive skills (accepting challenges, persist past failure, proactive effort, etc..), provide learners good tools for problem solving, clear goals, lowered cost of failure, provides consistent feedback, encourages the articulation of knowledge and production of new knowledge, holds learners to same standards but allows students to reach these standards in different ways, and prepares students for more advanced learning for the future [Gee 2013]. For gamers to be skilled players they must think like the designers because they must figure out how the rules in the game system work together to be able to use them to effectively accomplish the tasks in the game. When gamers have a strong understanding of these rules they can be used to modify the gaming experience to their advantage. In the same way learners, should attempt to think as a teacher, to be able to teach others what they have learned, and to be able to modify newly gathered information and use it to their advantage. "Good game designers are teachers, and good teachers are designers of good learning experiences. But, both game designers and good teachers are designing systems with lots of good types of well-integrated interactions and tools, each being used for what it is good at" [Gee 2013].

2.2.6 Training with Computer-Supported Motor Imagery in Post-Stroke Rehabilitation

This paper describes a clinical protocol in which interactive tools are used to stimulate motor imagery in hemiplegic stroke patients [Gaggioli et al. 2004]. The purpose of this process was to help patients recover lost motor functions. This protocol consists of an inpatient and outpatient base that combines physical and mental practices. The inpatient phase was conducted in a laboratory setting using a custom made interactive workbench that they called the VR Mirror[1]. Later, a portable device was used to guide the patients with mental and physical practice in their home settings. Mental practice is a training technique that the patients were asked to do which meant for them to repeatedly rehears a motor act in their working memory, without producing any overt physical action. Mental stimulation of a physical activity in working memory without the use of muscular actions can be described as motor imagery. Unlike visual imagery, where subjects imagine the environment that they move in, motor imagery takes place when someone focuses on to the kinesthetic sensations associated with body movement [Gaggioli et al. 2004].

Interactive technology was used to assist the patient in creating motor imagery that they can then use during mental practice. During the inpatient phase, patients used a movement tracking system and a custom interactive workbench called the VR Mirror. The VR Mirror displays a 3D image of the movement that the patient will perform. The patient is given a mirrored picture of the action they would do with a healthy limb which they view in an ego-centric perspective that facilitates the generation of kinesthetic motor imagery. The outpatient phase was when patients continued their rehabilitation exercises from home. A home portable device was used to display a sequence of movies that illustrate to the patient the movements that they are trying to learn. After watching the movies, the patient would imagine performing the task with their impaired arm and once the mental practice is over they practice the movement with their impaired arm. This rehabilitation technique is a combination of mental and physical practice that uses interactive technology to provide the patient visual and auditory cues that draws their attention to the underlying dynamic structure of a movement, facilitating the generation of mental imagery. The combination of audio and visual cues provided by the VR mirror greatly facilitates the patient's task in generating the kind of motor imagery required for effective mental rehearsal. Arm-tracking also played an important role by making it possible to record the dynamic features of the patient's movements while also allowing for objective, real-time comparisons between the movement of the impaired limb and an ideal performance.

[1]Note: The paper identifies the technology being used as providing a virtual reality experience but because they do not use a VR headset in their experiment and the test subject is referencing virtual content in a real environment, the experiment can more accurately be described as a mixed reality experience in today's terminology.

2.3 Augmented Reality (AR)

In this section we will review research that have tested the effects of combining AR technology with education and procedural learning. Articles in this section such as [Lee 2012] and [Radu 2014] provide a variety of examples of how AR has been used for educational purposes. We will review articles written by Henderson [2011] and Wasko [2013] that have tested the effectiveness of using an AR interface as a means of providing users instructions that will help them to complete specific tasks. In [Dunleavy et al. 2008] we are able to gain insight on what the potential learning value AR can provide to learning situations that are shared between teachers and their students. We will then review [Ozan Cakmakci and Coutaz 2006], [Motokawa and Saito 2006], and [Chow et al. 2013], which are research projects that have explored different ways AR technology can be used as a training tool for music development. Finally, we will conclude this section with a review of AR application that are currently being developed for AR.

For someone to be able to develop a well-crafted AR application it is important that they have a good grasp of how these technologies are created as well as what systems are most appropriate for the intended experience. AR applications work because a device can determine how content will be displayed based on the environmental scene as well as camera tracking capabilities. Smartphones, tablets, and other devices are capable of recognizing elements in their field of view based on what markers, optical images, or interest points are specified by the developer. Tracking also allows for the device to capture data relating to feature detection, edge detection, as well as other methods of digital image interpretation [Carmigniani et al. 2010]. When a device can successfully recognize 2D representations of a physical environment it will be able to determine how the virtual content should be displayed. For a developer to create the best experience for an AR application, it is important that they understand the three different displays that they have at their disposal. Those are head mounted displays (HMDs), handheld displays, and spatial displays [Carmigniani et al. 2010]. Each display is fundamentally different and provides its own set of benefits depending on the role of the user and the overall experience. When using a HMD, a developer has complete control over the visuals their user will see when wearing the display. If developing an application for an optical-see-through display it is possible to give a user an experience that gives them a more natural sense of the real environment. Some disadvantages are things such as the requirement to wear cameras on the user's head as well as an unnatural experience that can be caused by viewing content on video-see-through displays or time lag and jittering of virtual images that can be experienced when viewing content from an optical-see-through display. Handheld devices have several benefits such as being portable, powerful CPU, camera, accelerometer, GPS, and solid state compass. The size of displays on smartphones and tablets tends to be a problem for any application that requires a lot of virtual content or a complex user interface. Lastly, spatial displays systems can be applied with a video-see-through, an optical-see-through, or a direct augmentation. Optical-see-through displays can give a user a more natural sense of their environment and a direct augmentation display has the benefits of being able to project directly onto physical surfaces [Carmigniani et al. 2010].

2.3.1 AR in Education and Training

Here we discuss several ways AR has already been used in educational settings to help students become more engaged as they learn something new. This article discusses how AR applications can be used in both school and business settings. Their research helps us to discern the overall value of AR as a tool for education by providing an example of how this technology can be used to aid learners by allowing them to control virtual content. AR serves a powerful role in education because it is believed to have a more streamlined approach with wide user adoption due to improvements in technology [Lee 2012]. Having a better understanding of how AR has been applied to different aspects of education will greatly improve how a developer will approach making an application with the goals of helping the user learn.

Augmented reality has a strong potential in education because it allows for contextual on-site learning and provides a sense of exploration. Users tend to have a sense of discovery as they begin to see the relationship between the augmented digital content and how it relates to the physical environment [Johnson et al. 2010]. Several AR applications have been developed over the years relating to education. Learning applications have been designed for biology, mathematics / geometry, and physics. The Specialist Schools and Academies Trust (SSAT) demonstrated that teachers could use AR technology to show what organs of human beings consists of and how they look by watching 3D computer-generated models in the classroom. AR has also been used in dynamic differential geometry education, such as giving the viewer the ability to observe interesting curves, surfaces, and other geometric shapes [Lee 2012].

2.3.2 AR in Education – a Meta-Review and Cross-Media Analysis

There is a lot of research that suggests that AR systems have the potential to improve student learning, however the educational community remains unclear regarding the educational usefulness of AR. The skepticism comes from the fact that there is still little context to when AR technology is more effective than other educational mediums. In this paper the authors compare 26 publications that have compared AR versus non-AR learning methods and provides a list of positive and negative impacts of AR experiences on student learning [Radu 2014].

Based on the analysis conducted in this research the author presents a heuristic questionnaire that can be used for judging the educational potential of an AR experience. The author provided a theoretical basis to educational institutions that are interested in leveraging the educational benefits of AR by conducting an integrated analysis of various empirical research studies.

One benefit to learning with the use of AR is the increased understanding of content it provides students. Spatial structure and function is an area where students have successfully been taught about geometrical shapes, chemical structures, mechanical machinery, astronomy configurations and the spatial configuration of human organs. Language associations is another area AR has been seen to be beneficial for students. Studies that focused on teaching students the meaning of written words have resulted in improved memory, as well as reading and writing scores. Research also indicates that content learned through AR results in a stronger memory of what was learned compared to non-AR experiences. The long-term memory of students who learned about turbines using an AR experience did not significantly degrade after one week where students who learned from other media showed significant decreases in memory recall. Improved physical task performance has also been analyzed intensively in previous research projects relating to learning via AR applications. Through an AR experience, maintenance tasks are performed with higher accuracy, and learning transferred towards users being able to effectively operating machinery. Users of AR systems tend to show significantly faster speed in locating important information and show significantly less head movements. Users also tend to have faster task completion times and tend to make less errors. Users using AR support also have significantly lower cognitive load compared to other learning conditions. AR experiences have been seen to aid in the improvement of collaborative situations because digital content and work areas can be shared amongst a group of people. The final reason that has come up in many research papers is the increased motivation that students perceive when learning through an AR experience. This high enthusiasm for using new technology for learning experiences tends to lead to students to feeling higher satisfaction, having fun, and becoming more likely to be willing to repeat the AR experience.

AR technology has led to the development of complex experiences that improve the effectiveness of learning that non-AR methods cannot do as well. To have a strong sense of what aspects of AR are most influential to learning, it is important to understand the underlying technological and psychological factors which AR can leverage in an educational experience. Effective learning experiences can be created when designers capitalize on aspects of an AR medium that allows for the most affordances. How effectively an AR application can educate its users will always be determined by how well it was designed. However, factors can be generally categorized to give a sense of which technology is more effective in which areas. Applications designed for head-mounted displays are generally considered to have stronger influences with factors such as the use of audio, 3D visuals, spatial and temporal alignment, directing attention, interaction, and collaboration. Unlike books, video, smartphones, tablets, and desktops, AR applications are not limited to a 2D surface.

Mayer's multimedia learning theory postulates that the human brain has a limited capacity for processing information in any given moment and when these boundaries are strained it can lead to cognitive overload. Two lessons that are important to understand when discussing how education can benefit from digital media are known as the spatial contiguity effect and the temporal contiguity effect. The spatial contiguity effect states that students learn effectively when they are provided multiple representations of the same information while being presented closely to one another rather than far apart. The temporal contiguity effect states that students can learn more effectively when multiple representations of the same information are presented at the same time, rather than being presented one after another. AR allows developers to design applications that utilize spatial and temporal alignment to the physical world. If utilized properly, these factors can help lead to providing users meaningful choices throughout the learning experience. Systems can monitor a user's activities and provide relevant feedback, bringing into context progression that has been made, and reducing the need for the learner to switch their attention between different media.

What makes AR a powerful tool for education is when an interactive digital simulation provides students experiences that are impossible in an otherwise completely standard learning environment. Developers can create experiences that stimulate learning by utilizing a mixed reality environment because it provides the unique opportunity where the user engages in an environment where digital content is not limited to factors that objects in the natural environment otherwise abide by. Examples of this would include giving a user the ability to control the spatial scale of a functioning solar system or manipulating the appearance of the physical environment. With the ability to integrate digital content with a user's learning environment, it is also possible to use that digital information to guide the user's attention to areas that are important to completing a task. The feature has been noted during several experiments relating towards physical assembly tasks, where AR is used to guide the attention of its user by highlighting important components. This mechanism is apparent in any task being learned through AR that utilizes visual perception of the spatial relationships of objects in the user's environment.

Radu [2014] also state that educational instructions can utilize both speech tone and visual indicators to bring a user's attention towards important information relating to the scene. When combined with AR this mechanism can be further leveraged to aid students with focusing on aspects of their environment that matter most.

AR systems generally make learning easier because students can use their body to interact with the system while transferring knowledge through manipulation of digital content. Users who are presented content through AR tend to have a stronger memory of what they have learned most likely because of the physical immersion of AR experiences. When a user is free to use their body to interact with the learning environment there is a chance the user will encode tactile and proprioceptive information.

Sorden [2012], in their studies of spatial learning in AR, hypothesize that visuo-spatial comprehension is enhanced when a user physically interacts with 3D content. If the application is designed to support ease of access the user's cognitive load can be reduced significantly, helping to promote the likelihood of student exploration and creativity in the learning experience. Studies such as the one conducted by Balog and Pribeanu [2010] have shown that some users are willing to sacrifice ease of use to stay engaged with an AR experience. This could be because of the novelty that is involved with user's excitement with new technology but according to flow theory, there are multiple factors that can influence engagement. Some examples are the availability of clear feedback, internal goals, and a balance between challenge and personal skills. Ease of use has the potential to play a positive or negative role in contributing to user engagement because the difficulty of using an interface may reduce user engagement, but the difficulty could be outweighed by other factors that motivate the user to continue the experience [Radu 2014].

2.3.3 AR Interfaces for Procedural Tasks

In this dissertation, Henderson [2011] explores approaches in which procedural tasks are aided by rendered augmented reality. Henderson argues that augmented reality interface can allow individuals to perform procedural tasks more quickly while exerting less effort and making fewer errors than other forms of assistance. He builds his case by creating two prototypes where one was designed to assist mechanics carrying out maintenance procedures while the other focused on aiding in the psychomotor phases of procedural tasks. Henderson's dissertation helps us to answer questions relating to how users interact with an application intended for AR and how the application can be designed to aid in procedural tasks. To do this it is important to first ask what aspects of mixed reality will be beneficial to the procedural task problem that needs to be solved. Henderson also discusses an aspect to procedural instruction design that he calls Opportunistic Controls. These are important to consider for applications intended for VR or AR, which are a combination of hand gestures, overlaid virtual widgets, and passive haptics to form an interactive interface for users using an application on a head mounted display.

The examples provided in this paper illustrate how some tasks require a substantial amount of concentration to navigate, perform maintenance, and repair. The experiments were done by assessing the effectiveness of using an AR application designed to be used with an HMD and wrist-worn control panel while mechanics are being tasked to perform maintenance inside an LAV-25A1 armored personnel carrier. Benefits that they found while conducting this study were subjects are less likely to make unnecessary movements such as head turns and aligning their body to their task area, effectively saving them time and energy. As stated by Henderson, saving time when performing dozens of potentially unfamiliar tasks distributed across a large system can be significant. Especially if the task requires the user to be cognizant of navigating within a work space while performing several other procedures. The results of this study also helped to uncover five aspects of their AR application that were essential in aiding their subjects with performing their tasks. Those aspects are text instructions, registered labels, a close-up view, 3D models of tools, and attention-directing information. Text instructions provided the user general information and warnings and registered labels showed the location of the target component and the surrounding context. A close-up view allowed them to depict a 3D virtual or real scene at close range while rendering it on a 2D screen-fixed panel so that their subjects can get a better view of hard to see places. 3D models of tools were virtual representations of what the subject was being informed to use and attention-directing information was used in the form of virtual arrows and highlighting effects.

2.3.4 Instructional Design Guidelines for Procedural Instruction in AR

In this dissertation, Wasko [2013] presents a study that explores a set of message design guidelines that can be used by novice designers to help them effectively develop instructional applications for AR. This research attempts to address the problem of there being no previously established set of rules for instructional design for AR by developing a theoretically grounded and expert validated set of guidelines. The goal was to create a set of guidelines that will help developers create instructional based AR applications. AR offers cognitive and psychomotor support for procedural learning because the additional visual information can aid users in the process of completing complex tasks. The method Wasko used for selecting the theoretical components discussed in his paper was by referring to the six principles of multimedia learning as described by Mayer in Applying the science of learning: evidence-based principles for the design of multimedia instruction. These six principles can be categorized by multimedia, contiguity, modality, redundancy, coherence, and personalization. The multimedia principle is based on the use of containing static drawings or active animations, graphics and words to give learners the opportunity to make connections between pictorial and verbal representations. Contiguity principle is an attempt at making content as clear and easy to understand as possible by preventing an extraneous overload during cognitive processing. Low and Sweller's, the modality principle in multimedia learning suggests that presenting information by utilizing both visual and auditory modes can expand effective working memory capacity, reducing the amount of excessive cognitive load. It is further explained that if the same information is presented to a user in multiple forms at the same time, it can interfere and degrade the learning process. An example of redundant information would be if both printed text and spoken words were provided to a user at the same time and say the same thing. Coherence principle tells us that people learn better from a multimedia message when unnecessary information is excluded because extra material can cause learners to devote valuable cognitive resources to things that are not essential to their learning experience. Finally, the personalization principle teaches us the value of using a conversational tone when communicating to the learner with spoken words or text. The reason this happens is because people generally learn better when they have a sense of social partnership with the narrator which can motivate the learner to put more effort in making sense of the content they are provided.

2.3.5 Affordances and Limitations of Immersive Participatory AR Simulations for Teaching and Learning

This study documents how teachers and students describe and comprehend the ways in which participating in augmented reality simulations can aid or hinder the teaching or learning process [Dunleavy et al. 2008]. Multiple qualitative case studies were conducted across two middle schools and one high school to document the affordances and limitations of AR simulations from a student and teacher perspective. Interactive, situated, collaborative and problem solving affordances of AR simulations tend to be highly engaging. Although AR simulations provide added value to the learning experience, it simultaneously presents unique technological, managerial, and cognitive challenges to teaching and learning. Despite the overall expansion of sophisticated technology, typical classrooms rarely leverage AR interfaces for teaching and learning immersive participatory simulations. This article describes early research into AR that assesses strengths and limitations of student engagement and learning in a typical classroom setting [Dunleavy et al. 2008].

A game called Alien Contact was created for this study providing teachers and students a learning experience that allowed for exploration of a wide area where students could communicate with one another and while learning math, language arts, and scientific literacy skills. The purpose of the study was to gain an understanding of how teachers and students describe the teaching and learning process within a participator AR simulation. Three case study sites were chosen for an in-depth examination of the phenomenon of AR simulations within varied school contexts and content areas. Students and teachers reported the most motivating and engaging factors were: using new technology to learn, collecting data outside, distributing knowledge, positive interdependence, and roles. One teacher was quoted saying that the students took on a new identity and that they all felt strong ownership towards the roles they were playing. This teacher also believed that the students would have been less eager to work together in a traditional non-AR learning experience because they would have been less likely to rely on the support of one another. This helps to suggest that the essence of projective identity can be leveraged within AR simulations to motivate students and enhance instruction in both novel and transformative ways. Strong group identity and competition was documented throughout the study as well. "According to students and teachers, this rushing/racing phenomenon seems to be a result of three factors: (1) unforeseen competitive nature developing between teams., (2) too many characters and items on each day, which forced the students to rush through in order to complete that days' activities; and (3) the proximity of the teams and small simulation space led students to try to get answers from other teams by over hearing or looking over shoulders" [Dunleavy et al. 2008] Teachers also reported a significant difference in the behavior and engagement of students during the AR implementation as compared to their typical classroom behavior.

2.3.6 An AR-Based Learning Assistant for Electric Bass Guitar

In this paper, the authors present a system that assists beginner level musicians in learning to play the electric bass guitar [Ozan Cakmakci and Coutaz 2006]. One major goal of this case study was to create a system that would accelerate the process of associating the notes from a musical score to the frets on the guitar. They did this by presenting the notes from a score, one note at a time, and visually representing them with visual markers that appear over the proper string and fret on the guitar. There system was designed so that it could progress from one note to the next based on when the player plays the right note. The motivation of this research was to overcome the perceptual discontinuities introduced by dispersed sources of information during the learning process [Ozan Cakmakci and Coutaz 2006]. The need to solve this issue comes from the challenge that players run into when learning how to associate written music with the finger board on the guitar. For a student to overcome this hurdle they will need to reference diagrams showing the notes as they appear on the instrument as well as develop their understanding of reading sheet music. It is common for information to feel scattered and every time the student takes their hands of their instrument to search for relative information that they need to reference, it can interrupt the flow of the practice session. The main components of the system that was created for this research consisted of tracking the position of the bass guitar and the student's finger then to overlay digital annotations that are synchronized with sound. The distance between the target note and the current finger position was computed at each frame for the system to determine whether to move on to the next note or wait for the current one. A finite state machine was used to represent a sequence of notes that the student would follow along and play. "As the system enters the starting state, it plays the note F, overlays a small dot to the user, showing where the note is on the fingerboard, and waits until the user puts his or her finger on the same note. This process is repeated until the state machine terminates via reaching the final state." [Ozan Cakmakci and Coutaz 2006]. In their conclusion, the authors found that the strength of their interface was the notion of being able to place information where it was needed while at the same time not interfering with the task the student is trying to learn.

2.3.7 Support System for Guitar Playing using AR Display

This article also explores how AR can be used as a tool for learning and teaching how to play the guitar [Ozan Cakmakci and Coutaz 2006]. The system that was created for this project shows a learner how to correctly hold the strings on the guitar by overlaying a virtual hand model over the strings on the guitar. This method was implemented because the authors believe that this would be enough for a student to reference to know where their hand and fingers should be positioned to play a chord. Like the research conducted by Ozan Cakmakci and Coutaz [2006], this study utilizes markers and edge detection to track relevant information relating to the position and placement of the student's hand and their guitar. One aspect of the design process that the authors expressed as being important is the ability to use AR to accurately register the visual guide to the instrument that is being played. By integrating edge with marker detection, the authors were provided a means for creating a user-friendly application for assisting students learning to play the guitar.

A USB camera and a display connected to a PC was used as the basic setup for this system. The student would face the camera which tracks and calculates the position of the guitar and the user while the student references the video captured on the display in front of them. The system then displays a computer-generated model of a hand to show the user the correct finger placement and holding positions. What the authors found from presenting their system to an audience was that the system resulted in a user-friendly experience that was generated from the visual guides that was provided to them. However, their system was operational only from specific angels that did not feel comfortable for everyone who tested the application.

2.3.8 Music Education using AR with a Head Mounted Display

This paper explores the use of augmented reality to create an immersive experience to improve the efficiency of learning how to play piano [Shacklock 2011]. The objective was to stimulate development for notation literacy and to create an application that motivates interest in playing the piano. By using a head mounted display the student can visually monitor their practice while having fun. This article mentions that traditional music education focuses on individual practice assisted by an instructor. The use of multimedia can lead to enhanced individual practice that benefits users by disguising laborious tasks as a fun computer game. Augmented reality can be used to create a more direct interaction between students and the system. One of the major difficulties that beginners run into is translating a note from the written score to the physical key on the keyboard [Shacklock 2011]. This research focuses on how an AR application could help to aid students develop their interest and motivation to play the piano by giving them a way to better interpret the notes in a written score. The application that was created was designed to facilitate the needs of beginners who cannot easily translate music written on a score to the respective keys on the keyboard. By using vertical falling blocks that line up to the keyboard they could communicate to the player the length of each note that needs to be held and when each key is meant to be pressed.

Feature detection was implemented by using markers that made it easier for the system to recognize where the keys on the keyboard were located. A problem that the authors ran into was making it so digital content maintained its relevance to the environment, no matter where the player was looking on the keyboard. Achieving this required multiple markers so that the system could register the position of the falling blocks accurately over the keys on the keyboard. Although this improved how the content was being registered to the keyboard it also resulted in an overall reduced performance. They also ran into problems that related to content jittering that came from noise and numerical errors in the markers. Performance analysis was retrieved with a MIDI interface because it is an event-based file format. This information includes the note that was played as well as the velocity at which the note was played. The feedback that AR applications for music learning can provide users important details on their performance that will allow them to set goals for mistakes made in future practices. The application that was made for this study included providing the player color coding of note visualizations in the AR view. After playing a song the system could provide the user results that showed them how accurately (or poorly) they performed by calculating how many notes they hit perfect, good, bad, or missed completely.

The users who tested the application found that the music notations proved distracting and found themselves just focusing on the falling notes. The application was not successful at aiding users develop notation literacy as much as it could teach the physical actions of playing the instrument. Their application was not able to address things such as: Game width, which suggests the game helps boost self-esteem, cognitive needs, self-accusation, and transcendence. Imitation, which should enable the player to constantly learn by potentially ranking songs by difficulty. Emotional impact was also something that could have added to the experience, which are common ways to achieve an improved emotional impact with the aid of visual and sound effects and rewards such as a high score lists. Future developments mentioned in this study suggested including performance analysis that present information that demonstrates the user's dynamics and articulation. Comprehensive feedback could benefit users by narrowing down specific areas that could use more improvement. Research into techniques for improving the efficiency of learning notation literacy would be beneficial to the music community because that is a problem that has existed for a long time.

2.3.9 Piano Training Applications that are Currently in Development for AR

There are only a handful of tools a person can consider using if they want a simple way of getting started with playing the piano. One could go to their local book store or library and find countless books that can give them a good place to start. This method provides its own challenges because a person must interpret what they have read and how it relates to the keyboard. This can prove to be too difficult for someone who has had no experience playing the piano or reading sheet music. Although reading sources are a good tool to use when developing skills to play piano, referencing books will not always be enough for a novice player to effectively train themselves. Another learning tool someone may consider using are video tutorials that can be found online. This can potentially be a great way for a person to jump right into playing the piano because the visual provided by a video may be easier for a beginner to reference compared to a book. However, problems that may arise from this is that a novice player may be tempted to reference videos that display skills that are still outside of their current playing level. It is important for novice players to play within their skill range because the more time a beginner spends perfecting simple techniques the more productive their practice sessions will be to their overall development [Evans n.d.]. As of now the most effective way to get started with playing the piano is to be taught one on one by a piano instructor. The benefit of having an instructor is that the person learning to play the piano has a personal coach with them throughout the practice session. Having access to an experienced piano player is very helpful, because the instructor can observe the beginner as they play and provide the student feedback custom to the student's performance and needs. Over the course of the last few years, applications intended for AR are currently being developed with the purpose of aiding pianist develop their skills for playing the piano.

Music Everywhere[2] is a HoloLens application that is currently under development by graduate students attending Carnegie Melon University that hopes to become an effective way of teaching people how to play piano. What makes this application unique is that it focuses on teaching improvisation in blues, rock, jazz and classical styles. They are demonstrating how their application can recognize notes that are being played by including a MIDI-over-Bluetooth connection to the HoloLens, that allows for a piano engaged interactive experience. The application also allows for referencing virtual hands, seeing and hearing examples of improvisations, as well as allowing the player to play their own solos while being accompanied by an AR-projected virtual band. Teomirn[3] is another HoloLens application that is currently in developed that is being designed to teach users how to play piano. What makes this application unique is that the application provides the user a personal virtual tutor that they can observe as it demonstrates a piece being played. However, it seems the tutor doesn't teach the user how to play by providing instruction, rather it seems the application will provide the tutor as an animation that the user can reference and emulate. Finally, Pianolens[4] is an application made by students attending Stanford University which hopes to aid in the facilitation of learning new music and the rehearsal process. The goal is to make the application provide an interactive sheet music display, teach music by demonstrating proper timing, and allowing for

[2] See: https://www.etc.cmu.edu/projects/music-everywhere/
[3] No authoritative source, see for example https://www.youtube.com/watch?v=aovJh2SxDYU
[4] No authoritative source, see for example https://www.youtube.com/watch?v=5TExa2L1rOM

easy navigation between songs or sections with in them.

2.4 Participatory Design

In this section we will conclude our background and related work by briefly discussing what was learned about conducting participatory research. Be reviewing the works of Spinuzzi [2005] and Bratteteig [2016] we learn how to determine when participatory design has been executed successfully and the benefits of having a user of the product that is being developed an active member of the creation process.

Spinuzzi [2005] defines participatory design research as research of its own right. He explains that participatory design has its own methodological orientation, methods, and techniques.

2.4.1 The Methodology of Participatory Design

Participatory design can draw on various research methods but the idea is this approach always is centered around iteratively constructing the design which is built up of designer-researcher and the participants who will use the design. The core of participatory design is to productively examine tacit, invisible aspects of human activity through design partnerships in which researcher-designers and participants cooperatively design artifacts, workflow, and work environments. The partnership must be conducted in an iterative way so that researcher-designers and participants can develop and refine their understanding of the activity. The developers of participatory design believed that tacit knowledge of the participant and the abstract knowledge of the researcher must be bridged, with each party valuing the end goal equally.

Participatory design's object of study is the tacit knowledge developed and used by those who work with technologies because tacit knowledge is typically difficult to describe and design for. Tacit knowledge is implicit and holistic because it is what people know without being able to articulate. When using the tool perspective, you allow yourself to recognize how the tool that is being researched can be further developed to support the needs of the user rather than disrupting their natural flow. Something that is very important to using participatory design is being able to describe the users' tacit knowledge and taking it into account when building new systems. The main idea is that the new system that is being created based on the participatory research is that it empowers the user who the product is made for.

Participatory design research tends to be quite flexible and can be put into tree basic stages in almost any situation when conducting this type of study. The first stage is the initial exploration of the work where designers meet the users and familiarize themselves with the users and their way of working. The second stage is the discovery processes where designers and users employ various techniques to understand and prioritize work organization and envision how things can potentially work. This is the time where both designer and participants get the chance to clarify goals and to agree on the desired outcome of the project. The final stage is prototyping which is when designers and users iteratively shape technological strategies to fit into the work flow.

Methods can also be grouped into three stages as well where the first stage is the initial exploration of the work. This stage draws on observations, interviews, walkthroughs, and examinations of artifacts. The second stage of developing a method for participatory design research is the discovery processes. This is the stage where researchers and users interact with each other the most. Techniques that have been used in the past to generate a deeper understanding of tacit knowledge are things like organizational games, role playing games, organizational toolkits, storyboarding, and workflow models. The final stage is to prototype where a variety of techniques for iteratively shaping artifact can be applied. Mockups and paper prototyping are examples of ways to start the prototyping process but what's most important is that results are disseminated in forms that users can understand.

Some say that limitations of methodology for participatory design exist because it mainly focuses on empowering workers and does not lend itself to radical change. Sometimes participatory designers can tend to focus too narrowly on artifacts rather than the overall workflow which does not lead to empowerment for the overall user activity. The method of participatory design studies can be described as exploring, approximating, then refining. The participatory designer plays the role of initiating and sustaining significant change at the research site. For some people this can be problematic because they think that it is possible that the researcher and the participant may assume to understand what the other is thinking and may "discover" what they wanted to discover. This can be less likely to happen if working in groups and building off one another.

Evaluating a participatory design research study has three criteria that must be met to maintain internal integrity. First, does the final product improve the quality of life for the user? To meet this criterion, the researchers and the users must have worked closely with one another and have agreed throughout the process. The second criteria are that the final product is created through collaborative development. Researcher-designers need participants not to be another researcher or developer but to help in uncovering the tacit knowledge and invisible practices that might otherwise have been lost. The last criterion is to have enacted an iterative process throughout the course of development. Tacit knowledge and practices are by nature difficult to reveal therefore sustained iterative reflections on designed artifacts are necessary for workers to be able to respond effectively [Spinuzzi 2005].

2.4.2 Disentangling Participatory Design

This book [Wagner et al. 2010] explores exactly the challenge for practitioners of participatory design by asking what participation means, who should participate and in which parts of a design process, what does it mean to share power with users and how are decisions to be mad in a participatory way? Participatory design as an approach to the design of complex systems takes the intended user and makes them a co-creator of the product. An important aspect of participatory design is that it gives an intended user a voice that has strong influence on the design and functionality of the product. One of the most common aspects of participatory design is the process of contacting and recruiting participants for the study. What is not as commonly discussed is the balance of power between the user-co-designer and the researcher-designer. This is important because participatory design is a collaborative process and for this to be the case, the participant must share influence that is equal to the researcher-designer and both sides should acknowledge one another as having different yet equally valuable expertise.

The core of participatory design can be described as designers committing to the sharing power with users and facilitating a process where users can take part in all phases of development. However, in the process of pursuing a participatory design approach, often researcher-designers find themselves in a dilemma of sharing power and the fact that they themselves as a designer and expert has considerable power. To address this, it is important to understand how participation in a design project is made possible. Given this dilemma, the researcher-designer must know how much participation should be expected from their participants for the project to meet its minimum requirements as a participatory design project.

"Design as a collaborative activity that sometimes involves a large network of actors (client, investor, specialists of all sorts, and more); the multi-disciplinarity of design work, which influences the ways designers express, represent, and communicate an evolving design concept; the role of artefacts and materials; the diversity of material practices which shape the design object, their historical-cultural roots and specificity; and the multiplicity of the design object itself, its changing representations in different media, and how it gets translated/transformed in the process of design" [Wagner et al. 2010 p. 39].

If design is looked at as an action that can be made upon the world that is aimed at modifying parts of the world to better act within the world, then 'the world' refers to the users' practices. Design can also be understood as the processes of 'seeing-moving-seeing' where the designer sees and evaluates the situation, makes some changes to the situation, and evaluates the results. "Working in some visual medium—drawing, in our examples—the designer sees what is 'there' in some representation of a site, draws in relation to it, and sees what has been drawn, thereby informing further designing. [...] The basic local unit of a design process, which we call a move experiment, involves several kinds of seeing, all dependent on visual apprehension, or literal seeing: the construction of figures or gestalts, which determine the things and relations in terms-of which the designer thinks; appreciation of the qualities in terms of which intentions are formed, problems are set, and solutions are judged; the recognition of intended and unintended consequences of moves" [Schön and Wiggins 1992 p. 135 and 154 f.]

It's important to keep in mind that as design choices are being made new situations are created that may result in new, unforeseen possibilities. This can affect the design process at large and are very hard to predict, even for experienced participatory designers. This type of collaborative process requires planning a complex process, distribution of work, discussions, negotiations, defining the problem, designing the solutions, and preparing for evaluation of the product in use. The practices of participatory design include participants to reflect on issues from the designer's perspective such as ease of use and the dynamics of decision-making.

Chapter 3: PROBLEM STATEMENT AND APPROACH

This thesis takes on the following problem and related goals:

1. We describe the process of creating an Augmented Reality (AR) application for the HoloLens that is designed to improve a students' ability to read musical notation. With the chosen approach, we address the need to explore and define key elements for making similar applications an effective enough tool that professional piano instructors could use it as an extension of their piano lessons.

2. The overall goal we adopt is to create a new method of visualizing music that can provide students with a supportive learning system in AR, demonstrating the correlation between notes on a score and how they are to be executed on the keyboard.

3. The outcome of the process is a set of guidelines that can be used as a reference for developers interested in creating piano training applications that want to effectively address notation literacy.

3.1 Approach

Using Microsoft's HoloLens, I developed an application that provides a virtual visual aid to support learning of major and minor scales, chords, and arpeggios. The app prototypes are designed for scenarios where students are taking lessons and will be in the presence of a piano instructor. I used Unity 5.5 with Microsoft's holotoolkit and Visual Studios 15 to create the application prototypes that I have named KeynVision (pronounced keen-vision). Upon completion, the application was able to project a variety of virtual visual aids that can be used in helping a piano teacher convey to the student a way of visualizing scales, chords, and arpeggios. The final prototypes have different drafts of visual aids that were considered for use to help the student visualize the sound of these piano practices by using falling blocks system where length of blocks represent the length of time each note is held for, a finger numbering system that show the finger number over the key that is supposed to be pressed and when, a written score system that shoes the notes as they would appear on sheet music, and a video recording or animation of a person's hand that demonstrates proper hand movements. Each exercise is viewable with each visual aid and were discussed with the members of my expert panel.

The process of engaging a panel of experts is meant to gather their perspective on what aspect of the teaching process they feel the technology provided can offer them. Common areas where panel members agreed on potentially effective ways to use the technology were used as input for guidelines as well as for the differnt versions of the prototypes. An iterative process of playtesting and feedback from the panel members was used to arrive at the first and the subsequent prototypes. These sessions consisted of time spent testing the application on the HoloLens from the perspective of the student as well as the teacher and it included a structured questionnaire at the end that was instrumental to make decisions on what changes will be made before the following meeting. After three rounds of playtest sessions, the report on the design choices and features found in this thesis was based on what the panel of experts felt was most important to the application. In the future works section, I discuss features, design choices, and theories that were commented on throughout the process of working with my expert panel. I conclude the section with suggestions for future projects that can potentially build on what I found.

3.2 Hypothesis

AR applications designed for head mounted displays provide piano instructors a new way of helping their students visualize the action of playing, by dynamically presenting the music in a way where the correlation between the notes on the staff and the physical movements associated with executing the task are more apparent than they would be if a student were to reference notation on a static page. Although there are other dynamic tutoring application such as Synthesia and FlowKey, a student who practices playing the piano using AR is likely to be much more physically immersed in the learning experience because of the unique qualities of learning through AR. There are many students who want to develop their skills at playing piano but often find it hard to focus or even feel that some aspects of the learning experience can be mundane or boring. There are many practical considerations for integrating AR technology into piano development. In our research, we will investigate guidelines and principles for developing a game-like training application intended to help students feel more excited about playing the piano by making their practice sessions a more enjoyable experience.

3.3 Methodology

This research was conducted using a participatory design methodology with a focus on iterative playtesting. We developed an application for the HoloLens that is intended to meet requirements that are needed for the application to be useful to piano instructors using this as a tool for training their students. The goal of the research was to help define what those requirements should be and create a list of common principles or guidelines that future developers should consider while creating a piano training system for AR. To achieve this goal, we relied on the feedback of our experienced expert panel taking on the role of potential clients.

Before conducting the iterative playtest sessions, we provided each member of our panel with a background and technology introduction that helped to familiarize them with the nature of our research. This was done by describing previous research that has been conducted such as Chow et al. [2013] and current AR training applications being developed such as Teomirn. The goal of each play test session was to test the status of the application and to discuss what aspects of the application appear to aid or hinder the learning experience. In between each playtest session, feedback gathered from our panel of experts was reviewed and changes to the application were made based on the prioritization of design choices that our panel had expressed as being the most important. During the following playtest session, those changes were discussed and pros and cons of the experience were further elaborated on.

We recruited three professional piano instructors in Philadelphia, Pennsylvania. Each playtest was conducted with one participant at a time, wearing the HoloLens as they observe the current version of the developed application. A structured questionnaire was developed based on [Balog and Pribeanu 2010; Dunleavy et al. 2008; Gee 2013; Long and Aleven 2014; Moi 2016; Radu 2014] in order to record relevant feedback. While conducting a playtest session, the participants were encouraged to elaborate on thoughts and feelings relating to the technology and the application. Participant's answers were recorded throughout. Each participant saw three versions of the prototype on three different occasions.

The description and summary of playtest and feedback results form the core contribution of this thesis. The resulting guidelines and the description of design choices that reflect the concerns and interests of the expert panel can be found in the evaluation section.

Chapter 4: IMPLEMENTATION

As mentioned above, for this study we created an application intended for the HoloLens. We picked the HoloLens because it is currently one of the best supported head-worn see-through AR devices available. Developing an application that can run on the HoloLens was made easier by utilizing the HoloToolKit, a Unity plugin by Microsoft for developers to start building basic AR applications. A plugin called MIDI Jack[1] was also integrated into the project to detect notes coming from a MIDI keyboard and to process them as input in the application. See Figures 4.1 and 4.2 for early interface mockups of the prototypes.

4.1 Developing KeynVision

The application was developed using Unity 5.5 and Visual Studio 15 and integrated code found in Microsoft's HoloToolKit and Keijiro's MidiJack plugins for Unity. In Unity, a 3D environment was created to closely match the dimensions of a standard size electronic keyboard. Then objects to represent notes were added. Initially, to test the feasibility of a piano training application for the HoloLens, the first prototype used a virtual keyboard and added falling blocks that lined up to each key that the player should press. This initial prototype was developed to demonstrate the potential and the limitations of a piano training application for the HoloLens in a relatively short amount of time. It served as the initial demo for the panel of experts.

The basic functionality of our prototypes follows the lessons of the available HoloAcademy tutorial courses. This enables the basic interactivity that is needed for a minimal piano application prototype such as moving and positioning the piano model in the user's room. For our research project, the default manipulation of objects suggested for the Hololens, using the pinch gesture discussed in the Holograms 101 course, was integrated so that the holographic play area can easily be selected and placed properly over the keys in the physical environment.

[1] See https://github.com/keijiro/MidiJack

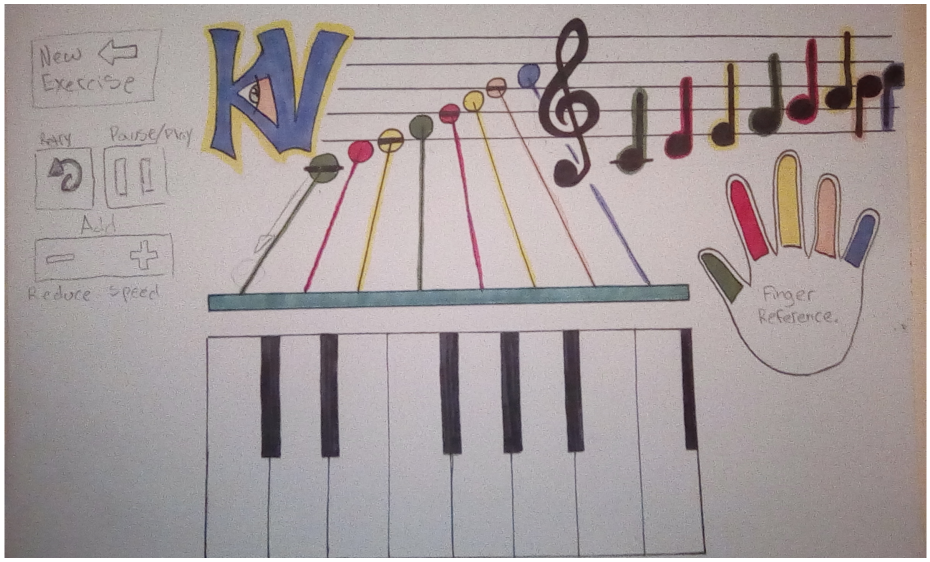

Figure 4.1: Early draft of visual layout for KeynVision.

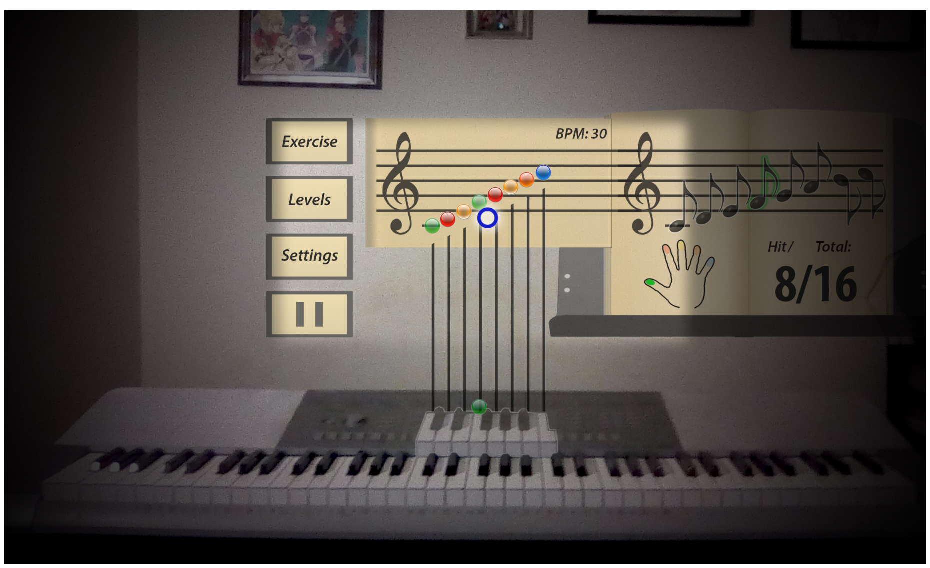

Figure 4.2: A visual mockup of a potential UI layout for KeynVision as viewed through the Hololens.

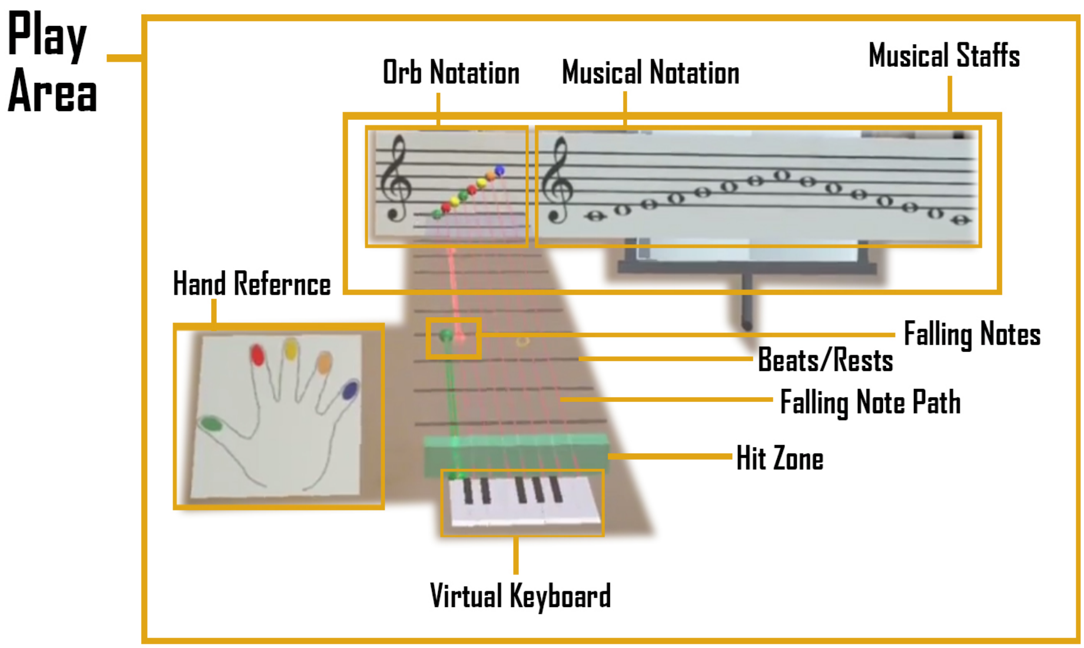

Figure 4.3: Reference of the Play Area elements.

4.2 Application Status - Round 01 through Round 03

In the following sections we review the performing and visual status of KeynVision during each round of playtest sessions that we conducted. The status of the application during each round remained consistent between each playtester that round. There was roughly one week of production time between each round of playtesting and all the changes that were made to the application after the first round were made based on feedback that was received from our expert panel.

4.2.1 Round 1

For the first iteration of the application, we created a full holographic keyboard with virtual blocks that spawned a certain distance away from the keys and would fly in the direction of the key that needed to be pressed. This layout is consistent with other piano training applications such as Synthesia, Yousician, PianoLens and Teomirn that use some variation of falling blocks to communicate the timing and rhythm of the piece that is being learned. See Figure 4.3 to see a diagram of the virtual play area.

It is important to consider that in an application for AR the "holograms" in the scene have to be po-

Figure 4.4: Status of KeynVision during the first round of iterative playtest sessions.

sitioned in a location in the physical environment rather than in a fixed location. Once this problem was addressed, we were able to demonstrate full control over how notes would spawn and move, allowing us to easily implement how falling notes could spawn from a position located on a musical staff and travel to the corresponding key on the virtual keyboard. One other problem that was important for us to address right away was to achieve a smooth performance of the application to avoid a distracting influence in feedback from experts. An important conclusion with respect to performance was to avoid transparent materials that turned out to be taxing on the hardware and removing any transparency resulted in a sizable performance increase without a reduction in functionality as transparency is a built-in feature of the Hololens display. Overall, the use of transparent holograms was not necessary for creating an efficient learning experience on the HoloLens. See Figure 4.4 for a image captured from the HoloLens of how the application functioned for the first round of playtesting.

4.2.2 Round 2

After the first playtest sessions was completed, feedback from our panel was considered and implementation of a musical staff into KeynVision was underway. Design choices that were prioritized after each playtest followed the aspects of the learning experience the panel expressed unanimous interest for. For example, during the first playtest panel members expressed the way notes were being visualized as being effective at communicating which key needs to be pressed when, but would prefer if the falling notes were a shape

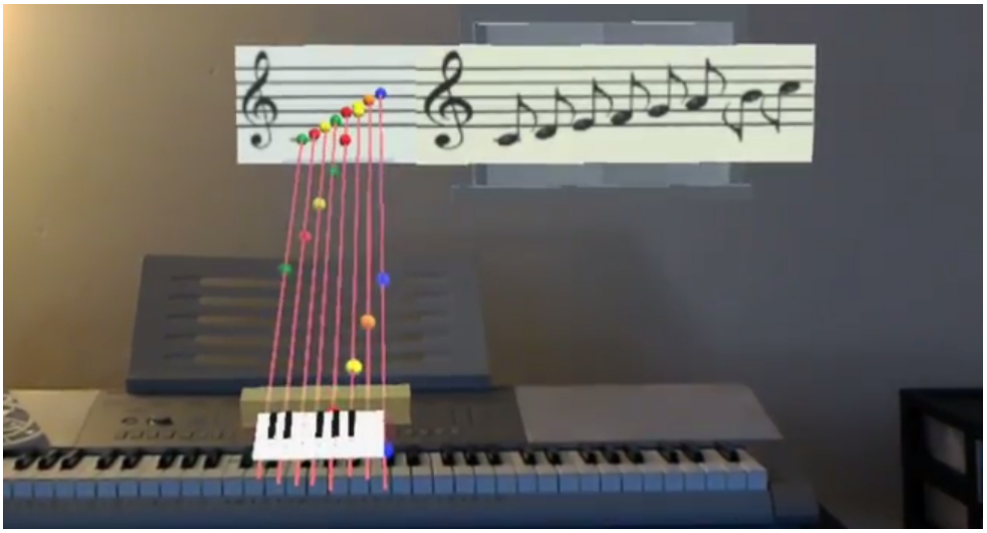

Figure 4.5: Status of KeynVision during the second round of iterative playtest sessions.

with softer edges. During this stage of development, we also concluded when sighting feedback that the application would only consist of exercises that could be practiced in one octave. Consequently, the rest of the virtual keyboard was removed.

This turned out to be a design choice that our panel found to be effective for helping to focus the application on the content directly related to the learning goal. We were also able to implement a level of MIDI interactivity when the application was running through Unity, displayed in the Hololens, and with a MIDI keyboard connected to the demo computer. The status of the application previous to the second round of iterative playtest sessions allowed for falling notes to get destroyed when the corresponding key on the MIDI keyboard was pressed while the falling note was in a predefined hit-zone. One challenge that became more apparent to us as we prepared for the second playtest session was the difficulty in trying to optimize the position of holographic elements in our scene as to make the most use of the limited field-of-view (FOV) that is provided by the HoloLens. We attempted to reduce how much the user would be required to look around through the environment by positioning the musical staffs further in the distance (as seen in Figure 4.5) so the user would have time to watch falling notes travel from their position on the orb staff to the keys on the virtual keyboard.

Although this was a design choice that yielded better results compared to the first iteration of the application, it ultimately is not a solution that completely solves the problem of creating a play area that can easily

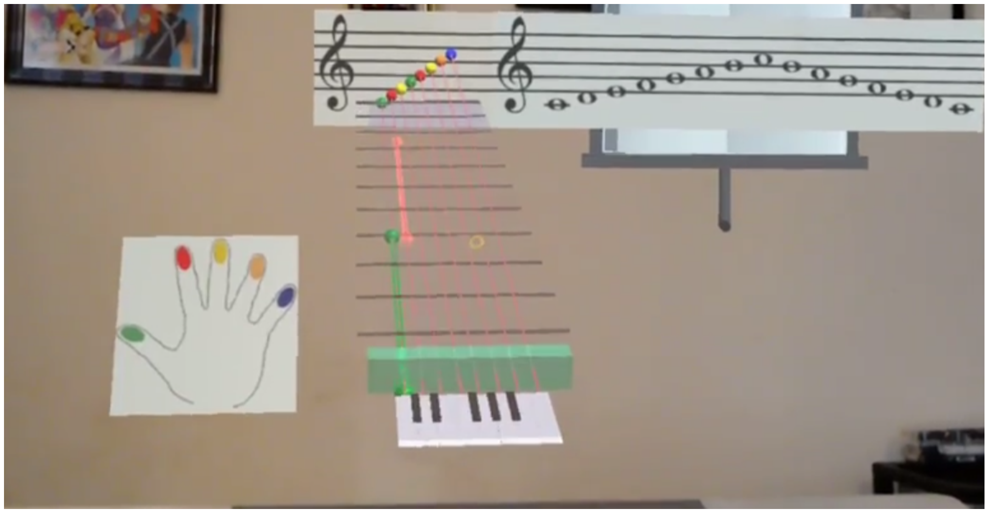

Figure 4.6: Status of KeynVision during the third round of iterative playtest sessions.

be viewed from the position the user sits in front of their keyboard. This was also a time in development where we were exploring what options exist for integrating a better level of feedback into the application. As mentioned above, we were able to get MIDI input working while the application was running through the Unity game engine but could not do the same for the simulation while it was running independently through the HoloLens. Connecting MIDI keyboards to the HoloLens via a micro USB to a USB converter is not effective because the micro USB port on the HoloLens is only designed for the device to charge and not to act as a "host", i.e. to take and pass information from other devices. Options for integrating microphone audio and pitch detection were also explored using pitch detector plugins. Similar solutions have been integrated successfully into apps such as FlowKey and Yousician. Although we were not able to successfully integrate pitch detection into our application, plugins such as simple pitch detector from the Unity Asset Store seem to be the most viable option for integrating pitch detection to a HoloLens application.

4.2.3 Round 3

Before the final playtest iteration, we continued to review the feedback that was gathered from our panel to determine which aspects of the application should be prioritized for the final playtest session. There were a few areas in the application that had noticeable issues for our panel, such as the accuracy of the notations used for some notes (specifically the facing direction of flags). Another element of the feedback received was the choice of speed for training: eighth notes are deemed too fast for a student who is just starting and it was recommended to slow it down to half or whole notes on the chosen tempo. Every member in our panel also expressed confusion about the addition of the representation of a sheet for the musical staff at the back of the play area. This object was hard to identify as a musical staff. Members of our panel were either bothered by it or did not notice it at all.

For the final playtest session, we were able to address the main areas of concern as well as a few others we found to be of equal importance. One aspect of the application that we needed to help make more understandable was the fingering pattern that was being communicated through the colors of the falling orbs. The way we did this was by adding a hand reference with the color on the finger that it is connected to. A bar for the stand was added as well as the use of different colors on the book to help tell the objects a part more easily. Another thing that our panel commented on, that they thought was important for us to include was a way for communicating the length of time a note needed to be held for before transitioning into the next note. We were able to do this by adding a bar that at the end of each falling note that would help the user understand that once they have pressed the key they should keep it pressed until the note finishes passing through the virtual keyboard (as seen in Figure 4.6). According to our panel, these were all good decisions for helping to make the application more suitable for learning how to play the piano.

Chapter 5: EVALUATION

Three piano instructors agreed to participate in our research project and helped us to validate a potential method that can be used for helping students improve their notation literacy through an augmented reality experience. The proposed layout was considered while attempting to address the issue of how to best communicate the correlation between notes on a musical staff and the keys that are pressed on the keyboard. The original layout that was drafted for the purpose of this research was created by taking into consideration aspects of the RETAIN model [Moi 2016] and the potential compromising effects of adding too many game-like elements to the learning experience [Long and Aleven 2014]. These considerations helped us to create a layout that prioritizes simplicity and attempts to limit the need of metaphorical elements that are common in many gamified tutoring systems. As discussed in Torrey and Shavlik [2009], transfer of learning from a source task to a target task is more likely to become a result when the source task is as similar to the target task as possible.

Before conducting the first playtest session, members of our expert panel were asked to fill out a questionnaire to help us get a better sense of their background and initial thoughts on integrating technology into piano development. Our panel has 30-plus years of combined experience as professional piano instructors, had little knowledge of AR, and never heard of the HoloLens before participating in our research. When asked if they thought the integration of technology into piano practice would be beneficial for students learning to play the piano, two-thirds of the panel felt that technology has the potential of being very helpful while the other member was on the fence but mostly leaning towards the addition of technology not being effective. The panel was asked if the use of technology would be beneficial for piano instructors if it were designed to be used as a tool for educating their students, members of our panel expressed a stronger sense of potential usefulness for technology that would be integrated into piano education with the piano instructor in mind. Our panel believes the most important reason a student or teacher would be interested in using technology for developing skills relating to playing the piano, is to take advantage of added benefits that are not achievable through a traditional learning experience. Although many potential

Table 5.1: Lessons learned regarding KeynVision prototypes and relating towards features and design elements that should be considered for future AR piano training applications.

Lesson Learned	Round Discussed / Project Version	See Section(s)
Device Ergonomics		
Posture	Versions 1, 2 and 3	5.1.1 5.1.4
Head Movement	Versions 1, 2 and 3	5.1.1 5.1.4
Audio Integration	Round 3	5.1.3
Interface Design		
Minimalism	Version 2	5.1.1
Readability of Holograms	Versions 1, 2 and 3	5.1.1
Fingering	Versions 2 and 3	5.1.1
Musical Notation	Versions 2 and 3	5.1.1 5.1.2
Maintain the Musical Staff	Versions 2 and 3	5.1.1 5.1.2
Interaction Design		
Developing Speed and Rhythm	Versions 2 and 3	5.1.1
Communicating Tempo and Rhythm	Versions 1, 2 and 3	5.1.1
Custom Settings	Rounds 2 and 3	5.1.3
Variety	Rounds 2 and 3	5.1.3
Tutorials	Rounds 2 and 3	5.1.3
Gamification and Incentives	Rounds 2 and 3	5.1.3
Useful Feedback	Rounds 2 and 3	5.1.3
From one Hand to two	Round 3	5.1.3
Encourage Good Technique	Versions 2 and 3	5.1.3

benefits may exist for integrating AR with traditional piano development, our panel expressed the cost of purchase, skepticism, and the time it would take to successfully integrate this technology into lessons, as all being likely reasons why instructors would be hesitant towards using AR as a tool for educating their students. The panel was also asked what area their students tend to struggle in the most and two-thirds replied saying having unrealistic expectations was the most common issue their students had, while the last member said their students seem to have more difficulty reading musical notation.

5.1 Structured Interviews and the Resulting Lessons Learned

The structured interview was composed of questions that were mentioned in the heuristic questionnaire created for determining the learning potential of an education experience through an AR platform [Radu 2014] as well as principles relating to how perceived usefulness can influence users' desires for integrating technology into a learning environment [Balog and Pribeanu 2010]. See table 5.1 for an overview of the resulting lessons learned regarding the development of the KeynVision prototypes, including the section to consult for more details.

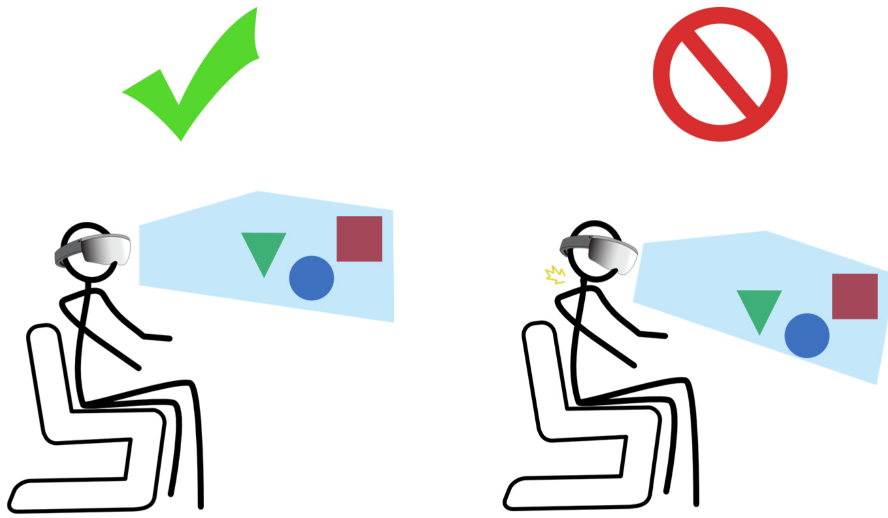

Figure 5.1: Illustration which demonstrates the importance of hologram placement for an AR application intended for piano development.

5.1.1 KeynVision

By creating KeynVision, we were able to present our panel of experts an example of what an AR application designed for improving notation literacy can potentially look like and how it would function. The purpose of presenting an application to our panel was so we could receive feedback based on a hands on experience. This was the most practical way for us to have our panel bring to our attention aspects of the learning process that can be enhanced within an augmented reality environment. This was also the best way for us to insure the current design aids the learning experience while also searching for potential problems that could potentially hinder or prevent how well the user is able to learn.

Version 1:

Some things that our panel found to work well with the original layout that was used during the first playtest are the use of falling blocks, and the use of reference lines to keep track of the position of incoming notes as well as to provide an additional reference that helps students group the white keys. Aspects of the application that we discussed as being a problem were things relating to the position of holographic content in the scene and how this directly influences the **posture** the user will be playing in, see Figure

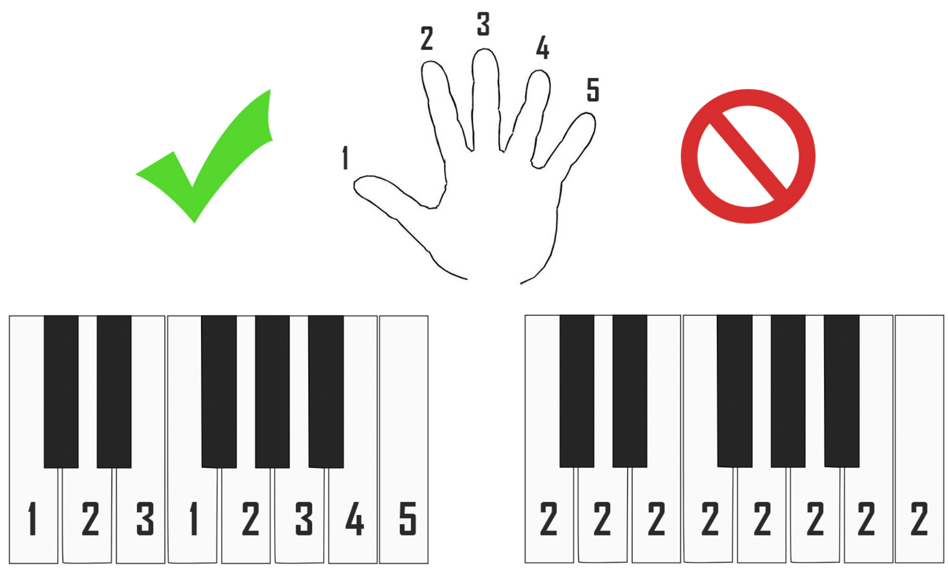

Figure 5.2: Illustration of the importance of using the proper fingering technique.

5.1. The way the application was functioning, the entire play area laid flat against the surface of the keys of the keyboard, which appeared to be a practical design choice when considering similar layouts seen in other AR-based piano training applications. In order for the user to be able to look at the virtual content, *the design should avoid requiring users to arch their neck to be able to see the holograms in the scene.*

Version 2:

By the time the second playtest had been conducted, the challenges of trying to design a method of visualizing musical notation within the limited field-of-view (FOV) offered by the HoloLens had become more apparent. Areas that our panel members felt were improved upon were aspects of the application that have to do with how notes were being visualized and the use of the staff within the application. The second iteration of the application attempted to address how finger numbering can be demonstrated to the user by replacing the number typically assigned to a finger with a color and the panel thought the use of colors was an effective way of portraying this principle through an AR experience. This is important to developing skills for playing the piano because the student needs to know how each finger needs to be used and should be encouraged to play properly. For an example of a traditional visualization of this teaching principle, see Figure 5.2.

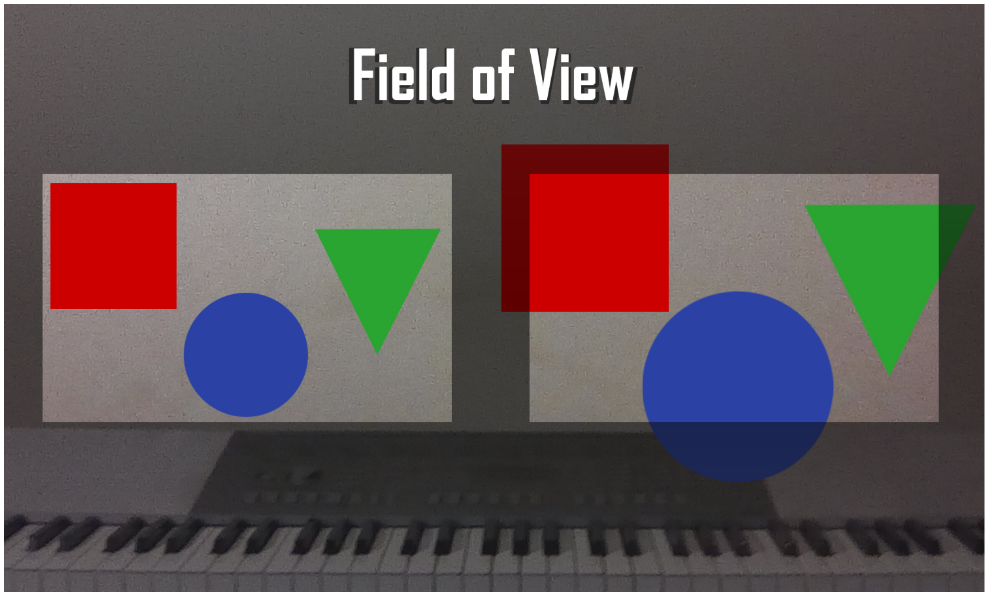

Figure 5.3: An illustration which demonstrates how holograms within a learning environment can be optimized to fit withing a limited FOV. (Left = Fully Optimized; Right = Not Fully Optimized)

Problems that we discussed as existing within the application during the second iterative playtest had to do with an object in the scene that did not communicate well, some of the note paths not lining up with the virtual keyboard, and a lack of understanding towards how long notes should be pressed as falling notes enter the hit-zone. After considering the feedback that was given to us for the second version of KeynVision that we developed, we began to see the challenge that we would be facing as we moving forward, as we tried to optimize the learning experience within the FOV that has been provided to us through the HoloLens. See Figure 5.3 for an image that conceptualizes what we mean by optimizing the FOV.

Version 3:

The addition of horizontal lines representing beats that fall towards the virtual keyboard are very useful for helping the user get into the habit of counting the beats as they play along. The addition of the bars that connect the start and end of each falling note was an effective way for communicating the length of time the user should keep each key pressed for. Although positive feedback was received in the previous iteration towards the color of falling notes, a hand reference was added as to give the user something they can use to identify each color with the intended finger that they should be used on. The speed that the current version of the application was considered to be more appropriate for a student who was just starting to learn to play the piano and the beats also helped to make the application provide a stronger sense of visual rhythm. The musical stand was also modified in this iteration and each panel member expressed the changes as being sufficient enough for them to determine what the object is supposed to represent. Panel members also suggested the current layout was sufficient for a student to be able to effectively learn how to play the exercises that have been implemented into our project.

Our panel members confirmed that the notation on the music staff correlates to the notation on the orb staff and each falling note lines up with the key that needs to be pressed while also providing information on when to release the key. The application seemed to provide all the necessary information needed to be able to learn from this scene. One panel member did not know how to interpret the orb at the end of a falling note because it was the same object as what is at the front of the falling note. He therefore was led to believe that he was supposed to press the key each time an orb would enter the hit-zone, which was not the intended result. Instead the application was set up as to destroy each orb under specific conditions that were predefined by MIDI input. Those conditions are to press the key as the first orb enters the hit-zone and the second orb is only destroyable when the user releases the key at the moment the orb enters the hit-zone.

A separate training level for chords was designed in a different way than notation that is used for communicating a scale or an arpeggio. One thing that we learned while creating a level for chords was that the level would have to be handled completely differently than what we did with our scale and arpeggio level. When creating a level for scales or arpeggios, it will be made up of a series of notes that are played sequentially; however, when creating a level for chords the player will have to play a progression of notes that are being played together. See Figure 5.4 for an example of a chord progression. Notation for chords is stacked vertically above one another, which makes drawing the paths from the orb staff to the keys on the virtual keyboard more challenging than exercises that consist of notes that ascend or descend up and down the keyboard over time. When making a level for chords it is not possible to use paths that are evenly spaced and can easily be read when falling notes are being visualized as they are in the current system. The way we attempted to resolve this before the third playtest was by removing the staff from the orb staff and substitute it with a setup that places all the orb spawn positions directly next to one another, as seen in

Figure 5.5. *With this set up, we were able to maintain the spacing of the paths the falling notes travel down but our panel felt that changing the position of the orbs to be anything but what is being portrayed on the* **musical staff** *would be taking out an essential aspect of the learning experience we were trying to achieve.*

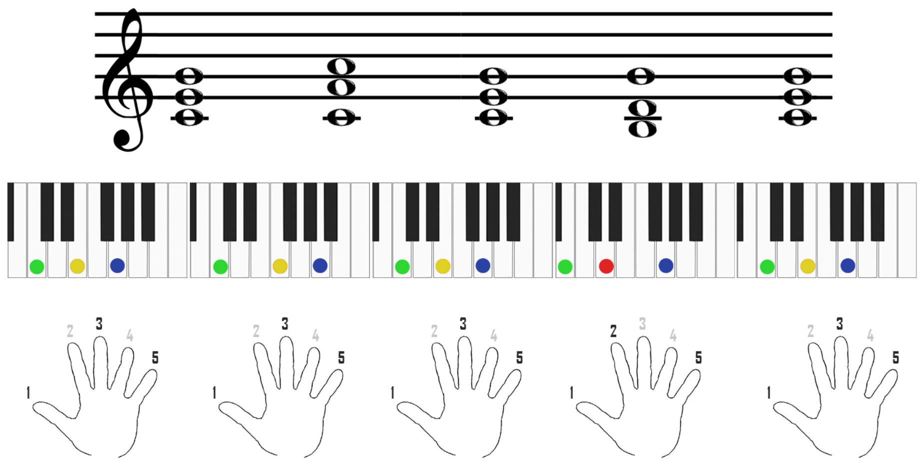

Figure 5.4: A diagram that illustrates the which keys are being pressed by which fingers throughout a simple chord progression.

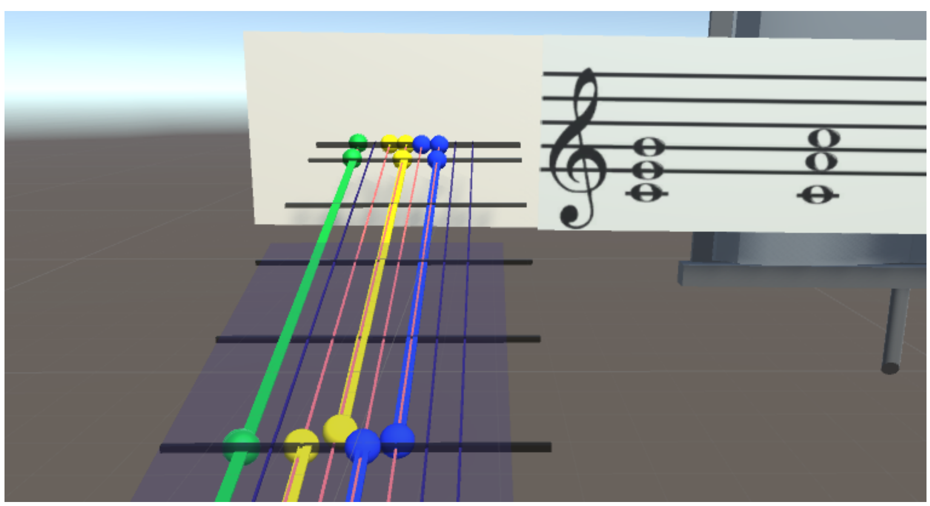

Figure 5.5: A close up of the implementation that was considered for handling a level with a simple chord progression.

5.1.2 Visualizing Musical Notation in AR

Notation literacy is one of the most important aspects of piano development and is an area that piano instructors treat as an integral part of what they teach their students. Although AR may potentially have many benefits for students who are interested in developing skills for playing the piano, piano instructors are highly unlikely to integrate an application into their lessons if the application fails to address areas that are important to what they teach. An essential part of the production of this application and the integration of an expert panel with our research was to help us identify a method that would be effective for visualizing musical notation as it would be played on the keyboard. The layout that we created was validated by our panel as a method that seems to effectively communicate what notes on the staff mean to the player when they start to play those notes on their keyboard. Everything that resulted after the validation of the original layout hoped to expand on ways to more effectively communicate how to play a scale with the addition of virtual content experienced through an AR environment.

After the second round, one aspect of musical notation that members of our panel wanted to see us communicate more clearly had to do with how falling notes relate to the measure they are being played in and the time spent holding keys down. During the final playtest, our panel helped bring our attention towards specific things that could be considered to better address how musical notation was being handled in our AR application. One thing that appeared to be odd to one of our panel members was how falling notes spawn at the end when she expressed that she would rather see the falling note come out of the orb staff over time, rather than just appearing from it's end. To help students get even more so into the habit of counting as they play, a panel member also suggested that the next falling note that is going to instantiate from the orb staff will blink twice (once per beat) before spawning the next falling note. We were also given a suggestion from a panel member that described how bars within the falling notes which represent the length of time a note needs to be held can change in saturation over time as a way of communicating to the player that the key is being held down. The addition of numbers traveling down the falling notes and the beats/rests to show the student what numbers to count along with. The use of a metronome was also expressed as being very important to the learning experience and would be helpful to have included in the application. The reason it is convenient for the user to have a metronome built into an application is because the student or teacher will not have to synchronize a physical metronome with the application.

Through our playtesting process, we were able to uncover several methods that seem promising for the overall improvement of visualizing musical notation through an AR experience, more than could be covered with the prototyping of KeynVision itself. We discussed the importance of incorporating all forms of notation into an application that wants to help its users develop long-term notation literacy. A straightforward place to start would be the addition of half, quarter, and eighth notes towards a variety of different rhythms that they can practice playing in. Up to the final playtest with our expert panel, we focused on exercises that used whole notes. One comment that was made by our expert panel was that if we were using notation that included stems or flags on the note head that it would also be important to communicate that with the notation on the orb staff. However, as we continued to discuss this we also came to the conclusion that the addition of stems and flags on the orb staff would be sufficient and would not have to attached to the falling notes because the timing of when to press each key will be communicated through the timing and speed of the flying note as it approaches the virtual keyboard.

5.1.3 Development of Future Applications

Throughout the course of our discussions, we were able to shed some light on aspects of the learning and training processes that are essential to piano development that would need to be considered or addressed if an AR application wishes to accommodate the needs of both students and instructors. There are many features and design choices that our panel of experts expressed as being factors they would have to consider if they were attempting to evaluate the usefulness of an AR application designed for piano development. Features and design choices discussed in this section were not implemented into KeynVision because of time restrictions or other limitations but should still be considered when developing future AR piano development applications.

Exercises:

Applications that are intended to be used for developing a users ability to play the piano should include all forms of exercises and practicing techniques. All forms of piano playing should be acknowledged and implemented into future AR piano training applications. It is good to have a variety of songs that the user can practice playing but a user will need to be equal exposure to scales, chords, and arpeggios as they develop their skills. When discussing chords with our panel, they suggested creating levels that teaches the student a series of chords and to have them play them in progression. When making considerations for features that would be needed to help piano instructors educate their students think of important aspects of the teaching process that could be helpful to include in the application. One example of this would be the use of "∧" to show the student the relationship between notes as to help them gain an understanding of half and whole steps.

Technique:

In KeynVision we were able to demonstrate a method for communicating finger numbering to the user by providing color coded orbs and a reference of a hand drawing with the colors filled into the corresponding finger. This was something that members of our panel were appreciative of but it is an area that can easily be expanded on more. One thing future app developers can consider is making it so the color on the hand reference lights up when it is the one that needs to be used while the fingers that don't need to be used remain a muted color until they are needed. Other options that our members would find interesting in future application would be the introduction of a numbering system that could follow along with the falling notes. A similar method can be adopted for teaching students the letters of the notes on the musical staff where instead of finger numbers traveling with the falling notes it would be the letter of the note itself. These are good examples of a feature that piano instructors would want to be able to turn on or off depending on whether it is appropriate for the students level or not. If this type of numbering system were to be consider for a game-like tutoring experience where the student practices on their own, then it is important that as the student progresses that the use of numbers is reduces over time. Another benefit to communicating finger numbering to the user is that this can also be used to help teach the student how to cross the thumb under the fingers or cross the fingers over the thumb when playing up and down the keyboard. This was communicated in our application with the use of color coding falling notes to which finger needs to be used. A way future applications can expand on this is to include icons to the hand reference that signal the user when they need to cross under or over. Another option would be to take note to applications like MusicEverywhere and Teomirn which have the use of animated hands to demonstrate proper hand positioning and movement.

Articulation, Dynamics, and Rhythm:

Communicating rhythm will need to be factored into the learning experience because it is such an integral part to learning to play the piano. The first step to implementing rhythm into an AR piano training application would be to include exercises that demonstrate the use of a variety of note values (whole notes, half notes, quarter notes, eighth notes, etc.). Exercises that help to build a student's understanding of rhythm would become even more effective with the addition of a metronome. Including the use of single note melodies would help to provide a variety of notes, a melodic curve, and a different rhythm for each note. Future AR applications will become more powerful tools for learning to play the piano developers find ways to communicate how loud the user should be playing each note. As a student becomes more familiar with different exercises that can be played on the piano they will need to develop an understanding of how exercises and songs can sound different depending on how the pianist plays it. If an AR training application is able to show the student examples of exercises that are played with short and detached notes and show them the same exercise with long and connected notes, it will help the student begin to understand concepts of articulation.

Customization, Features, and Settings

Something that was discussed extensively throughout each round of playtest sessions is the importance of being able to customize the learning experience. At the most fundamental level, the piano instructor and student will want a variety of options for the types of exercises they can practice to the speed the exercise should be playing at and how many octaves the student should be playing in. The use of both hands is important to how students learn to play the piano and an AR application will be more effective as a tool for piano instructors to integrate into their lessons if the application allows for practicing with hands individually or at the same time. One area of customization that was heavily discussed throughout the course of the three rounds of playtest sessions was in regard to the position of holographic objects in the play area. The challenges we ran into developing KeynVision was the entire play area was being handled as a single object that the user would be able to select and place over their keyboard. The problem with this method is that it makes it practically impossible to optimize the field of view so that it can easily be viewed within the HoloLens' restricted field of view. Even as technology continues to give us more sophisticated

HMDs for AR, the limited field of view we are currently stuck with will become less and less of a problem. However, we argue that even if the user has a relatively wide field of view, there is still a chance that the standard setup will not have elements in the learning environment (virtual keyboard, musical staffs, hand reference, etc.) in a place where it can be comfortably viewed for every student. The solution is to make every element in the scene a separate object that the student can manipulate into a position that makes the most sense for them.

Gamification

Some panel members expressed that the addition of more 3D elements and visual effects have the potential of making the experience more enjoyable and appealing to look at. KeynVision is an application that demonstrates at least one way of designing a system for visualizing musical notation but future applications will need to consider the addition of UI, screens that appear after a player completes an exercise, and other visual elements. If the application being developed wants to prioritize the user's learning, it is important that the use of any visuals are non-intrusive to the learning experience. While the student is learning it is important to restrict the number of visuals on the screen so the don't get distracted. However, if there are scenes in between the times the student is learning, the introduction of different visual elements should be treated as opportunities to show the user something visually appealing. What will be visually appealing to the user will depend on the age group the application is being designed for but a few examples of things future AR developers can consider would be the use of balloons or confetti at the end of a completed exercise. Other game-like features that can play an important role in an AR application intended for piano development are principles that are commonly attributed to how players unlock new levels after completing earlier ones. This would be important for any application that is intended to be played by students for long periods of time because a student is only able to maximize the effectiveness of their practice sessions if they spend their time practicing exercises that are withing their skill level. Requirements that can be included in these types of piano training applications can be to have the student execute a specific exercise a certain number of times with exact tempo and equal force being distributed between each keys. Not only will the performance of the student matter for determining when the student can move on to more challenging levels, it will also be beneficial for piano instructors if they are able to see what their student has been practicing between lessons. This information can potentially lead to piano instructors being able to better address the needs of their students if future AR applications are able to provide detailed performance data that is able to separate areas where a students are playing proficient from areas where the student is struggling in. Finally, another aspect to game-like aspects that have a place in AR piano training applications is the added sense of incentive that comes with unlocking new challenges or beating a previous high score. One way incentives can be implemented into an AR piano training application would be to allow students to view songs that they haven't unlocked yet. Even if the student isn't at a level where they can effectively practice those songs, students can get an extra boost of motivation knowing what they should be able to play if they keep practicing and complete all the levels required to unlock the challenging levels.

Tutorials:

The use of tutorials will play an important role in the development of students understanding of different principles and techniques involving piano development but it will also serve as an effective method for introducing the user to the AR experience. Future app developers should always assume that the user will be completely new to AR and should be prepared to use tutorials to develop the user's understanding of how they can maneuver through a holographic environment. The use of tutorials will also help the user understand what the purpose of different elements in the scene mean and how they translate to notation literacy and how notation correlates to actions required for executing an exercise. It can also be very helpful for the student if they can have the option to simply watch an exercise as it is being played. If the application chooses to implement animated hands then there should be a play mode that the user can select to just watch exercises or songs being played. If the application doesn't make use of animated hands then it would still be considered beneficial for the student if they could just watch the exercise being demonstrated to them. Tutorials that are meant to demonstrate to the user the proper placement and position of their hands as the play, it is essential that the student is able to hear the sound of the exercise or song being played. A means of communicating to the user proper body positioning is also an important aspect of piano development that the student should be able to pick up on. Teomirn seems to try to address this by adding a completely virtual tutor to the application that the user can watch perform songs. This would also be a viable option for future applications but another option that could also be helpful would be the use of images that can be used to illustrate to the student proper wrist, elbow, and shoulder positions. Lastly, it is important to consider when it is best to use visual or when to use audio to communicate a lessons the user is supposed to learn from the tutorial. The application will be visual heavy for the most part of the learning experience, so the use of audio can be effective for communicating to the user important aspects they are supposed to take away from the tutorials they watch. Using text in AR is okay when it is being used for UI but it is not recommended to deliver tutorials, lessons, or instructions through text.

5.1.4 Unexpected Results

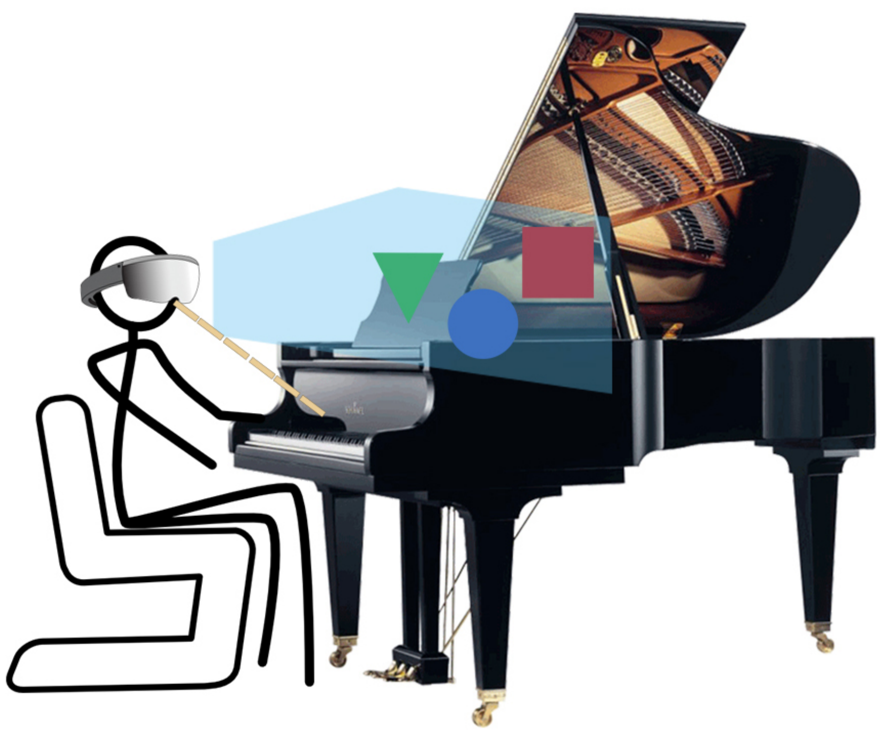

Figure 5.6: A diagram that illustrates how a user can use their peripheral (yellow dashed line) to keep track of where their hands are on the keyboard while their focus the rest of their attention on holograms rest of the visuals in the scene.

In this section, we discuss results of the expert panel process that fall outside the expected categories of feedback we considered at the beginning of the process. While working with panel member Janet, we discussed the idea of potentially placing the virtual keyboard high enough in the physical environment that it stayed within the HoloLens' field of view (See Figure 5.6). When creating the original layout for this system, the virtual keys were imagined as being directly behind the keys on the physical keyboard. This

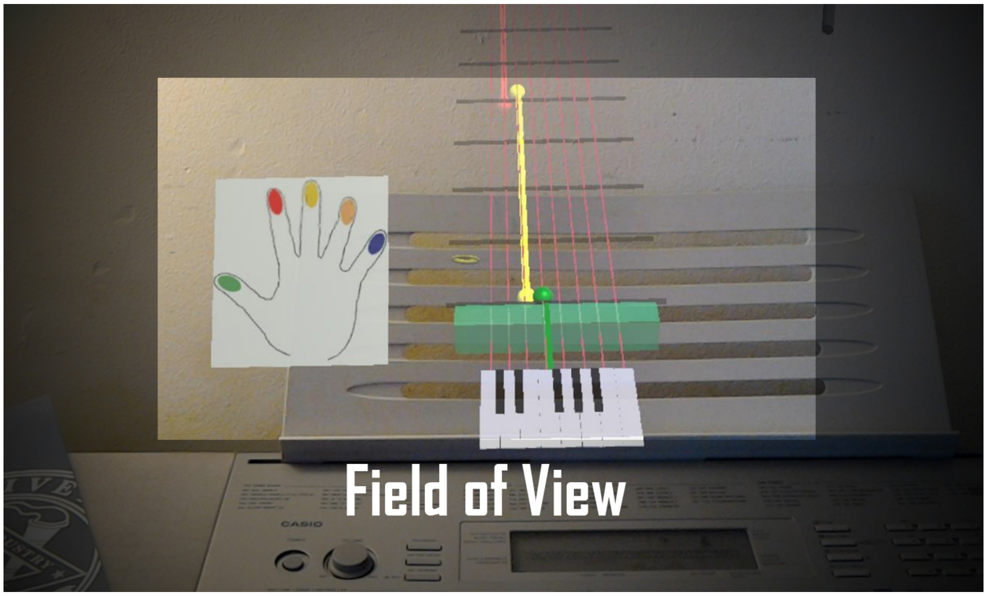

Figure 5.7: HoloLens screen capture that illustrates the field of view from the perspective of a user looking downward at the virtual keys.

was considered to be the best place to put the virtual keyboard because the student would be able to watch the falling notes travel not just to the virtual keyboard but all the way down to the keys of the physical keyboard. See Figures 5.7 and 5.8. However, Janet brought up an interesting point, saying she could use her peripheral to see where her hands were on the keyboard and the virtual keys were a strong enough reference that it would communicate well even if it was not directly lined up to their corresponding keys on the physical keyboard. See Figure 5.9 for an image of what the scene would look like if all the elements necessary for learning were all visible within the FOV.

The added benefit of placing the virtual keyboard higher up in the physical environment is that it makes the entire play area visible withing the HoloLens' field of view. When all of the content is within the field of view of the device the user will be able to see everything that is important for learning the exercise without having to move their head to look back and forth between areas of interest. Finally, this method would also be very effective for creating a learning environment that allows the user to maintain a comfortable posture. By limiting the user's need to look downward, the likeliness of the user straining their neck is reduced significantly because the weight of the HoloLens will be distributed evenly across the head.

The general problem that was discussed among members of the panel with the system that was pro-

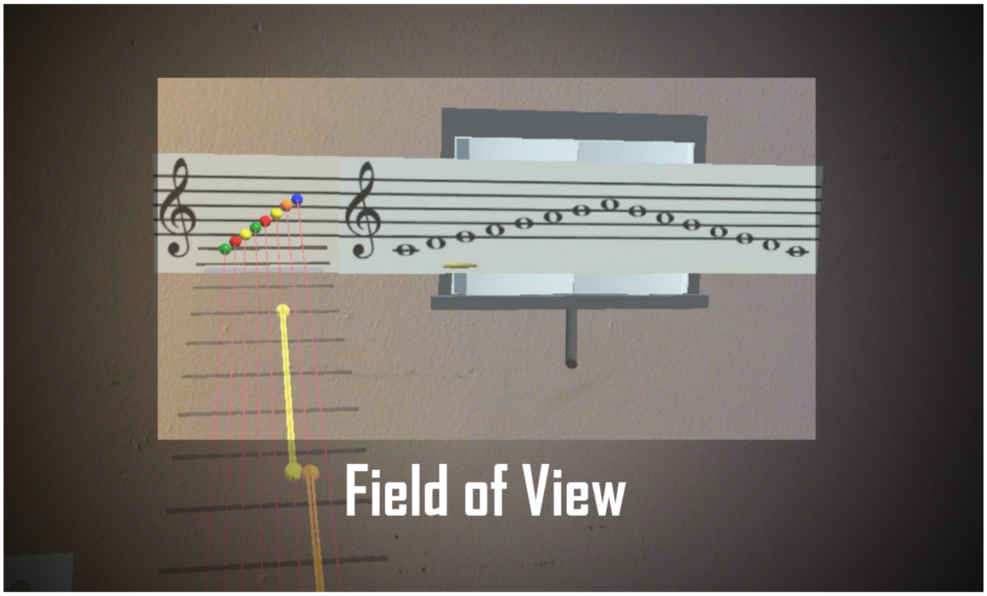

Figure 5.8: HoloLens screen capture that illustrates the field of view from the perspective of a user looking up toward the musical staffs.

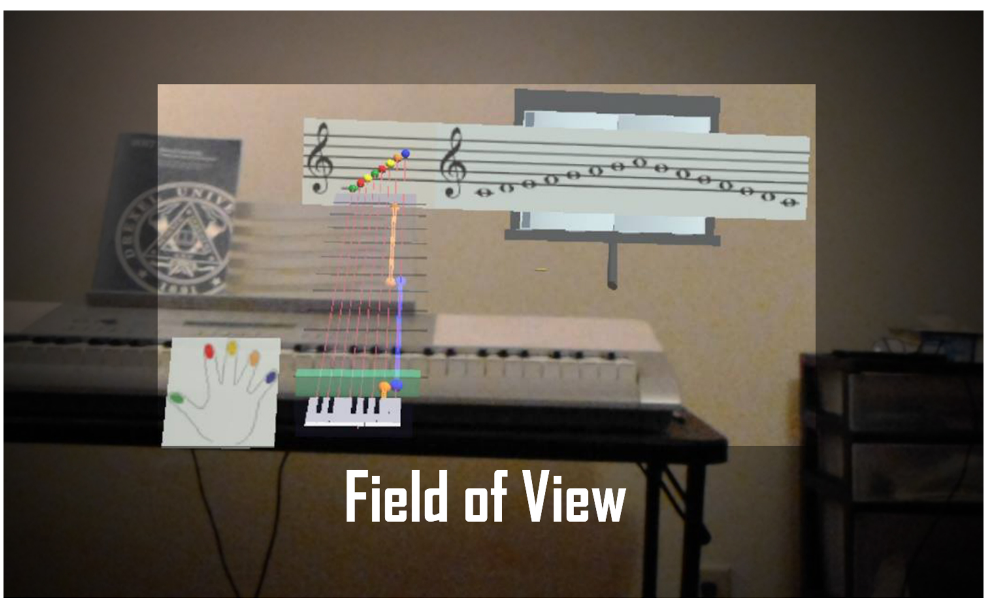

Figure 5.9: HoloLens screen capture that illustrates the ideal field of view from the perspective of a user looking at the play area. Note: the ideal view is not being represented based on the position of the user relative to the keyboard but the content fitting withing the field of view.

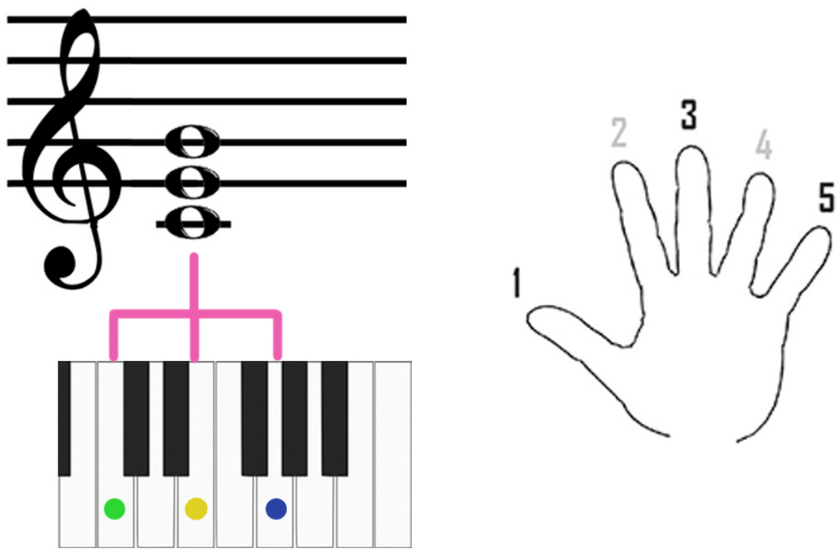

Figure 5.10: A diagram that illustrates how a chord can maintain the way it appears on the staff and be distributed into evenly spaced paths the falling notes can travel down.

posed for managing chords was the fact that manipulating the orb staff so that it doesn't match with the musical staff could potentially result in the removal of an essential element for the student's learning. While discussing this issue with Gina, a simple solution was suggested that would make it so the orb staff would reflect the musical staff and the falling notes can still travel down evenly spaced note paths. The strategy that she suggested (as seen in Figure 5.10) was to make the group of notes travel down a single path, then split apart into three separate paths where each individual note travels down it's corresponding key on the virtual keyboard.

While discussing what the application could potentially look and behave like in a more thoroughly developed application, Ian brought up the importance of keeping the treble and bass clefs stacked on top of one another as they would normally appear on a standard sheet of music. For an exercises that requires the use of more than one hand and both clefs, the orb staff might need to be moved to another location so that the entire width of a bar can be referenced. "If applications like this are intend to help students improve their notation literacy, it is important that the application gets them into the habit of following notes on a score like more experienced players normally do when reading sheet music. See Figure 5.11. When looking at sheet music the student develops the ability to zig-zag up and down between what is happening in the

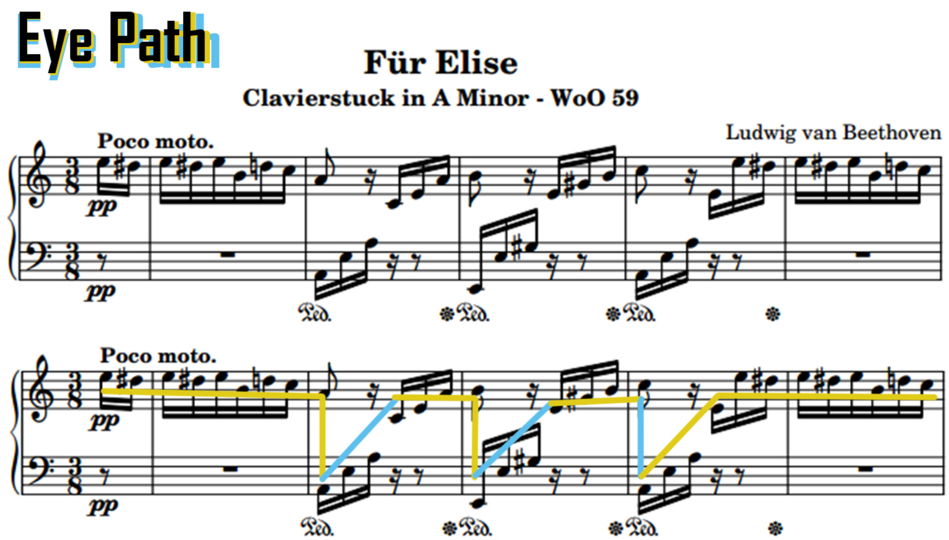

Figure 5.11: A diagram that illustrates the path a student's eyes should be trained to follow as they continue to develop their notation literacy.

treble clef and base clef."

Something else that Ian expressed a lot of interest in was the potential use the HoloLens can offer for instructors interested in teaching students online. One problem that Ian experiences when trying to give tips to students via video chat is that he doesn't have a way of showing the student the way their hands should be. There is also a huge benefit for the instructor if they have a way of watching the student's hands as they play as to give them the appropriate feedback. The HoloLens provides a unique opportunity to address some of these issues because the device has a camera that works similarly to a go-pro that can record video from the perspective of the wearer (as seen in Figure 5.12. The HoloLens also allows for the use of windows that work similarly to those on a computer but with the added benefit of being able to view them in the physical environment. If these windows were used in a video chat between a student and instructor it could be a potentially effective tool for training students from different time-zones or even over seas. The topic of Remote Piano Learning is also being explored by the developers of MusicEverywhere.

5.1.5 Our Panel's Final Thoughts

In this section, we present the final responses of our panel members after the conclusion of the process.

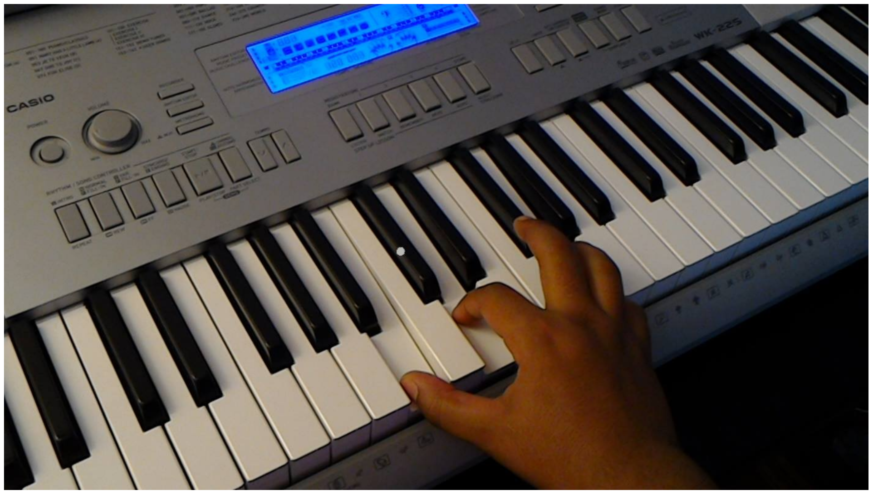

Figure 5.12: This is a picture that was taken from the HoloLens that demonstrates the potential of sharing images captured from the device and what value that may have if it could be shared via a video chat between students and instructors.

1. How has being a participant in our expert panel changed your views on the idea of integrating augmented reality technology into piano lessons (or as a learning supplement to be used in between piano lessons)?

   (a) ”Maybe cool if it weren't expensive. Also, I'm not really techy.”

   (b) ”Well, before this panel I knew nothing about AR, especially as it applied to piano learning, so my knowledge of what's possible and what people have done already was significantly increased. I still am not convinced that it would be a good idea to use with children, because of the way screen-usage affects brain development and because I think the added challenge of mentally transitioning between the AR mind space and the regular reality mind space would negate whatever benefit might be derived. I do think it would be useful for adults.”

   (c) ”As a full time piano teacher, I've always have been excited to incorporate new technology into the learning process for students. I teach all my lessons face to face with students, but I've always wanted to figure out a functional way to teach using webcams is a similar platform of Skype. Unfortunately I've been concerned that 2 webcams would not be a proper way to demonstrate how to play a piece of music to a student since teaching needs to be practically 100% interactive. When I tried out the AR headset for the first time I realized that this could be the missing element in the way piano (or any instrument) could efficiently be taught when teacher and student aren't in the same room. ”

2. What would you consider to be the most interesting benefits an augmented reality application that is designed for piano training has to offer people who are interested in learning to play the piano?
   (a) ”Helping students who have no sense of rhythm and/or who really like technology and/or learning visually.”
   (b) ”I suppose it's the ability for instant feedback, which you wouldn't get from trying to learn from a Youtube video.”
   (c) ”The AR technology alone would attract hesitant music lovers who have always been curious about learning an instrument. I've seen friends of mine who were afraid to pick up an instrument eagerly try out Guitar Hero when it first came out. Although it was a video game, you still had to learn basics with hand eye coordination, finger control and rhythm. Those things don”t sound very fun when you hand someone a thick music theory book with all the answers. I believe that this AR technology could encourage tons of new beginners to start learning and if the software is created properly, these people will be hooked. ”
3. What are your hopes and expectations for augmented reality becoming a practical tool that can be used by both piano instructors and people who are interested in learning how to play?
   (a) ”It would become cheaper.”
   (b) ”I'm not sure - this may be myopic of me but the use of AR for piano lessons still seems like an unnecessary and perhaps not altogether helpful addition to piano learning for children. For adults, I think it could be a good way to learn for people who maybe didn't want to hire a teacher or who wanted a practice incentive.”
   (c) ”I hope this technology is out on the market ASAP! I need it to take my piano teaching business to the next level. From a business standpoint, like most music teachers that teach privately, I mainly teach from when kids get home from school (3:15pm) to right before bedtime (8/9pm) on weekdays. I would have to change my profession or start working at a grade school or university

to be able to work a 9-5pm schedule. BUT, if I was able to teach students from around the world any time I choose because of time zone differences and conduct the lessons from my home or anywhere I travel that has a keyboard accessible, I would have no need to change occupations."

5.1.6 Design Guidelines

This section summarizes the design guidelines identified during the expert review process in a concise and simplified manner.

1. POSTURE

   - Support of good piano posture is essential because if the use of an AR application inadvertently teaches its users bad posture habits it could lead to discomfort or even injury.

2. HEAD MOVEMENT

   - It is okay if the user is required to move their head while navigating the interface. However, in order for an AR training application to be optimized to take advantage of the benefits offered by AR based learning, it is important that the user can see everything that is needed for them to learn, while limiting how much effort will be exerted from the user. By reducing the amount of unnecessary head movement that occurs during application usage, the user will be more likely to have a natural and seamless learning experience.

3. AUDIO INTEGRATION

   - Metronome or counter must be built into the application so that it is easily accessible to the user. The user should not have to try to time the use of a metronome so that the clicks match the timing of the visuals being displayed in the HoloLens.
   - Being able to hear the sound of notes in an exercise in a play mode where the user is only watching the visuals in the scene, would be considered an effective method for the user to learn from observation the musical notation while listening to the sound of the exercise or piece being played.

- Use of vocal instructions that speaks to the user would be considered as being more user friendly than the use of instructions that required the user to read.

4. MINIMALISM

   - Limit the amount of visuals there are in the scene to what is needed for the user to learn an exercise. This will make it easier for the user to focus their attention on what is most essential for the learning experience.

5. READABILITY OF HOLOGRAMS

   - Every holographic object in the scene should have a purpose and should be apparent to the user. It is also important that the use of special holographic objects or symbols is consistent throughout the learning experience. For example, if a symbol is used to represent when the user should press a key down, a different symbol or visual cue should be used to tell the user when to release the key.

6. FINGERING

   - Using colors to coordinate fingering patterns was considered an effective method for visualizing basic fingering patterns.
   - This method can easily be substitute with one that use numbers but what is most important is for the user to be able to identify which finger goes where. This simpler it is for the student to identify where each finger goes on the keyboard as well as when to press each key and how long to keep each one pressed, the easier it will be for the student to learn the proper fingering for each newly learned exercise.

7. MUSICAL NOTATION

   - Include the musical staff in the virtual environment as a reference. having notes travel down paths from the staff to the keyboard was considered an effective design choice for communicating which notes correlate to each key on the keyboard.

- Providing some distance between the staff and the keyboard was considered an effective technique for providing the user time to anticipate when to press each key as falling notes travels towards them.
- Adding length to the falling notes is an effective method for communicating how long each note needs to be held for.
- Chords are an integral aspect of piano playing and development. The system must be able to recognize multiple keys being pressed for notes that make up a chord in the same instance.
- When exploring different methods for visualizing chords on a staff and how they relate to the keys on the keyboard, do not obstruct or change how the notes appear on the musical staff. Find a way for communicating a group of notes that are meant to be played simultaneously. The easier it is for the user to understand how the notes correlate to the keys, the easier it will be for them to pick up on those correlation.

8. MAINTAIN THE MUSICAL STAFF
   - The musical staff and the orb staff should should always be identical to one another and should never be modified or obstructed by elements in the scene.
9. DEVELOPING SPEED AND RHYTHM
   - If the application is intended to help beginners develop their ability to play smooth and fast, the application should start the with a level that trains the student to play at a slow and steady pace.
   - Different rhythm variations should be implemented throughout different exercises because they are considered a commonly used technique in piano development.
10. COMMUNICATING TEMPO AND RHYTHM
    - The user should have some sense of the measure and how it relates to the notes being played.
    - Rests should be communicated through a symbol that helps the user know when not to play.
11. CUSTOM SETTINGS

- Must have settings that allow the user to adjust the speed of exercises.
- Must have settings that allow the user to select what octave they want to play in or change the number of octaves that can be played in.
- Fully customizable play area that allows the user to place any element in the scene (virtual keyboard, hand reference, and notation staff) anywhere the user wants them to be.
- Option to turn finger numbering (falling note number references, beat counting number references, finger numbering on hand reference) on or off.
- Should be able to customize lessons to a student's needs. Such as assigning lessons based on areas a student is struggling in.

12. VARIETY

    - The more exercises (scales, chords, and arpeggios) and the more songs (classical, baroque, jazz, rag time, etc.) a user can practice, the more valuable the application will be.

13. TUTORIALS

    - Should be used to define to the user all the elements in the play area (virtual keyboard, falling notes, orb staff, etc.)
    - Tutorials should also be used to demonstrate to the user basic piano principles, piano technique, and keys to understanding how musical notation is read.

14. GAMIFICATION AND INCENTIVES

    - The use of non-intrusive graphics, special effects, and animations can lead to a more enjoyable learning experience.
    - Celebrations when an exercise is completed or when a new high score has been achieved (I.e. balloons or confetti) is a good way to make the learning experience feel more rewarding.
    - A certain number of successful completions should be expected from the user before they can have full access to more difficult exercises.

- Challenging exercises and songs should be viewable to students even when they are not ready to practice them because this could become a motivational factor that will cause some students to want to work harder so they can play the more challenging pieces.
- Provide the user a log of previous playthroughs that illustrates their performance over time.

15. USEFUL FEEDBACK

    - A hit-zone (the area in the scene where falling notes must arrive before the player is supposed to strike the key) should be designed in a way that allows the system to provide the user feedback on whether the student is pressing keys too soon, perfect, or late.
    - Progress tracking should know how many successful playthroughs the user has had on any exercise or piece they've practiced and determine areas where the student needs improvement.
    - The application should be able to evaluate the student's timing and rhythm before determining whether the student can move onto the more challenging exercises.

16. FROM ONE HAND TO TWO

    - The system should be able to support learning experiences that allow the student to be able to practice with either hand or both at the same time.

17. ENCOURAGING GOOD TECHNIQUE

    - Thumb under, thumb over, fingering, accurate tempo, scales, chords, arpeggios, articulations, and dynamics are all techniques that should translate well for an AR piano training applications to be considered more useful.
    - Visual references that shows the user proper hand positioning and posture are essential for students who may not be playing in the presence of a piano instructor. This can be done with either figures with audio instructions, animations, or previously recorded videos.

5.1.7 Potential Solutions

There is a great deal of interest that currently exists for developing an AR based training application for piano development. Although AR technology is only recently becoming more readily available, developers are eager to start building applications that leverage the benefits that AR is able to provide its users. One of the most well noted aspects about AR is that it has been recognized as being a powerful educational tool that has the potential of making learning feel seamless and fun. Developers who are interested in creating a piano development application that is experienced through augmented reality will certainly run into many challenges that need to be properly addressed before the full potential of learning through AR can be recognized. The contents of this research should help developers take one step in the right direction in regards to visually communicating notation literacy to users with little or no experience playing the piano. We also laid out some important design principles and features to consider based on what things our panel of experts recognized as being the minimum requirements needed for an AR application that is intended to be experienced between the instructor and their students. In this section we will make a few suggestions that we believe are practical ways of trying to address some problems that we did not get far enough in development to address in our paper. Although there are many more challenges that will need solutions for, here are just a few potential solutions worth considering for developers who are interested in building off what was discussed in this paper will run into.

Further participatory research can result in very important findings relating towards piano development and improvement in notation literacy. A practical recommendation based on our experience working with our expert panel is to, if at all possible, invest in more than one HoloLens (or other comparable HMD) when having your experts review your application. Devices like the HoloLens are capable of syncing multiple devices so that more than one user can see the same holographic content, as demonstrated in Figure 5.13. As applications continue to increase in complexity, it would be beneficial to the developer if they were able to see the same thing the expert was looking at. Often times, the expert will not have a grasp of what words best describe what they are looking at and therefore it can be challenging to know what is causing the user to feel or think the way they do. However, if both the developer and the expert can see the same content all the expert has to do is point and the developer will be much more likely to understand what aspects of the application are working well and which need more improvement.

Through our application, we were able to test and verify the effectiveness of an AR experience that is designed to improve notation literacy. However, our application was only developed far enough to demon-

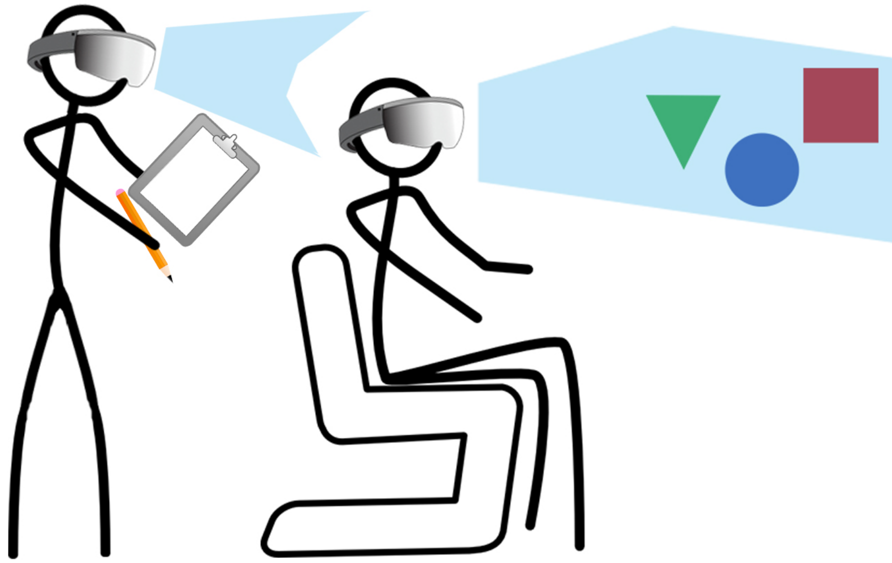

Figure 5.13: Two HMDs used by researcher and expert who tests the application simultaneously.

strate a single octave scale, chord, and an arpeggio. Moving forward, developers will need to find ways of implementing more complex exercises and eventually songs that maintain similar readability of the holograms in the scene. We were able to maintain the readability of holograms in our scene because the paths from the keys on our keyboard to the notes on the musical staff were always straight lines. One problem that currently exists within KeynVision is that the falling note paths do obstruct the users view of the musical staff. Another problem that occurs with having the paths connect directly to the position of the note on the staff, is that it makes the length each falling note travels down different depending on how high or low the note is on the staff. This makes it so even if each falling note travels at the same speed, they will not arrive to the keyboard/virtual keyboard at the same time because the distances they travel are not the same. The simplest and most effective way to resolve this can be seen in Figure 5.14. Although this might make it slightly harder for the user to determine which falling note goes to which note, ultimately this will be a more effective method for the user to learn notation literacy because it completely eliminates all holographic content that can obstruct the view of the musical staff. This should be expected from future applications as well; however, this is not a practical solution for more complex exercises because it is impossible to draw straight lines from a musical staff to the keys on the keyboard if the staff remains static in the environment. Perhaps a more practical solution would be something like what we see happening in applications for smartphones and tablets like FlowKey that have one bar that contains all the musical notation for a piece that animates from the right side of the user's field of view to their left. Because current HMDs have a relatively small field of view, the user will most likely be limited to seeing one to two measures at any given moment. Although our research was limited to testing only a few examples of how to visualize musical notation the lesson that can be taken is the importance of simplicity in an AR training application. The reason why our panel of experts considered our application to be effective at teaching the exercises we discussed was because everything in our scene correlates to one another in a clear way. A solution that we recommend for future applications that intend to handle more complex pieces is a system where the spawn position of falling orbs is not come directly from the position of the note on the musical staff. Instead the spawn position of each note can be start from directly under where the musical notation ends and the paths each falling orb travels down can remain a straight line that connects to the corresponding key. Please refer to Figures 5.15 and 5.16 to see an illustration of how this method of visualizing musical notation could potentially look like. Although this method is a little more detached than what we demonstrate in our research, this set up makes it certain that the addition of holographic elements in the scene will never obstruct the viewer of the musical notation that they are ultimately trying to learn.

The last thing we want to leave designers and developers with is the idea that we want users to be able to not just show improvement for playing piano while in an augmented reality experience but to be able to show growth in skill even after the student has put down the AR device. As stated by Moi [2016], students are able to learn more effectively when they must take newly learned skills and apply them to a new situation. The way we would like to see developers address this in future applications is to reduce the amount of visual aids that are added to the scene as the student continues to advance through out the training application. If the goal is to help students improve their notation literacy, one thing that can be implemented to the application is every time an exercise or piece is successfully executed, the path lines end further away from the keys on the virtual keyboard/physical keyboard, until eventually the only reference the student will be referencing is the notation on the musical score. This transition between a full reference of the falling orb paths to just a musical staff reference can be seen in Figures 5.17 5.18 5.19.

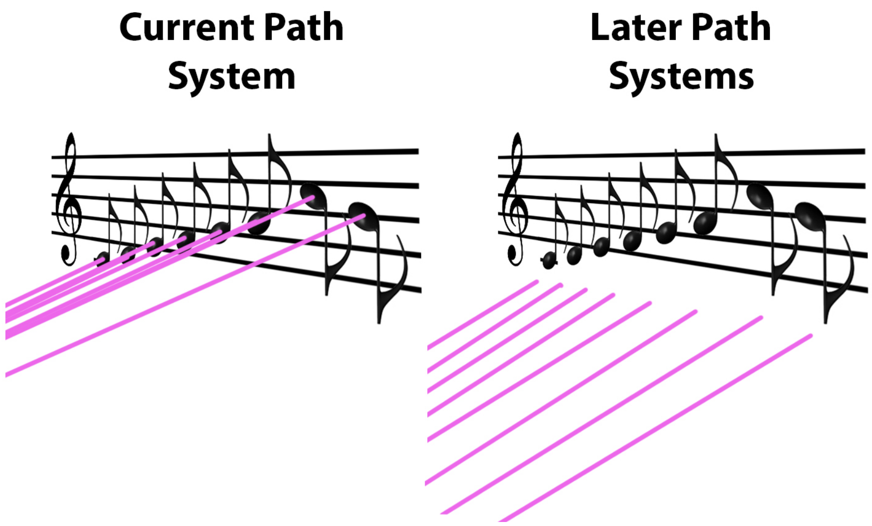

Figure 5.14: How falling note paths could be placed at the bottom of the musical staff, rather than being directly connected to each note.

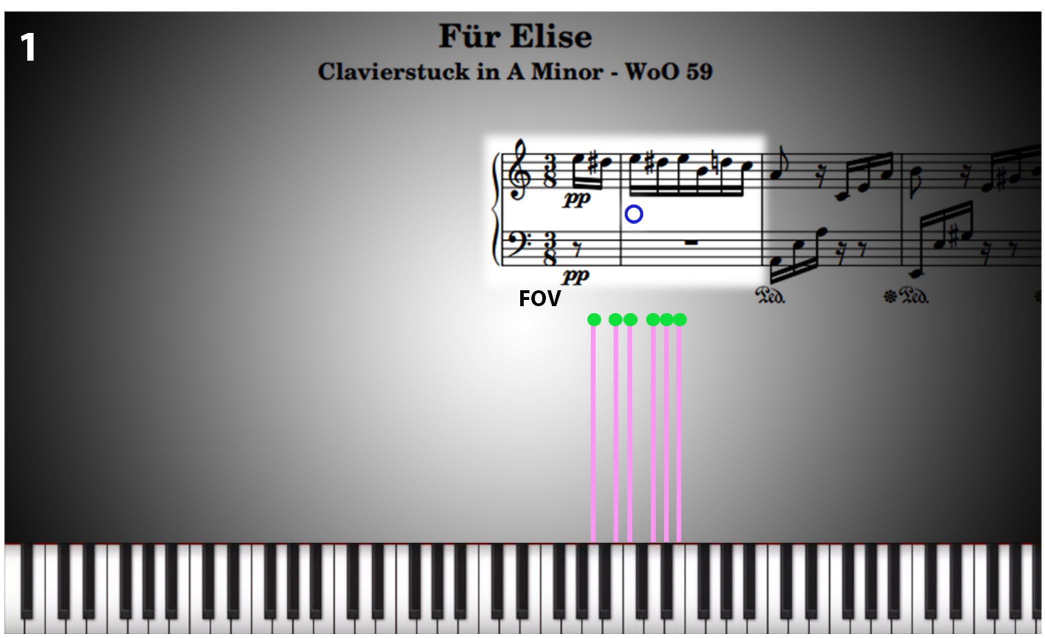

Figure 5.15: How an AR piano training application can handle a more complex piece with one bar of music before transitioning to the next measure.

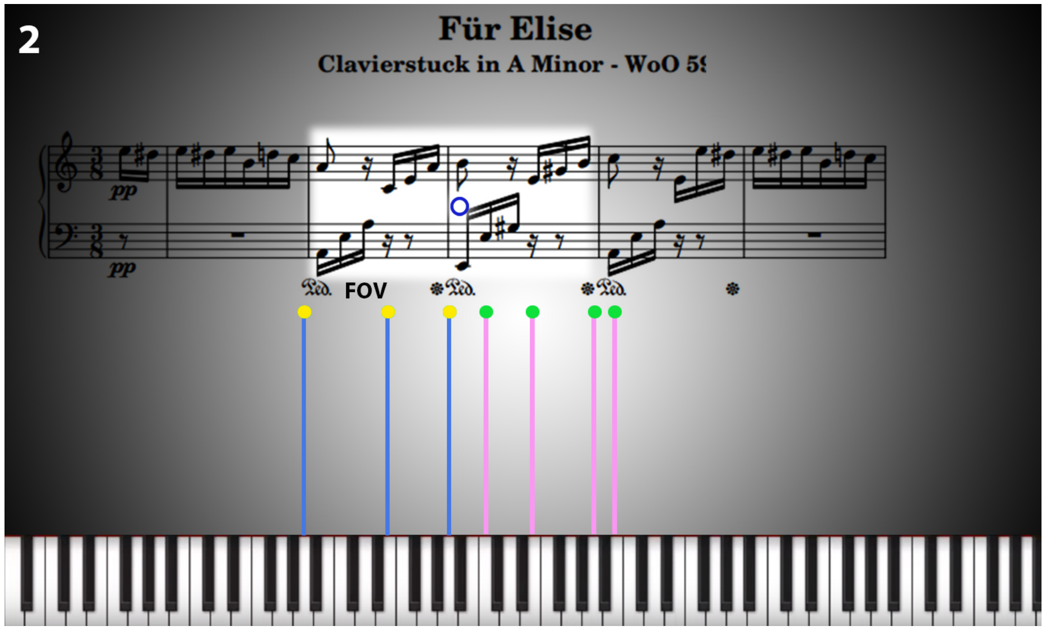

Figure 5.16: How an AR piano training application can handle a more complex piece with one bar of music after transitioning from the first measure to the second one. Note: In this illustration pink lines-green orbs represent notes played with the right hand while blue lines-yellow orbs represent notes played by the left. This could be further defined as to communicate to the user finger numbering with orb colors as was illustrated in KeynVision.

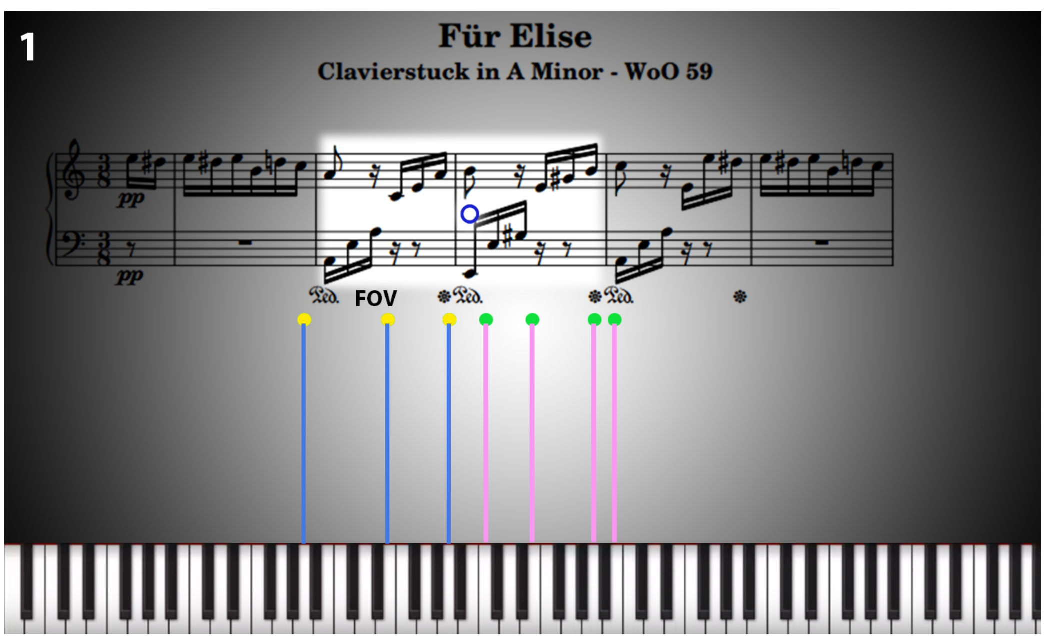

Figure 5.17: Full reference of the falling orb paths.

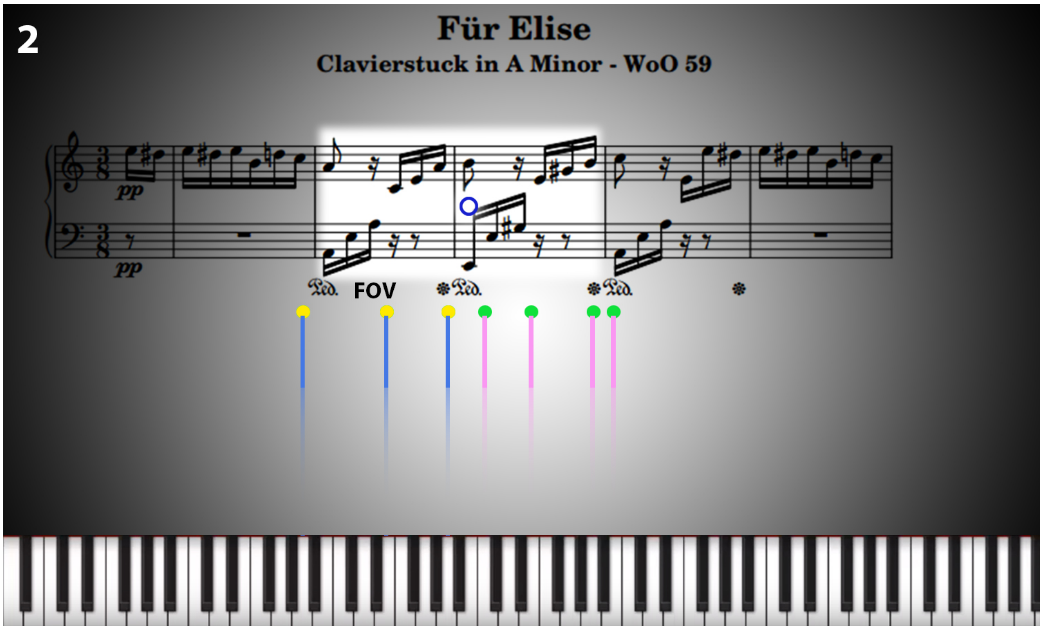

Figure 5.18: About half of the reference of the falling orb paths. Note: In order for the user to keep track of tempo and rhythm, the hit-zone needs to be accounted for as the paths are retracted from the scene.

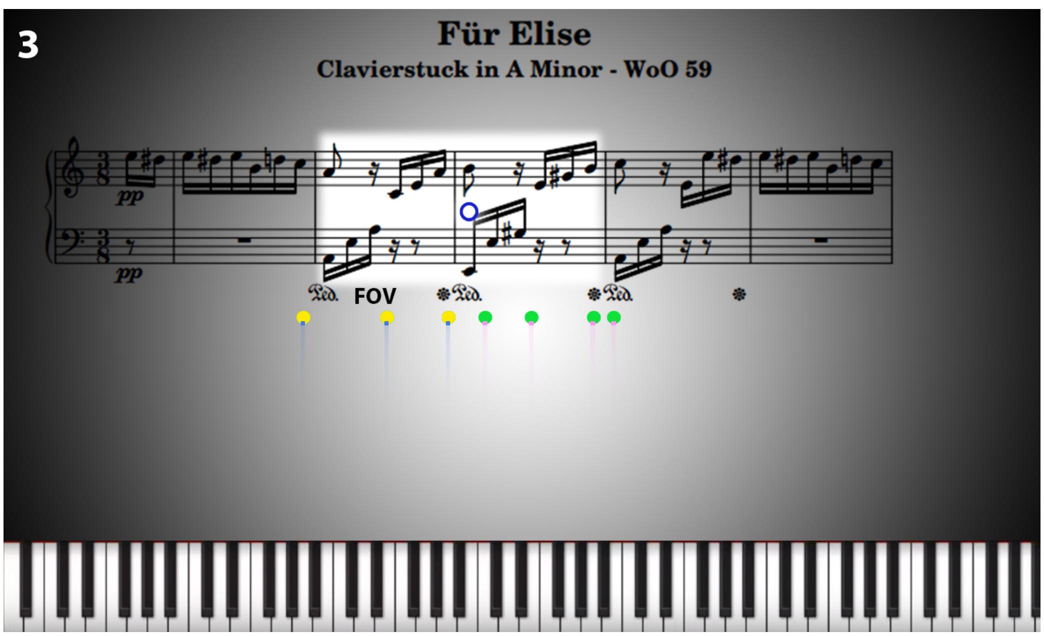

Figure 5.19: Without any reference of the falling orb paths. Note: At this stage, the musical notation should be considered the hit-zone. This should help the user get into the habit of playing to the right rhythm and tempo even after the additional visuals have been removed from the scene.

Chapter 6: FUTURE WORK AND CONCLUSION

The FOV was a problem that persisted into the third round of playtesting and the members of our expert panel all expressed this as an area that will need to continue to be improved. When the user aligns the play area to their keyboard, the application handles all the object in the scene as a single object. This is likely to continue to be a problem until AR devices improve enough to give users and developers a wider FOV to work with. What is likely to be the most effective way to optimize the current limitations of the FOV is to allow the user to move and place different elements in the scene, such as the hand reference, the virtual keyboard, and the staff area. This way, the user can get accustomed to practicing in a way that is most comfortable for them. There were also a few instances where some panel members felt like objects were not lining up properly relative to other objects in the scene. This seems to have been a result of participants not looking at the play area from its intended angel because the falling orbs, beat references, and the virtual keyboard are all objects that are positioned or moving in 3D space, it is possible to perceive the position of objects differently depending on the perspective the user is looking from. One participant also commented on how they felt like the orb that appears at the end of each falling note seems to suggest that the user needs to strike the key a second time before playing the following note. The intended purpose of this design was to signal to the player where one note ends and the next one begins. One way this could have been communicated better is to to have made the end of the falling note with a different symbol or object than what is used at the start.

After the conclusion of the final playtest, we concluded that the current status of the application would be challenging to integrate into a play mode that is meant to support two handed play that maintains a straight path from the score to the virtual keyboard for it to follow. The straight paths which orbs travel down help to make it easier to understand the correlation between the position of notes on the staff and the way the notes and their paths correlate to the keys on the keyboard communicates effectively. However, maintaining evenly spaced lines becomes less practical as soon as exercises begin to increase in difficulty with the current system that is being used in this application. Maintaining the current layout while the student is trying to practice with both hands at the same time will result in at least one major problem. That problem is if we are to maintain the way notes appear on a staff, it would be impractical to try to draw straight paths that connect each note to on the staff to its corrisponding key on the keyboard.

6.1 Future Work

Future piano related AR research projects should consider the use of an expert panel because as applications continue to handle more complex exercises and musical pieces, the the more valuable an expert pianist will become to the research project. The value of having an expert participate in the development of similar projects can be gauged by how little the developer knows about the needs of the user they are creating the application compared to experts that they recruit. Everything done in our project was within the grasp of a beginner pianist but our panel was able to help us in many ways. The same will be true as more complex lessons are introduced into a mixed reality environment because the more sophisticated a lesson is the more important it is to have experts validate the lessons are being communicated effectively. Having a panel of experts will help the developer identify what the student needs to learn more effectively as well as helping define common problems that students will likely run into. The more the needs and challenges of the intended user can be identified, the more effectively the developer can find solutions that can then be implemented into the application. More development of similar piano training applications are still needed because once one has been thoroughly developed and validated by piano instructors or expert pianist a qualitative study can be conducted. We believe it would be more effective to conduct a qualitative study after an application has been developed with the help of expert pianist who have years of experience to draw from. However, in order for us to know how effective the application is at teaching students who have never learned to play the piano before. A study can be conducted between two or more groups where one learns in a traditional manner and the other learns with an AR experience. If a study wanted to compare more groups it could be interesting to see how a third group compares when using other training application such as Yousician and Flowkey. We suspect that AR is an effective tool for teaching students how to play the piano but how effective the application is at teaching is not dependent on the technology as much as it is the design Radu [2014]. Creating an effective application for teaching how to play the piano is no easy task but becomes significantly more plausible with the insight of someone who has formal training or has taught students how to play.

A thoroughly designed system could one day incorporate many of the other benefits that technology has been able to offer. Especially in the area of collecting data that could potentially be meaningful to piano instructors and their students. Data can be provided to instructors that allows them to give their students personalized help based on each student's performances and needs. One example of this would be to give instructors a way of tracking the hours that their students are practicing between lessons, while another example would be to track and determine what individual parts of a song or an exercise the student seems to be struggling with. This is information that developers are already good at collecting and these principles are of course applicable when discussing the potential uses and benefits of AR in piano development. Another important factor to consider when creating an AR training application is the general audience and age group that the app is being designed for. Elements that are commonly attributed to children's games may have a strong place in these types of training applications because of the additional immersion value that is provided. Whether those elements are expressed in terms of collecting rewards over time or a confetti celebration after a successful playthrough of an exercise, these things can be very valuable to creating an enjoyable experience. However, it is important to keep in mind that the priority of creating a training application is that the user can increase the effectiveness of their practice sessions. What AR provides users is an immersive experience that brings virtual elements into the learning environment that can be used to guide the attention of the user to meaningful aspects of the task they are trying to execute. In the scenario where a student is attempting to develop their skills for playing the piano, an AR application for a HMD like the HoloLens has the potential to show the user some nuances that may exist while engaging in the learning process. Some of these nuances occur because students who are just learning how to play often have a hard time deciphering how notes on a musical staff translate to the actions that are executed on the keyboard. AR provides a unique opportunity for improving notation literacy because notation on a musical staff can by dynamically animated as to demonstrate how long notes should be held for and how long pauses should be before playing the next note. Future iterations should help students further build their understanding of relationships between notes when both hands are being used to play. An application like the one that was created for this study, would be intended for students who are just learning to play the piano while also being an effective tool that can be used by piano instructors as an extension of their lessons. For an application to be an effective tool for professionals, the top priority should always be making the tool effective at communicating aspects of the learning experience that are difficult to convey through conventional methods. Educational learning applications have been criticized in the past as not being able to provide a learning experience that transfers when the student steps away from the learning environment that is provided by the application and tries to perform what they've learned separate from the technology. For piano development, piano instructors will not be interested in letting their students use an application that is going to condition them to only perform well when the application is present. If features, environment layout, and stylistic choices are not considered carefully, it could potentially hinder the student's ability to improve their understanding of the information being provided to them and ultimately effect their performance.

6.2 Conclusion

We believe AR provides a unique opportunity for piano development because it can help provide concrete meaning to elements such as notation that appear to be abstract to beginners. This is done by creating direct relationships between holograms and the physical environment as a means of shaping how students visualize music. We suspect that as students continue to train using an AR interactive application, the stronger their visual representations of the piece or exercise will become. The more vivid of a mental picture a student has of the music they are learning to play, the more likely they will be to recall the exercise when playing it without the aid of the AR training application Bernardi [2013].

The more similar a target task is with a source task, the more likely a user will be able to transfer lessons learned from one activity and apply it to the other. This may call for further debate, but our impression is that when AR is used as a tool for training people, the line between the source task and the target task is slightly blurred because the student is using a physical keyboard and their hands and fingers in the same way they would if they were learning in a traditional learning experience. Torrey and Shavlik [2009] explain that the more a source task is like a target task, the more likely the transfer of knowledge will take place when the student applies skills gained from the source task and applies it to the target task. Many of the things our panel of experts discussed is in the realm of reality of things that can be developed and implemented into an application that anyone can use. However, what is important to be certain of is whether the application and the technology are good tools for people to use if they want to learn to play the piano. Not only do we believe augmented reality devices such as the HoloLens will be useful tools for music instructors and their students; we also believe that the dynamic animations that are provided to the user through augmented reality training simulations are effective at communicating information to the user that are more difficult to convey through a standard musical staff or an application for a smartphone or tablet. AR allows the user to visually interpret nuances of performing different tasks within an intended learning environment, which provides the learner more opportunities to piece together information that will likely lead to improving the overall effectiveness of their practice sessions.

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Appendix A: Structured Interviews

A.1 Round 01 - Janet Miller

1. What about the HoloLens seems useful?
   (a) Proximity of information in HoloLens to keys on keyboard.
2. What about the HoloLens seems difficult to use or confusing?
   (a) Seemed to be experiencing latency issues with holograms not staying in their proper position over the keyboard as the participant looks away and back towards the playing area.
3. What do you feel worked well about the application?
   (a) The falling blocks are easy to understand relating towards their speed and which key they belong to.
4. What do you feel could use more improvement in the application?
   (a) Positioning of holographic content should support good piano posture.
   (b) Currently the holograms are positioned in a way that requires the user to look down which is typically frowned upon but the weight of the HoloLens can be felt on the neck when looking in this position as well.
5. What design choices/features do you feel would result in an enjoyable experience?
   (a) Would like to see how more graphics could be implemented into the experience. Feels like anything that is already commonly seen in games such as UI or screens that come up after a student completes something would be important for making the experience enjoyable.
   (b) Also, brought up the idea of making the environment customizable with non-intrusive graphics or effects could make the experience more personal to the student.

6. What do you feel an AR piano training application should have if it is intended for piano instructors who are considering to incorporate the HoloLens with their piano lessons?
    (a) When referencing a mockup of what the application would look like with a music staff in it, it is important that the lines are very clear, especially the ledger lines.
7. Does the application appear to make a difficult concept easier to understand?
    (a) The technology could potentially help to make the concept of playing the piano easier to understand. As for the application, now it is still hard to say for certain but thinks adding the musical staff will be a step in the right direction.
8. What changes do you feel would improve a student's understanding of different concepts towards learning to play the piano?
    (a) Integrating a staff that illustrates in written notation what the student is learning.
    (b) Integrating some type of numbering system that tells the student what finger goes to which note.
9. Was there anything in the application that seemed irrelevant to you?
    (a) Still getting use to using the technology. Things like selecting holograms with the pinch gesture and wearing the HoloLens still feels unnatural.
10. Does the application appear to direct learner attention to important aspects of the learning experience?
    (a) During this playtest, the application is just looping three notes as they ascend and descend. It is a simple example but yes, it is clear what the user should be looking at.
11. The way the application is currently running, does it appear to create an experience where learners will feel physically immersed in the learning experience?
    (a) Feels like it is still too soon to tell and will hold her answer until the following playtest.

12. What changes could be made to the way notes are being handled to better contextualize the task of playing a scale (or other relatable exercise) on the keyboard?
    (a) The next step would be to create a complete scale and create some way of making it clear what finger the student should be using for each note.
13. What aspects of piano development do you feel would be important to include in the application for effective learning and practice sessions?
    (a) It would be good if there was a way to communicate to the student what their hand position and posture should be like.
14. How do you imagine this application should look or function as exercises increase in difficulty?
    (a) Would want to be able to choose from any scale, adjust the speed of the exercise, and increase numbers of octaves that can be played in.
15. What is your first impression of how notes are being visualized in the application?
    (a) The cubes make sense but would be interested in seeing different ways of visualizing notes and is excited to see how the staff will look when integrated into the scene.
16. How useful do feel the current way of visualizing notes is and how can this area be improved?
    (a) Same answer that is for 16.
17. How would you describe visualizing music?
    (a) Feeling (imagining) the motion of playing.
18. How do you imagine an application like this one being implemented into routine piano practice?
    (a) Will think about it and provide an answer during the next playtest session.

A.2 Round 01 - Gina Purri

1. What about the HoloLens seems useful?

   (a) Very cool to see objects in the room and feels kids would have a strong interest.

2. What about the HoloLens seems difficult to use or confusing?

   (a) Air-Tap gesture is odd, holograms don't line up nicely, and getting use to wearing the headset.

   (b) Is concerned how wearing the headset and the angel of the content being projected in the HoloLens will influence the natural ratios that occur between the keyboard height, seat height, and arm and wrist angels. Feels like the best solution for this problem would be to create a holographic play area that can be adjustable so the student is playing in a position that is most comfortable for them.

3. What do you feel worked well about the application?

   (a) Colors look nice, the motion of the notes communicates well to what would need to be done on the keyboard and the fixed position of the holographic keyboard helps for context.

4. What do you feel could use more improvement in the application?

   (a) Address basic glitches relating to notes flying around while the keyboard is still being placed in its proper position.

   (b) After watching the application for a while it seems to have a glitch where the screen turns completely white for a moment.

5. What design choices/features do you feel would result in an enjoyable experience?

   (a) Does not like the way notes are currently being visualized as blocks. Describes the hard edges on blocks to be too rough and thinks objects with soft edges would have a positive effect.

6. What do you feel an AR piano training application should have if it is intended for piano instructors who are considering to incorporate the technology in their piano lessons?

   (a) Training video – full tutorial for older users (who tend to be instructors).

   (b) Customization – picking different colors, score, settings for basic features that allow for control over how the holographic play area is positioned in the environment.

   (c) Game like celebrations when an exercise is completed or a new goal was achieved (imagines cartoony balloons or confetti).

7. Does the application appear to make a difficult concept easier to understand?
   (a) Hard to tell, feels like it would depend on the user's goals. If someone just wants to play for fun, she feels like they would be able learn by following along with the flying notes but remains skeptical on how well a student would be able to play what they've learned when they've put away the HoloLens.

8. What changes do you feel would improve a student's understanding of different concepts towards learning to play the piano?
   (a) Option of including letters with the falling notes but with the option to turn it off.

9. Was there anything in the application that seemed irrelevant to you?
   (a) Ref lines were not distracting but not sure how helpful they were.

10. Does the application appear to direct learner attention to important aspects of the learning experience?
    (a) So far the application is just asking the user to follow along so it is very mimic like, which can be helpful to telling the student what they need to do with their body but she wonders if the overall experience may distract the student of their body placement. Wonders if it would be possible to incorporate technology that could be worn around the wrist that can give feedback to the user based on the position of their hand and wrist.

11. The way the application is currently running, does it appear to create an experience where learners will feel physically immersed in the learning experience?
    (a) Feels like as long the user has holograms in their field of view that the user will likely feel physically immersed in the experience. Came to this conclusion when she looked in a different part of the room that was not populated with holograms.

12. What changes could be made to the way notes are being handled to better contextualize the task of playing a scale (or other relatable exercise) on the keyboard?
    (a) Incorporating notes as they would appear on the staff is a step in the right direction.
13. What aspects of piano development do you feel would be important to include in the application for effective learning and practice sessions?
    (a) Thinks it would be helpful if letters could be used.
    (b) Having the option to increase or decrease tempo.
    (c) Being able to keep track of successful playthroughs of each exercise that is practiced.
14. How do you imagine this application should look or function as exercises increase in difficulty?
    (a) Making sure that the improvement of a student's timing and rhythm is considered before they move on to more challenging exercises.
15. What is your first impression of how notes are being visualized in the application?
    (a) Discussed in question 5.
16. How useful do you feel the current way of visualizing notes is and how can this area be improved?
    (a) Discussed in question 5 and will elaborate more during the next playtest.
17. How would you describe visualizing music in a more traditional sense?
    (a) While sitting down at a keyboard – sight reading.
    (b) While not sitting down at a keyboard – visualizes more of the sense of touching the keys on the keyboard.
18. How do you imagine an application like this one being implemented into routine piano practice?
    (a) So far, the application appears to be more useful as a practice tool that would be used between piano lessons.

A.3 Round 01 - Ian McGuire

1. What about the HoloLens seems useful?

    (a) The visual aspect of everything seems like it would be useful for keeping younger students engaged in the learning experience.

    (b) Feels like it could be just as beneficial for older students. Made a comment relating to the HoloLens potentially providing an opportunity to provide students better training online because video chat is currently challenging to use when teaching students over the internet. He said that if there was a way for him to train students from different time-zones it would improve his daily productivity drastically.

2. What about the HoloLens seems difficult to use or confusing?

    (a) The overall experience felt disorienting at first. Wearing the HoloLens and seeing holograms in the room came off as being weird. Felt like some of the problem was coming from the way the gaze cursor was being illustrated. Suggested instead of having a blue ring to maybe make the ring more transparent or make it a glowing area.

3. What do you feel worked well about the application?

    (a) Reference lines were helpful for grouping the white keys which he feels like is helpful for the student developing their understanding of the overall layout of the keyboard.

4. What do you feel could use more improvement in the application?

    (a) Posture is big for playing any instrument. If a student gets into bad posture habits, after a short period the student will start to feel pain wherever they are exerting a bad posture. Feels as though this problem would be resolved with a lighter headset or if some type of counter weight was incorporated to compensate for the weight pulling the user's head forward.

    (b) Use of a metronome.

5. What design choices/features do you feel would result in an enjoyable experience?

   (a) Nothing jumps to mind in the moment.

6. What do you feel an AR piano training application should have if it is intended for piano instructors who are considering to incorporate the technology in their piano lessons?

   (a) Rhythm needs to be factored into the learning experience. This can be done by differentiating between quarter and half notes and incorporating a metronome.

7. Does the application appear to make a difficult concept easier to understand?

   (a) Yes, but will be more certain when he's had a chance to test what it feels like to engage in an exercise that can capture his performance.

8. What changes do you feel would improve a student's understanding of different concepts towards learning to play the piano?

   (a) Found it hard to say for certain and is holding off till he sees more being demonstrated in the application.

9. Was there anything in the application that seemed irrelevant to you?

   (a) The ring that was being used as the user's gaze cursor felt distracting.

10. Does the application appear to direct learner attention to important aspects of the learning experience?

   (a) Yes. Holograms are interesting to look at so it should be effective at keeping students engaged with the learning experience. This could help students so they are less likely to be distracted by things that may be happening in the environment.

11. The way the application is currently running, does it appear to enable learners to feel physically immersed in the learning experience?

   (a) Yes. Strongly feel like the learning experience to be physically immersive.

12. What changes could be made to the way notes are being handled to better contextualize the task of playing a scale (or other relatable exercise) on the keyboard?

(a) Determine the difference between quarter notes, half notes, and note heads.

13. What aspects of piano development do you feel would be important to include in the application for effective learning and practice sessions?

    (a) Single note melodies – Would include a variety of notes, a melodic curve and a different rhythm for each note.

    (b) Chords and chord progressions over time.

    (c) Using both hands for song and patterns with the option to practice with hands individually.

14. How do you imagine this application should look or function as exercises increase in difficulty?

    (a) Including what was discussed in question 13, would also like to see the application address articulation and dynamics of how notes can be played. Dynamics relates to the volume that a note is plays, staccato marks are short and detached whereas legato are played smooth and connected.

15. What is your first impression of how notes are being visualized in the application?

    (a) Thinks it's a reasonable way to represent notes.

16. How useful do feel the current way of visualizing notes is and how can this area be improved?

    (a) It could be sufficient for helping students understand which keys need to be pressed when playing but feel the most important changes that could be made relate to what we discuss in questions 13 and 14.

17. How would you describe visualizing music in a more traditional sense?

    (a) I partly imagine the keyboard and the keys and mostly think about how the notes relate to each other (do-re-me-fa-so), visual layout of the keyboard or how notes relate to each other in a piece.

18. How do you imagine an application like this one being implemented into routine piano practice?

    (a) If the application provides sheet music, supports play with both hands with the option to practice with one, and to be able to learn specific songs.

(b) It is important for students to get into the habit of practicing for a minimum of 15 – 30 minutes a day. “As a teacher, I would be satisfied with my students using this device when practicing from home if it encourages them to practice every day.”

A.4 Round 02 - Janet Miller

First Impressions: There is a limited field of view that makes it harder to see everything that the user would want to look at from a comfortable perspective. It would also beneficial for the student if they went through a tutorial that explains different aspects of the scene as they are first being introduced to the exercises in the application.

1. What do you feel is working well about the application?
   (a) Everything is even, visually appealing and looks fun.
2. What do you feel could use more improvement in the application?
   (a) Optimize the field of view by testing what it would feel like to place the virtual keyboard higher up on the play area. (Instead of just being at the back of the physical keys) Can use peripheral to see real keys. May eliminate strain on neck and support a more natural body posture.
   (b) Make it clearer to which color correlates to with each finger.
3. What design choices/features do you feel would result in a more enjoyable experience?
   (a) Treble clef along with the rest of the notes in the staff to the right should be 3d, instead of being flat.
   (b) It might be a good practice to use 3D objects whenever possible.
4. What do you feel an AR piano training application should have if it is intended for piano instructors who are considering to incorporate the HoloLens with their piano lessons?
   (a) It’s important that the student can practice in more in one octave.
   (b) Having a variety of exercises or songs to practice from.
   (c) Being able to increase or decrease the speed of the exercise that is being practiced.

   (d) Metronome clicks being added would be helpful as well. This could lead to a big advantage because some people have a hard time using a metronome but with if these types of people play with a dynamic visual in front of them, it could lead to them being able to process an aspect of piano playing that was previously hard for them to grasp.

5. Does the application appear to make difficult concepts easier to understand?
   (a) I would assume so. I'm looking at the application from the perspective of someone who has been playing for many years. What makes it harder to gage is that all we've seen so far is easy to grasp.
   (b) The way the notes on the staff are directly connected to the keys that are supposed to be pressed should make learning the keys and the finger pattern easier for anyone who hasn't been playing piano their whole life.

6. What changes do you feel would improve a student's understanding of the concept of what they are learning?
   (a) It's important that the student plays slowly at first. Start with whole or half notes.
   (b) I imagine the tutorial to using an application like this one should explain to the user one step at a time what areas they should be looking at as they learn.
   (c) Having a wider field of view would have been nicer.

7. Was there anything in the application that seemed irrelevant to you?
   (a) Nothing seemed off but didn't notice the object behind the staff was music stand.
   (b) Random green ball got stuck floating around in the scene.

8. Does the application appear to direct learner attention to important aspects of the learning experience?
   (a) Yes, things are lined properly and unnecessary visuals are not in the application compared to last time.

9. The way the application is currently running, does it appear to enable learners to feel physically immersed in the learning experience?
   (a) Probably more when the player is playing for a while and when they are getting feedback from how they play.
   (b) Have different rhythms variations to make it more interesting. (This would be implemented in a normal lesson.
10. What changes could be made to the way notes are being handled to better contextualize the task of playing a scale (or other relatable exercise) on the keyboard?
    (a) Starting slowly. Start with a low note value and build up from there.
    (b) Maybe put numbers on the orbs that represent the finger that should be used.
    (c) Discussed adding stems to the orbs that stay on the staff and Janet felt that starting without stems should be okay early on (especially if starting with whole notes) but should be considered for exercises using half notes, quarter notes, eighth notes, etc...
11. What aspects of piano development do you feel would be important to include in the application for effective learning and practice sessions?
    (a) Differentiating between different types of notations.
    (b) Making it clear when to cross with the thumb or to end on the pinky (when playing in more than one octave).
    (c) Hold the resting note twice as long. Simple way to help the student learn the scale. Make them play the first and last note in the octave with more emphasis than the notes in between.
12. How do you imagine this application should look or function as exercises increase in difficulty?
    (a) Discussed in questions 4, 6, 10, and 11.
    (b) Adding some sense of the measure as it relates to the notes that are being played.

(c) It is common for people referencing notes on a staff to be playing something wrong and not be able to see why they are not playing something the way it is written. If students had a way to see the exercise or song, the way it's supposed to be played with dynamic visuals, it's safe to say that they would eventually see the errors in their performances and can correct them sooner. Some students have a hard time knowing what they needed to look when looking at the staff. Some get overwhelmed, and don't know if they should focus more on the lines of the staff compared to the rest of the note head.

13. What is your impression of how notes are being visualized in the application in this iteration?

    (a) Discussed in questions 5, 6, 10, 11, and 12.

14. How useful do feel the current way of visualizing notes (as they relate to the keyboard) is and what can be changed to possible improve this area?

    (a) If considering to add stems to incoming notes, make it so the user can turn them on or off.

15. What changes do you feel are most necessary for this application to be considered for implementation into your routine piano lessons?

    (a) Having scale ascend and descend.

    (b) A certain number of successful completion before moving on to next exercise or increasing in difficulty.

    (c) Having a measured rest before the nest repletion happens. Making the spacing musical.

A.5 Round 02 - Gina Purri

First Impressions: Expressed the idea of adding a silhouette drawing of a hand to the scene that has the color of a note on the finger it belongs to. That should be helpful for bridging the gap between the color of the orbs and the finger that the student is supposed to use.

1. What do you feel is working well about the application?

    (a) The spheres are nice.

   (b) Colors corresponding to fingers is good. Especially for kids.
   (c) Notes on the staff looks good. G-clef looks good.
   (d) The new layout has improved. Much easier to see holograms in the scene without having to strain the neck.

2. What do you feel could use more improvement in the application?
   (a) Falling notes didn't appear to be lining up with the keyboard accurately.
   (b) Use quarter notes instead of eighth notes.

3. What design choices/features do you feel could be made as to result in a more enjoyable experience?
   (a) The notes on the right can be spaced out just a little bit more.
   (b) The last two notes have their flags facing in the wrong directions.

4. What do you feel an AR piano training application should have if it is intended for piano instructors who are considering to incorporate the HoloLens with their piano lessons?
   (a) The option to increase or decrease the speed of the exercise that is being played.
   (b) The option to select from different scales, chords, arpeggios, and songs.
   (c) To be able to show half-step and whole step differences. Using the "carrot" symbol to reference notes and their relation to each other.
   (d) Base-clef. Essentially, would want to be able to play notes lower and higher on the keyboard.
   (e) After discussing potentially including colors to the notes on the staff to the right: Consider providing an option for being able to turn them on or off.

5. Does the application appear to make a difficult concept easier to understand?
   (a) The color coding that is associated with each of the falling spheres appears to be helpful because the order the fingers are used in is important when learning to play the piano. Knowing which color goes to with which finger might be hard at first but should be easy to pick up on as the student continues to use the application over time.

6. What changes do you feel would improve a student's understanding of different concepts towards learning to play the piano?
    (a) Consider adding stems to the orbs on the left that remain on the staff.
7. Was there anything in the application that seemed irrelevant to you?
    (a) The music stand didn't communicate well. Couldn't tell what it was, so it seemed out of place. Consider adding the bar to make it look more like a stand and it should help it be more obvious.
8. Does the application appear to direct learner attention to important aspects of the learning experience?
    (a) Yes.
9. The way the application is currently running, does it appear to create an experience where learners will feel physically immersed in the learning experience?
    (a) It appears to be the case.
10. What changes could be made to the way notes are being handled to better contextualize the task of playing a scale (or other relatable exercise) on the keyboard?
    (a) Adding the stem to the notes to the orbs on the staff to the left.
    (b) Consider spacing the stationary notes on the left side a little apart so they match the spacing of the notes on the right.
11. What aspects of piano development do you feel would be important to include in the application for effective learning and practice sessions?
    (a) It would be interesting if there was a glove that could evaluate the student's hand shape to provide feedback towards their posture.
    (b) Anything that helps to communicate the rhythm, pitch, and fingering.
12. How do you imagine this application should look or function as exercises increase in difficulty?

    (a) Increasing octaves.

13. What is your impression of how notes are being visualized in the application in this iteration?

    (a) The way light is reflecting from the notes on the staff to the right is appealing to the eye.

14. How useful do you feel the current way of visualizing notes (as they relate to the keyboard) is and what can be changed to possibly improve this area?

    (a) Consider bringing the virtual keyboard down so they are on the same level as the lines going out into the distance.

    (b) Make the keys on the virtual keyboard light up when the user presses the keys on their keyboard.

15. What changes do you feel are most necessary for this application to be considered for implementation into your routine piano lessons?

    (a) Being able to change the speed at which the exercise is being played.

    (b) Being able to choose from a variety of lessons or songs.

A.6 Round 02 - Ian McGuire

General Thoughts: When making a level for chords, consider going back and forth between shapes. Starting with two and if these levels need to increase in difficulty, the student can continue building up their skills as they learn to switch between three or more chords and arranging them in different ways. I imagine that students using this application would result in them being able to improve over time. If the results are anything like when people play guitar hero, then it should be completely possible for a person who uses an application like this one for a long enough time that they would see a visible improvement in their performance.

1. What do you feel is working well about the application?

    (a) Likes the staff being referenced.

    (b) Color for fingering is cool and makes sense.

   (c) Notes coming towards the user is helpful for building the relationship between the staff and the keys on the keyboard.

2. What do you feel could use more improvement in the application?

   (a) Making feedback more clear and expanding on the hit-zone. Consider making it so the player can know whether they are playing a note too early, right on time, or a little too late.

   (b) Having a better sense of rhythm and the length of each note being played. Consider adding a trail to the orbs if the player needs to hold a note down.

   (c) Resting – Consider adding a symbol that helps the user know when not to play. Part of notation is that they right out the notes that you want to hear as well as the spaces where there should be silence. A representation of how long to wait before playing the next note.

3. What design choices/features do you feel would result in a more enjoyable experience?

   (a) Still getting use to looking at the staff and looking down at the keyboard. Most piano instructors consider it a bad habit to look down at the hands to much because the student might lose their place on the sheet music. Try your best to make the distance between the staff and the keyboard close enough where the user doesn't have to turn their head too much.

4. What do you feel an AR piano training application should have if it is intended for piano instructors who are considering to incorporate the HoloLens with their piano lessons?

   (a) Metronome click and perhaps a sound effect when notes are being played correctly vs incorrectly.

   (b) Articulations – staccato notes – short legato has a slur line about them. Most books at the beginner lever will address these aspects of piano playing as well. Accents – are adding emphasis to each note.

5. Does the application appear to make difficult concepts easier to understand?

   (a) Absolutely. The relationship of where the notes are on the staff and how they match with the keys on the keyboard is a helpful design choice.

(b) The coloring of notes should be beneficial for developing finger coordination.

(c) The distance of the notes as they approach the user is nice because it provides the player some anticipation before they start to play the notes. This anticipation should help the student have a grasp of the overall tempo they should be playing as well.

6. What changes do you feel would improve a student's understanding of different concepts towards learning to play the piano?

    (a) Communicating other notation symbols such as rests and breaks.

7. Was there anything in the application that seemed irrelevant to you?

    (a) Had no idea what the music stand and music book were. Not knowing what it was, found it distracting and felt that it might be easier to reference without it there.

8. Does the application appear to direct learner attention to important aspects of the learning experience?

    (a) Discussed in questions 1 and 5.

9. The way the application is currently running, does it appear to enable learners to feel physically immersed in the learning experience?

    (a) Yes, it does. Feels like there is more to look at compared to the previous version and that has improved how it feels to follow along.

10. What changes could be made to the way notes are being handled to better contextualize the task of playing a scale (or other relatable exercise) on the keyboard?

    (a) Discussed in questions 2 and 6.

11. What aspects of piano development do you feel would be important to include in the application for effective learning and practice sessions?

    (a) Discussed in questions 2, 4, and 6.

12. How do you imagine this application should look or function as exercises increase in difficulty?
    (a) The student should be able to practice with two hands (one or the other or both).
    (b) Options for increasing or decreasing speed.
    (c) Should be able to play multiple notes at the same time. Would be important when the student wants to start learning to play chords.
13. What is your impression of how notes are being visualized in the application in this iteration?
    (a) Discussed in 2, 6, and 12.
    (b) Consider using "X" or a ball that is colored differently from the others to represent when rests/breaks.
14. How useful do feel the current way of visualizing notes (as they relate to the keyboard) is and what can be changed to possible improve this area?
    (a) Discussed in questions 1, 5, 6, 12, and 13.
15. What changes do you feel are most necessary for this application to be considered for implementation into your routine piano lessons?
    (a) Notations are important but right now it is still hard to tell. Wants to hold his opinion until after he's had a chance to test playing the application as he follows along.

A.7 Round 03 - Janet Miller

First Impressions: Having a way to keep track of the beats is a nice addition to the scene and will help with communicating to the student when they should be counting. I also like that the notes are communicating legato playing style. However, I feel like the black bar should not be directly on the ledger line for middle-c. Otherwise, the visuals connect to what the student is playing and is communicating the exercise the student would be learning in a clear way.

1. What do you feel is working well about the application?

(a) Beats are an excellent addition.

(b) This version starts to show what potential an application like this might have when trying to communicate some level of articulation. The visuals help in seeing how the transition from one note to the next should be.

(c) The speed of this version is a great speed for a student who is just beginning.

(d) Gives off a stronger sense of what the beat and exercise feels like.

(e) Shapes on the fingers matches some instructors teaching styles. If the orbs could be customized or changed to highlight the part of the finger the student should be using when playing could be a cool additional setting for instructors to play with.

2. What do you feel could use more improvement in the application?

(a) Creating tutorials that describe the different elements in the scene as well as explain the meaning of notations and nature of exercises.

(b) Instead of just having the falling notes spawn from the end of the note, they should come out of the orb-staff as move towards the user over time. Feels like the note should be played right as it leaves from the orb staff. Consider providing a play mode that allows the player to just press they keys on their keyboard and have the notes animate our from the orb staff.

(c) Feels like the hand reference should be leveled evenly with the virtual keyboard. This way the objects can be closer together and require the user to have to move their head around less.

3. What design choices/features do you feel would result in a more enjoyable experience?

(a) The use of effects can be helpful for communicating to the player if they are playing accurately, can potentially make the experience feel more rewarding when they play well, and should make the overall visuals in the scene more appealing.

4. What do you feel an AR piano training application should have if it is intended for piano instructors who are considering to incorporate the technology in their piano lessons?

   (a) Finger numbering. This can be included with exercises that take place when a student is in the earlier stages of development, but as they continue to play more advanced exercises the numbers can start to be removed from the scene. Traditional piano learning books do this because earlier passages will include the fingering for more notes and later passages will much less, such as only showing finger numbers for 1, 3, and 5.
   (b) A built-in metronome. Is important because it is something that students must get use to listening to as they practice. The experience will be more user friendly if it has one built in because people who want to use one will never have to worry about trying to time their metronome with the visuals in the application.

5. Does the application appear to make difficult concepts easier to understand?
   (a) Yes, visual rhythm is communicating well. Probably the biggest benefit AR applications like this can offer is that they provide students a visual of the notes on the staff how they would appear over time and this helps to better convey how each note relates to one another (i.e. how long notes should be held and how much time should pass before playing the next note).
   (b) Hand visual makes the experience that much more user friendly. Consider putting the number on the fingers.
6. What changes do you feel would improve a student's understanding of the concept of what they are learning?
   (a) Everything should have a label on it. If a user is going through several exercises they should always know what they are practicing is called.
7. Was there anything in the application that seemed irrelevant to you?
   (a) The bar on the middle-C. It can be a little under the ledger line or it could be taken completely off the orb staff.
8. How do you feel about the way chords are being managed compared to scales and arpeggios?
   (a) The way they are being visualized makes sense.

(b) The way the current layout for chords is, it will likely cause people to not care about the position of the notes on the orb staff. The way it is now, students are likely to focus on how the notes move up and down on the keyboard.

9. Does the application appear to direct learner attention to important aspects of the learning experience?
   (a) Yes. Will be more clear when everything is in the same field of view.
10. The way the application is currently running, does it appear to enable learners to feel physically immersed in the learning experience?
    (a) The application seems to be engaging. Adding a few visual and sound effects could help in making a more compelling experience.
11. What changes could be made to the way notes are being handled to better contextualize the task of playing a scale (or other relatable exercise) on the keyboard?
    (a) Making the orbs on the orb staff make the orb that is about to spawn the next falling note blink twice (once per beat) before the falling note spawns.
    (b) 2b, 4a, and 7.
12. What aspects of piano development do you feel would be important to include in the application for effective learning and practice sessions?
    (a) 2a and 4b.
13. How do you imagine this application should look or function as exercises increase in difficulty?
    (a) Tutorials can be used to teach the student basic principles relating to piano technique and reading notation as they progress through more challenging exercises.
14. What is your impression of how notes are being visualized in the application in this iteration?
    (a) 2b and 7.

15. How useful do you feel the current way of visualizing notes (as they relate to the keyboard) is and what can be changed to possibly improve this area?
    (a) 1, 2b, 4a, and 7.
16. What changes do you feel are most necessary for this application to be considered for implementation into your routine piano lessons?
    (a) Communicating finger numbering to the student would be a helpful tool for instructors like myself.

A.8 Round 03 - Gina Purri

First Impressions: Would like it if everything in the scene was visible within the field of view. The way the application was currently running, it still requires the user to have to turn their neck in more direction then they should have to.

1. What do you feel is working well about the application?
    (a) Likes the addition of the colored lines between two consecutive orbs to suggest the length of time the note needs to be held.
    (b) Likes that this iteration is including a descending scale and the spacing of notes on the score are good.
    (c) Music stand communicates a little more clearly.
2. What do you feel could use more improvement in the application?
    (a) It's hard to tell if the falling orbs are lining up with the virtual keys properly as they reach the virtual keyboard reference. Repositioning herself to be directly in front of the virtual keyboard seemed to resolve this issue.
    (b) The bars between the orbs that represent the notes length for notes A, B, and upper-C overlap with their corresponding virtual keys. Looks odd because that does not happen with the other virtual keys.

(c) Timing of metronome should line up exactly on beat with the beat reference and orbs when they arrive to the play zone.

3. What design choices/features do you feel would result in a more enjoyable experience?

   (a) Recommends putting the hand reference on the right side of the virtual keyboard reference. Feels like the current way is a bit counter intuitive because looking back and forth between the hand reference and the musical staff seems like it would be more work than just having everything on the right.

   (b) Still feels like the position of the orbs that stay stationed on the score to the left could be spaced out more.

   (c) Notes on the staff to the right could light up based on whichever note (and color) is currently needs to be played.

   (d) More game like events and feedback, such as being told great job when completing a new exercise or receiving different rewards for completing more challenging exercises.

4. What do you feel an AR piano training application should have if it is intended for piano instructors who are considering to incorporate the technology in their piano lessons?

   (a) Mentioned that the use of sound in this application could be effectively used in a few different ways. Thinks it could be beneficial for the student if they can watch an exercise they are learning being demonstrated as they hear it being played. It will also benefit some students if they can hear a reference of each note being played as they are practicing. Could help improve the student's ability to time when they should press and release each key. A metronome or voice that counts each beat as the student practices.

   (b) Option to select from different scales, chords, and arpeggios.

   (c) Option to adjust how long you play each note for.

5. Does the application appear to make difficult concepts easier to understand?

   (a) The lesson is very simple, so it is hard to determine the right answer to that.

   (b) Being able to visualize how the music sounds is a strong advantage that is provided by the technology so it feels safe to assume that the application is making it easier to understand.

6. What changes do you feel would improve a student's understanding of the concept of what they are learning?

   (a) Having some type of visual reference that shows the user proper hand positioning and posture. Maybe an over the shoulder perspective of someone playing.

   (b) As a player has a key pressed it could be helpful if the bars representing the notes length changed in saturation every beat that note was held. This could help the student get in the habit of counting as they play.

7. Was there anything in the application that seemed irrelevant to you?

   (a) The meaning of the beat reference was not apparent at first and would need to be explained at some point if they were in a completed application. The beat reference is generating 5 lines per measure. The way the application is currently running, the beats are the spaces between the lines.

8. How do you feel about the way chords are being managed compared to scales and arpeggios?

   (a) Thinks it would be better if the orb-staff was not replaced with the current set up (which places the orb-spawn-positions next to each other in a straight line), fill it in just like they would be on the staff to the right. Instead of the orbs traveling down a path that goes straight from the position of the orb on the orb-staff to the keys that make up the chord, have one line come straight down from the grouped notes that make up the chord and have that line split it into separate paths that leads each orb to their corresponding key.

9. Does the application appear to direct learner attention to important aspects of the learning experience?

   (a) The way the application is currently set up, the layout is effective at communicating things that are important to students who are just beginning. Length of time each note needs to be held.

Shows where notes are on the staff as well as the keys they go to at the same time.

10. The way the application is currently running, does it appear to enable learners to feel physically immersed in the learning experience?
    (a) Yes. The application seems to be engaging.
11. What changes could be made to the way notes are being handled to better contextualize the task of playing a scale (or other relatable exercise) on the keyboard?
    (a) To help communicate counting beats better, consider adding the beat numbers next to the space (line) that it is next to.
    (b) Feels like it could be beneficial to make the bars that represent the length of each note change slightly for each beat that they hold the key pressed down. For example, this could be done by making the color of the bar decrease in saturation every beat the key is pressed as to help the student improve their ability to count as they play.
12. What aspects of piano development do you feel would be important to include in the application for effective learning and practice sessions?
    (a) 4a and 6b.
13. How do you imagine this application should look or function as exercises increase in difficulty?
    (a) 3, 4b, 4c, 6 and 8a.
14. What is your impression of how notes are being visualized in the application for this iteration?
    (a) 2a, 2b, 3b, 3c, and 6.
15. How useful do you feel the current way of visualizing notes (as they relate to the keyboard) is and what can be changed to possibly improve this area?
    (a) 5b and 9.
16. What changes do you feel are most necessary for this application to be considered for implementation into your routine piano lessons?

(a) Option to move different elements in the learning scene.

(b) Option to increase or decrease the speed that the student practices in.

A.9 Round 03 - Ian McGuire

First Impressions: The way the notes are currently being projected in the application, it's hard to tell if the user is supposed to press the key for both the first and last orbs or just initial one.

1. What do you feel is working well about the application?

    (a) The music stand looks more like a music stand. Separating the colors between the book and the stand helped to tell those objects a part. The addition of a bar also helps in communicating what it is. Feels like the music stand also helps with communicating that the exercise that the student will be learning takes place in that area.

    (b) The way the notation on the music staff connects to the notation on the orb staff and how each falling notes lines up with the key that needs to be pressed while providing a way of know when to release; the application seems to provide all the necessary information needed to be able to learn from this scene.

2. What do you feel could use more improvement in the application?

    (a) Chang the symbol or object that is being used at the end of falling notes so the user doesn't get confused as to having to strike the same key and know to just press the next one.

3. What design choices/features do you feel would result in a more enjoyable experience?

    (a) Giving the incentives would be useful. When some students are given a lesson book they will tend to go straight to the end and think to themselves, "okay, if I do all the exercises, I should be able to play this by the end." Making it so students can view harder exercises could potentially turn into motivation for wanting to master earlier exercises. Score or progress log that tells the student their high scores so they keep track of their progress.

4. What do you feel an AR piano training application should have if it is intended for piano instructors who are considering to incorporate the technology in their piano lessons?

(a) Feels like the use of vocal instructions would be important for an application like this because if someone is using the application when practicing on their own, having any more visual information in the scene could cause the overall experience to feel overwhelming. Would dislike it if there were any text instructions in the scene telling the user what they need to do while trying to look at the different elements in the scene. Highly recommends that instructions or advice given to the student while they are in a tutorial or practicing an exercise should be done with sound.

(b) Would like it if elements such as the hand reference could be turned on or off. Having the hand reference might cause the scene to look more overwhelming than it needs to be for some beginner students.

(c) If the application were going to include a base clef or support two handed training exercises you would not want to separate the base clef from the treble clef and they should overlap like they would on a normal score (treble top and clef bottom). Perhaps the orb staff can be moved somewhere else and the musical staff can spread across the entire width of the keyboard? When looking at sheet music the student develops the ability to zig-zag up and down between what is happening in the treble and base clefs.

(d) More content and variety of lessons. Different scales, chords, arpeggios, song variety, and audio.

(e) Tutorial that describes all the elements in the scene. Advice could be given to the student based on performance using audio. Addition of theme music would make the experience more enjoyable. Sound of metronome would be very helpful. Backing track that plays along with the student to force them to think about rhythm and not about their own timing.

5. Does the application appear to make difficult concepts easier to understand?

   (a) Yes.

6. What changes do you feel would improve a student's understanding of the concept of what they are learning?

(a) Tutorials that help the student build up their knowledge of different aspects of notation literacy and principles of basic piano technique. Notation literacy – Staff, ledger lines, bar lines, G clef, F clef, and all the different notes and rests. Technique – Thumb under, thumb over, fingering, accurate tempo, scales, chords, arpeggios, articulation.

(b) Being able to demonstrate proper hand positioning and posture.

7. Was there anything in the application that seemed irrelevant to you?

   (a) The gaze cursor stands out more than it should and feels distracting. It seems like it doesn't have an important role to the overall experience after the holograms have been placed over the keyboard. Maybe it is something that the user can turn off or on or be changed to a glowing light, rather than being a ring.

8. How do you feel about the way chords are being managed compared to scales and arpeggios?

   (a) The problem with the current layout for chords is the user will lose the letter of what the falling note is referencing on the staff. The current setup could potentially take out an important element the student would need to learn the meaning of the notations. This could cause the student to not care so much about the letter each note represents and focus all their energy on pressing the keys when they need to. If applications like this are intending to help students improve their notation literacy, then it needs to get the student in the habit of following notes on a score like they normally would on a regular sheet of music.

9. Does the application appear to direct learner attention to important aspects of the learning experience?

   (a) Yes. The application shows everything that is needed for someone to be able to get a sense of what needs to be done. Everything seems interesting enough that a student would feel compelled to play for a while. If that is the case, then a student who follows along with the application as it is right now should be able to understand everything that is important to understand to be able to perform the exercise.

10. The way the application is currently running, does it appear to enable learners to feel physically immersed in the learning experience?

    (a) Yes, but feels that every time that a student must look up or around to see the full picture of the scene could potentially break their immersion. If everything in the scene can fit within the user's field of view, requiring them to look around less, it will make looking at everything in the scene much easier and probably make the learning experience feel more immersive. This point can also be used to argue the need for a wider field-of-view.

11. What changes could be made to the way notes are being handled to better contextualize the task of playing a scale (or other relatable exercise) on the keyboard?

    (a) 2, 4c, 6a, and 8.

12. What aspects of piano development do you feel would be important to include in the application for effective learning and practice sessions?

    (a) Being able to custom tailor lessons to the student's needs. Being able to assign specific lessons to the student. Getting a sense of how the student has progressed between lessons.

13. How do you imagine this application should look or function as exercises increase in difficulty?

    (a) 4d.

14. What is your impression of how notes are being visualized in the application in this iteration?

    (a) Found the second orb at the end of falling notes to be confusing but the overall length of each note effectively communicates the length of time the note should be held for.

15. How useful do you feel the current way of visualizing notes (as they relate to the keyboard) is and what can be changed to possibly improve this area?

    (a) 2, 4c, 6a, 8, and 14.

16. What changes do you feel are most necessary for this application to be considered for implementation into your routine piano lessons?

(a) Being able to demonstrate proper hand positioning and posture. If there were a way to record the instructor's hands and share the video with the student, the student can reference it while they practice from home.It would also be beneficial for referencing the student's hands to see if they are using proper fingering techniques. If there were a way to interact with students online using this technology and it provided live video chat where instructors can direct their student and demonstrate to them proper technique, this could potentially allow piano instructors to teach students at any time of day and with anyone from anywhere in the world.

Appendix B: Participant Q and A's

B.1 Participant Form: Questions

These are the questions that our panel was asked before conducting the first round of iterative playtesting.

[1]

1. How many years of experience do you have as a piano instructor?
   (a) 1 - 5
   (b) 6 - 10
   (c) 11 - 15
   (d) 16 - 20
   (e) 20 or more
   (f) none
2. Do you think integrating technology with piano practice would be beneficial for people who are interested in learning to play the piano?
   (a) Scale from 1 - 5, 1 being not at all and 5 being very much.
3. Do you think integrating technology would be beneficial for piano instructors teaching students to play the piano?
   (a) Scale from 1 - 5, 1 being not at all and 5 being very much.
4. Which do you think is the most important reason why a student or teacher would be interested in using technology in their practice/teaching sessions?
   (a) Added benefits of technology not already provided in a traditional learning environment.

[1] See the following link for our panel's responses. https://drive.google.com/file/d/0B5ZCZwgg9fTDZ1VoNXZQMHhUUHc/view?usp=sharing

  (b) Novelty of using new technology.
  (c) Other

5. Which do you think is the most important reason why a student or teacher would NOT be interested in using technology in their practice/teaching sessions?
   (a) Cost of buying the technology.
   (b) Skepticism of technology actually being useful to your work.
   (c) Time it would take to learn to properly integrate the technology into lessons.
   (d) Other
6. Which reasoning do you feel best explains what causes people who have an interest for playing piano to not follow through with that interest?
   (a) Finding time to practice.
   (b) Costs (lessons or a piano/electronic keyboard)
   (c) Doubt in one's ability to play well and(or) frustration at current playing level.
   (d) Other
7. Based on your experience, what area would you say beginners struggle with the most?
   (a) Not practicing enough.
   (b) Having unrealistic expectations.
   (c) Paying attention to their fingering.
   (d) Learning to read sheet music.
   (e) Other
8. How familiar are you with mental practice as a method of music learning?
   (a) Scale from 1 - 5, 1 being not at all and 5 being very much.

9. How important do you feel visualizing sound, images, or motion is for students learning to play the piano?
   (a) Scale from 1 - 5, 1 being not at all and 5 being very much.
10. Which aspects of visualizing music do you feel is most important for learning piano?
    (a) Images - such as notes on a score or other visual aid.
    (b) Sound
    (c) Motion of hands or fingers.
    (d) None
    (e) Other
11. How familiar are you with augmented reality? (also known as AR)
    (a) Scale from 1 - 5, 1 being not at all and 5 being very much.
12. Have you ever used or played an AR application?
    (a) Yes
    (b) No
    (c) Other
13. How familiar are you with Microsoft's HoloLens?
    (a) Scale from 1 - 5, 1 being not at all and 5 being very much.
14. When it comes to the HoloLens you have. . .
    (a) Seen it in adds.
    (b) Read an article or two.
    (c) Seen it being demonstrated at a conference or show.
    (d) I've used it or have one!

(e) Never heard of it.

15. At the end of each meeting we will engage in a structured Q&A discussing the use of technology in piano lessons and what currently seems to be effective or ineffective about the application I'm making. Are you comfortable with me taking an audio recording of our conversation? (It will only be referenced by me for when I write my paper)

    (a) Yes

    (b) No

16. Are you comfortable with me using or referencing your name in my paper?

    (a) Yes

    (b) No

17. If you have any thoughts or questions you'd like to share regarding mental practice, Microsoft's HoloLens, or anything else, feel free to leave them here.

    (a) Short Answer

B.2 Final Thoughts & Guidelines: Questions

These are the questions that our panel were asked after concluding our final iterative playtest. [2]

The following questions were answered with a scale from 1 to 5 with 1 meaning the person answering the question strongly disagrees while a 5 means they strongly agree.

1. **Support of good piano posture is essential because an AR application should not inadvertently teach bad habits. After a short period of playing with bad posture, the student will start to feel pain wherever they are not properly positioned.**

2. **Minimize the number of unnecessary visuals in the scene as to focus the user's attention on aspects of the holographic environment that are most important to the learning experience.**

[2] See the following link for our panel's responses. https://drive.google.com/open?id=0B5ZCZwgg9fTDTWVhUXZPZFQ3TVU

3. **Using colors to coordinate fingering patterns is important because knowing which finger goes where is hard for students at first but is something that they can pick up on as they continue to use the application over time.**

4. **Every holographic object in the scene should have a purpose and should be apparent to the user. It is important that the use of special holographic objects or symbols are used to tell the user to perform a specific action and it should be consistent throughout the learning experience.**

5. **Limit how much the user is required to move their head when observing essential visuals for their learning experience. This can be done by optimizing the HoloLens' field of view to contain as much of the holographic scene as possible. Note: Some head movement is okay but to create a learning environment that the user can engage with comfortably. It is important to limit unnecessary movement so the user can have as much of a natural and seamless learning experience possible.**

6. **If the application is intended for beginners, the application should start with a level that trains the student to play at a slow and steady pace. Different rhythm variations should be Implemented because they are a common part of piano lessons.**

7. **If you have any suggestions or comments about the guidelines discussed in this section, please leave your thoughts bellow.**

8. **It is helpful to have a musical staff in the virtual environment as a reference.**

9. **Notes traveling down paths from the staff to the keyboard is an effective design choice for communicating how notes on a score translate to the keys on a keyboard.**

10. **Providing some distance between the staff and the keyboard is helpful for giving the player a sense of anticipation as the falling notes travel towards them.**

11. **Adding length to falling notes is an effective way of communicating the length of time the note needs to be pressed and held before releasing.**

12. **To better communicate the action of holding keys down, the bar representing the length of time the note is held can change overtime as to indicate to the user that they have pressed the right key, with the right amount of pressure, and the right length of time.**
13. **It is important to consider the use of all notation symbols (such as rests, breaks, sharps, flats, whole notes, half notes, quarter notes, eighth notes, etc.)**
14. **Learning chords is important for piano playing, so the system must be able to manage processing multiple inputs for notes that make up a chord in the same instance.**
15. **It is generally better to use 3D holograms when working in AR compared to flat surface holograms.**
16. **The user should have some sense of the measure and how it relates to the notes being played.**
17. **Rests should be communicated through a symbol that helps the user know when not to play.**
18. **Having the numbers that correlate to each beat come down alongside the spaces that represent the beat can help the student get into the habit of counting while they play.**
19. **Stems and flags should be on the stationary orbs of the orb staff. However, added stems and flags to falling notes may cause more clutter than what is necessary.**
20. **The musical staff and the orb staff should never be modified or obstructed and the notation should always appear the same way as it would if it were written on normal sheet music.**
21. **If you have any suggestions or comments about the guidelines discussed in this section, please leave your thoughts bellow.**
22. **Having an option to adjust the speed of the exercise is an essential feature.**
23. **Having an option to change the number of octaves that can be played in is an essential feature.**

24. **Fully customizable play area that allows the user to place any element in the scene (virtual keyboard, hand reference, and notation staff anywhere the user wants to) would be considered and essential feature.**

25. **Option to turn finger numbering (falling note number references, beat counting number references, finger numbering on hand reference) on or off would be considered and essential feature.**

26. **Should be able to see the letter associated with each falling note but it should be given an option to turn it on or off.**

27. **Customizing lessons to the student's needs (such as assigning lessons based on areas a student is struggling in) would be a valuable feature.**

28. **The more of a variety of exercises that can be picked from (scales, chords, and arpeggios). Or songs that can be practiced (classical, baroque, jazz, rag time, etc.) The more value the application will have.**

29. **Tutorials should define all the elements in the holographic play scene (virtual keyboard, falling notes, orb staff, etc.) Demonstrate basic piano principles, piano technique, and reading notations.**

30. **Metronome or counter should be built right into the application.**

31. **Hearing the notes in an exercise being played as the user observes the notes being generated in the scene is a good way for the user to learn from observation.**

32. **Use of vocal instructions that speaks new information to the user will be more user friendly than using instructions that are in text format.**

33. **The use of non-intrusive graphics, special effects, and animations can lead to a more enjoyable learning experience.**

34. **Celebrations when an exercise is completed or when a new high score has been achieved (I.e. balloons or confetti) is a good way to make the learning experience feel rewarding.**

35. **A certain number of successful completions should be expected from the user before they can start learning more difficult exercises.**

36. **The application should be able to keep track of progress a student makes as they practice over time. Should know how many successful playthroughs the user has had on any exercise and determine areas where the student needs improvement.**

37. **The application should be able to evaluate the student's timing and rhythm before determining whether the student can move onto the next exercise.**

38. **A hit-zone (the defined area where the player knows they are supposed to strike the key) should communicate to the user when they are supposed to time pressing each key and the hit-zone should provide the user feedback based on whether the student is playing too early, perfect, or too late.**

39. **The student should be able to practice with either hand or both at the same time. Demonstrate proper hand positioning and posture.**

40. **Thumb under, thumb over, fingering, accurate tempo, scales, chords, arpeggios, articulations, and dynamics are all techniques that should be translated well.**

41. **Visual references that show the user proper hand positioning and posture (animation or video recording) would be beneficial for introductory level students.**

42. **Falling notes can have numbers on them to associate them more clearly to the finger that is being used but it should only be used during early development.**

43. **Numbers for fingering can slowly be reduced over time as the student gets more experience.**

44. **Labels should be applied to scales, chords, arpeggios, songs, different notations, elements of the play area etc. for the user to refer to at any time.**

45. **Challenging exercises and songs should be viewable to students even when they are not ready to practice them because this could motivate them to make the harder levels their goal.**

46. **Providing the student a log of previous playthroughs and their overall performance is a good tool for giving the student more incentive to try to do better.**

47. **If you have any suggestions or comments about the guidelines discussed in this section, please leave your thoughts bellow.**

The following questions were short answer questions.

1. **How has being a participant in our expert panel changed your views on the idea of integrating augmented reality technology into piano lessons (or as a learning supplement to be used in between piano lessons)?**

2. **What would you consider to be the most interesting benefits an augmented reality application that is designed for piano training has to offer people who are interested in learning to play the piano?**

3. **What are your hopes and expectations for augmented reality becoming a practical tool that can be used by both piano instructors and people who are interested in learning how to play?**

4. **If you have any other final thoughts you'd like to leave with us please use the space bellow.**