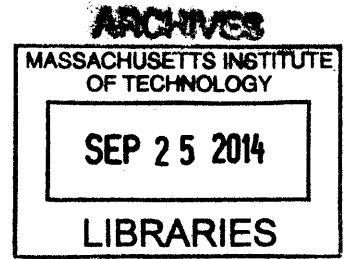# Design, Implementation, and Evaluation of a Social Learning Network for Chess

by

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Submitted to the Department of Electrical Engineering and Computer
Science
in partial fulfillment of the requirements for the degree of

Master of Science in Electrical Engineering

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Abstract

This thesis demonstrates how an active team environment, enabled by educational technology, enhances an individual's learning experience. With the inspiration and insight from international chess Grandmaster Maurice Ashley, who is also an experienced and successful chess coach, this thesis examines the question in the context of chess. Two of GM Ashley's acclaimed chess skill builders, Pawn Mower and Chess-Maze are digitally transformed, and then extended to create a social learning network. Three types of team interactions are designed, which we call EnLighten Me, Peers' Peek, and Heat Map respectively. EnLighten Me and Peers' Peek are implemented into browser-based webpage, while Heat Map is visualized in a mobile application written on the Android platform. A comparative experiment is then designed according to learning theory, to test the effectiveness of the proposed social learning network. User data was collected and interpreted for possible future work.

Acknowledgments

Thanks to my advisor Andy Lippman for his guidance and support. Thanks to Andy also for his trust, wisdom, and one of a kind humor. Working with him has truly been a pleasure.

Thanks to chess Grandmaster Maurice Ashely for his inspiration and passion. It is usually hard to make serious things fun and fun things serious, but the collaboration with Maurice has been proven to be one of the exceptions.

Thanks to my lab mates and friends, especially Travis Rich, Ying Yin, and Ying-zong Huang, for their help through each stage in this project.

Thanks to my mom and late dad for everything. I love them very much, and I am forever in debt to their love and generosity.

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Chapter 1

Introduction

1.1 Motivations

How technology can enable and enhance one's learning has long been a vibrant study field, and with the booming of the massive open online courses (MOOCs), answering this question is especially timely.

To be effective, educational technologies must be designed based on what we know about how people learn. But what exactly is learning? A quote from United States Supreme Court Justice Potter Stewart in 1964, on a completely different subject, surprisingly describes learning well. "I shall not today attempt further to define the kinds of material I understand to be embraced within that shorthand description... and perhaps I could never succeed in intelligibly doing so. But I know it when I see it..."

There is in fact no ubiquitously accepted definition of learning, mainly due to the abstract and complex nature of the matter. Viewed from different perspectives, learning can take the form of different activities, effects, and thus have different definitions. Therefore, it is important to place learning theory in historical perspective and get a somewhat holistic appreciation, to better leverage the technologies to aid the learning process.

1.2 Learning Theories

People's curiosity about how learning works can be traced back for more than 2000 years to the ancient civilizations, when some of the biggest names in philosophy were also the early pioneers exploring the filed of human learning. In Greece, Plato (427 - 347 B.C.) as a rationalist, believed that knowledge was inherited, and can be gained by reflecting on the contents of one's mind [8]. Socrates (469 - 399 B.C.) established the dialectic method of discovering truth through conversations with fellow citizens [6]. Plato's student, Aristotle (384 - 322 B.C), the empiricist, developed a scientific method of gathering data to study the world around him. The Romans differed from the Greeks in their concept of education, they emphasized education as vocational training, rather than as training of the mind for the discovery of truth [1]. In China, Confucius (551 - 479 BC) believed in the superiority of personal exemplification over explicit rules of behavior. Still, after his death, aphorisms concerning his teachings would be compiled by his students into *The Analects*.

The Renaissance (15th to the 17th centuries) revived the Greek concept of liberal education, which stressed education as an exploration of the arts and humanities [1]. Rene Descartes (1596 - 1650) revived the Platonic concept of innate knowledge, his first description of reflex action was influential in psychology for over 300 years [3]. John Locke (1632 - 1704) revived Aristotle's empiricism with the concept that the child's mind is a blank tablet (tabula rasa) that gets shaped and formed by his/her own experiences. Kant (1724 - 1804) refined and modernized Plato's rationalist theory with his suggestion that "a priori" knowledge was knowledge that was present before experience. This learning theory opened the door to Piaget and others who would further develop the ideas of cognition [6].

It was not until the 19th century that scientific approach, that is, objective tests, was introduced into the study of learning. Many education psychologists would credit Edward Thorndike (1874 - 1949) for such introduction. Thorndike believed that learning was incremental and that people learned through a trial-and-error approach. [1]. He favored students' active learning and sought to structure the environment to

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ensure certain stimuli that would 'produce' learning [4].

The 20th century debate on how people learn has focused largely on behaviorist vs. cognitive psychology. The father of modern behaviorism, B. F. Skinner (1904 -1990), further developed Thorndike's Stimulus-Response learning theory. He was responsible for developing programmed learning which was based on his stimulus response research on rats and pigeons in experiments that provided positive reinforcement for "correct" responses. The idea of programmed learning would later be adopted into online education [8].

Behaviorist learning theory has had substantial influence in education, guiding the development of highly-sequenced and structured curricula, programmed instructional approaches, workbooks, and other tools [1]. Even the most popular definition of learning, suggested by Kimble in 1961, 'Learning is a relatively permanent change in a behavioral tendency, which occurs as a result of reinforced practice.' [8] seems to favor the viewpoint given by behaviorist.

However, evidence has accrued that tasks requiring more complex thinking and higher mental processes are not generally well-learned through behaviorist methods and require more attention to how people perceive, process, and make sense of what they are experiencing [1].

Jean Piaget (1896 - 1980) was the first to state that learning is a developmental cognitive process, that students create knowledge rather than receive knowledge from the teacher. His work acknowledged the utility of some behaviorally-guided rote learning while also arguing that other activities that support students' exploration are essential [4].

The Soviet scientist Lev Vygotsky (1896 - 1934) extended Piaget's developmental theory of cognitive abilities of the individual to include the notion of social-cultural cognition - that is, the idea that all learning occurs in a cultural context and involves social interactions. He proposed a concept called Zone of Proximal Development (ZPD), which largely contributes to the social learning network designed in this thesis. The basic idea is that students learn subjects best just beyond their range of existing experience with assistance from the teacher or another peer to bridge the distance

from what they know or can do independently and what they can know or do with assistance [9]. A visualization of the ZPD concept is shown in Figure 1-1[1] , Vygotsky explained that "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers. For example, two 8 yr. old children may be able to complete a task that an average 8 yr. old cannot do. Next, more difficult tasks are presented with very little assistance from an adult. In the end, both children were able to complete the task." [10]
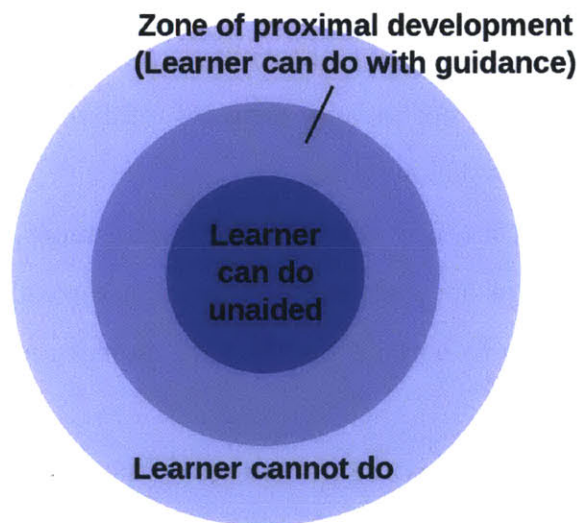
Figure 1-1: Zone of Proximal Development

In large part because of differences in underlying views of the purposes of education, debates continue about "best" teaching practices. There is however greater appreciation of the fact that different strategies are useful for different kinds of learning.

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[1]Figure credit to Wikipedia.com

1.3 Empirical Observations

In parallel with the psychological advancement in learning theories, expert practitioners also provided us a set of understandings about how people learn that have practical implications for teaching. John Dewey (1859 - 1952), who established the first laboratory school, was one of the first to suggest that learning was a situated activity. He believed that the teacher's goal is to understand both the demands of the discipline and the needs of the child and then to provide learning experiences to enable the student to uncover the curriculum [1] .

The idea was later celebrated by Maria Montessori (1870 - 1952), the first woman in Italy to receive a medical degree, and whose educational method is in use even nowadays throughout the world. She believed that students learn through carefully chosen activities. "The task of the teacher becomes that of preparing a series of cultural activities spread over a specially prepared environment and then refraining from obtrusive interference." [7]

Jerome Bruner (1915 -) developed the idea that if complex material is broken down into its essential ideas, any student can learn any subject matter. "Any subject can be taught effectively in some intellectually honest form to any child at any stage of development." [2] Many of his ideas would be used by Seymour Papert as a basis for Logo software in the 1980s.

Implied by these observations is the importance of well-designed learning material and inspirational instructor in the learning process, a description that the collaborator of this thesis, chess Grandmaster Maurice Ashley, and his puzzle skill builders for chess, fit well. GM Ashley is the first African American chess grandmaster, and he for many years has been coaching young kids chess using his uniquely designed set of chess variants. These chess variants, or skill builders, aim at improving players' chess game, as well as stretching their cognitive skills. His special approach is not only claimed by his students to be "fun", but also proven to be effective too. Two teams that he coached, the Raging Rooks of Harlem and the Dark Knights, both from Harlem New York City, have won national championships under his guidance.

1.4 Outline and Contributions

We applied both behavioral and cognitive theories, to extend two of GM Ashley's chess skill builders, to a social learning network. Two websites, and an Android mobile application are built for this purpose. It has games, exercises, all designed to get you to think like strategist. They are about chess and thinking.

In the remainder of this thesis, Chapter 2 continues to provide psychological, practical, and technical background of learning in the digital age. Related works are introduced, in particular, GM Ashley's two skill builders for chess, Pawn Mower and ChessMaze. Chapter 3 presents the proposed social learning network. Three different team modes are designed, called EnLighten Me, Peers' Peek and Heat Map respectively. EnLighten Me focuses on one-to-one help, Peers' Peek on many-to-one (with identity) help, and Heat Map on anonymous many-to-one help with a birds-view visualization. Chapter 4 describes the implementation. The description starts with the conversion of the above mentioned two skill builders to stand-alone applications, i.e., a software that works locally without requiring network connectivity, in terms of the architecture of design and the technical implementation. Then the stand-alone softwares powered with network connectivity and database are transformed to realize EnLighten Me and Peers' Peek. For Heat Map, an Android application is built to utilize the portability and versatility of mobile phones. Chapter 5 moves on to the evaluation. The design of a comparative experiment is described, under which the three proposed team modes are tested. This chapter also includes analysis of collected user data, and its heuristic interpretation. Chapter 6 provides conclusion and thoughts on future work.

Chapter 2

Background

2.1 Educational Technology

Defined by Association for Educational Communications and Technology (AECT), educational technology is more tangible than learning itself. It is "the study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources." [5]

In a broader sense, any human advance facilitated for the purpose of knowledge acquisition should be considered as educational technology. The invention of paper and printing, for instance, is a huge step forward in transmitting one's knowledge to another, or past to future self when at the time narration and recitation were the dominant communication method. This thesis takes a narrower view, a view implicitly expressed in the AECT definition, and focuses only on educational technologies powered by computer and the internet. The paper and printing invention, in this regard, would be replaced by, say, the birth of iPad®. Like paper and printing, iPad was not invented specifically on the mission to reform education either. But nonetheless it has gradually become a common classroom companion, and is even required for the newly enrolled in Webb School, a private school in Knoxville, TN, and Arkansas State University.

The intentional use of computers to complement or supplement human teachers began not long after the invention of the first modern electronic general-purpose

computer Electronic Numerical Integrator And Computer (ENIAC) itself in 1946. In 1960, physicists and engineers at University of Illinois at Urbana-Champaign (UIUC) started experimenting a system called Programmed Logic for Automatic Teaching Operations (PLATO) for pedagogy.

PLATO was the first major social computing environment. It allows a student to log into the system on a remote computer terminal, get connected to the distant server, which were initially only located at UIUC, and work on, say math problems, at his own pace. The system presents a set of questions, to which the student's answers will be instantly evaluated. After answering enough questions correctly, the student gets the permission to move on to the next topic. By the late 1970s, PLATO supported several thousand graphics terminals distributed worldwide, running on nearly a dozen different networked mainframe computers, and gained huge success. More than 15,000 hours of instruction were developed for PLATO - representing perhaps the largest single investment in educational technology content ever made, even to this day.

PLATO's approach on the content format was largely inspired by learning theory behaviorist B. F. Skinner and his 'teaching machine', a device he invented in 1958. The 'teaching machine' involves the following features: 1)Small Steps, 2)Overt responding, 3)Immediate feedback, and 4) Self-pacing, and is based on Skinner's many years' development of 'programmed learning'. As described previously, PLATO delivers all these features, while additionally also provides sophisticated interactive simulations, advanced educational games, and other interactive learning environments. Many modern concepts in multi-user computing owe much to PLATO, including forums, message boards, online testing, e-mail, chat rooms, picture languages, instant messaging, remote screen sharing, and multiplayer games.

Over the years, new technology have been adopted by the computer-assisted learning community. One of the major improvements is the introduction of machine learning into the online evaluating system. Machine learning is, in layman's terms, pattern matching. The computer takes in leaners' input data and compare it with preset models, and then determine how well the learner did in a certain task, or predicts what

kind of mistakes he tends to make. Such introduction opens the door to a wider types of questions that can be asked in a platform like PLATO, for example, a short essay.

In the new Millennium, interest in online learning community surges. In 2001, MIT introduced OCW (Online CourseWare), an ambition to allow potential learners to download all the raw learning material as used by MIT students in their residential courses without having to get admitted into the institution first. Many engineering students, including myself before entering MIT, have benefited greatly from being able to practice over and over again using the curated material made available through OCW.

Nowadays, the online learning community, exemplified by MOOCs, uses a variety of techniques rooted from both theoretical experiment or practical experience, to enhance students' learning experience. Khan Academy would offer students an abundant set of questions, in order to reinforce one's understanding on a particular concept should they find it challenging. Similarly, on edX, a joint initiative by MIT and Harvard to provide high quality online courses to the whole wide world, its launching course 6.002x, Circuits and Electronics, integrates a simulator into its curriculum. The simulator allows students to manipulate virtual circuit components and get real-time response, to help illustrate abstract ideas. It can also serves as an alternative to demos that are dangerous in real physical world setting, like when extremely high voltage measurement is involved. The cognitive psychologists also found their theories transferred into application in computer-aided learning, although a bit later. Khan Academy and edX gradually integrates either a forum or discussion panel into their course offering, or even the option of offline study group, for students to seek and offer support to each other, and form a community. Forums like Piazza, specializing in complementing offline real classroom education, or Quora, offering a wider selection of topics for discussion, have become invaluable tools in one's learning process.

This thesis extracts the elements that have been proven effective from history to integrate into the proposed social learning network design. The elements on the learner's side are teamwork and tenaciousness, and on the system side, a responsive

platform and well-crafted learning material, where in the context of this thesis, the well crafted learning material is two chess puzzle games designed by Grandmaster Maurice Ashley.

2.2   GM Ashley's Skill Builders for Chess

The collaborator of this thesis, Chess Grandmaster Maurice Ashley, has invented a set of chess variants, which he calls skill builders, to help teaching kids chess. Among the dozen skill builders, two are of particular interest for the building of a social learning network. First is "Pawn Mower", it has the simplest rules, and hence lowest hurdle to get started and the best participation. Second is what we call "ChessMaze", (for it rhymes with Team, desired in later part of this thesis), it has multiple solutions, out of which one is the optimal. For reference convenience, in the remainder of the thesis the term "skill builders" will be confined to the Pawn Mower and ChessMaze only, since the others are outside the scope of this thesis. Basic rules of the skill builders described below.

2.2.1   Pawn Mower

Pawn Mower allows only two types of pieces on the chess board: a few black pawns, and one white piece randomly chosen from the Queen, the Rook, the Bishop, and the Knight. The game challenges the players to capture all the black pawns with that one white piece, on a continuous path. Every move the white piece makes has to be a legal chess move that corresponds to the specific white piece's type. In addition, every move also has to be a capture, meaning that the white piece has to take down a black pawn. If there are pawns on the board or the player does not have any legal moves, then the player must back up and continue. The exercise helps practice chess, and also test visualization since you must plot the course of the white piece before moving, and receives media acclamation among chess community, for example, on a report from the Chess Drum. [1]

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[1]http://www.thechessdrum.net/blog/2010/08/15/ashleys-pawn-mower-puzzle-debuts/

See Figure 2-1 for an example of Pawn Mower, the solution to this puzzle is shown in Figure 2-3
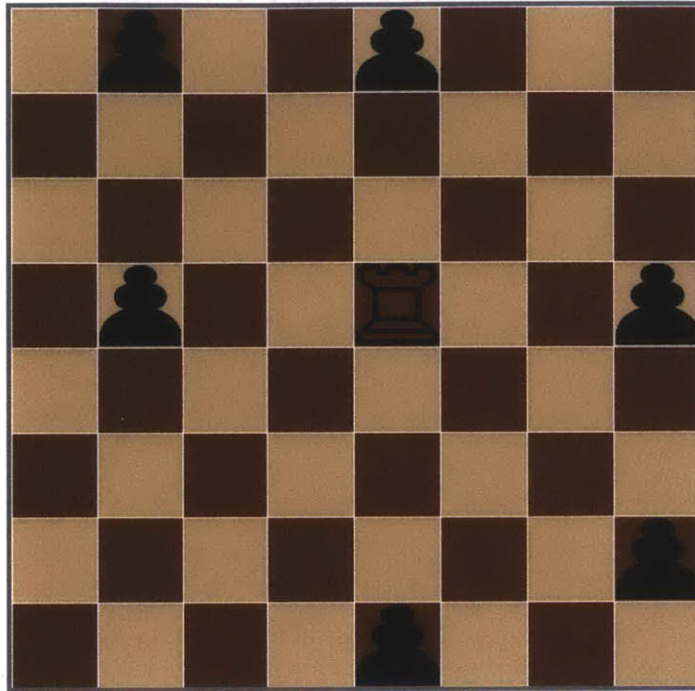

Figure 2-1: An example of Pawn Mower with a white Rook

2.2.2 ChessMaze

ChessMaze challenges the player to move the white King from a given starting point to a given destination on the chess board. Every move the white King makes has to be a legal King move. Besides, a few black pieces are scattered on the board, and while these black pieces are not able to make a move, they do impose potential threat on the white King: once the King step on a square thats guarded by any black piece, the King loses.

See Figure 2-2 for an example of ChessMaze, the solution to this game is shown in Figure 2-4. Apart from helping hone certain chess skills, ChessMaze is also a perfect metaphor for life. Often times, taking detours are inevitable even if the desired destination seems to be just one step away, for there're always obstacles and pitfalls in life. The chosen example illustrate such lesson very well.
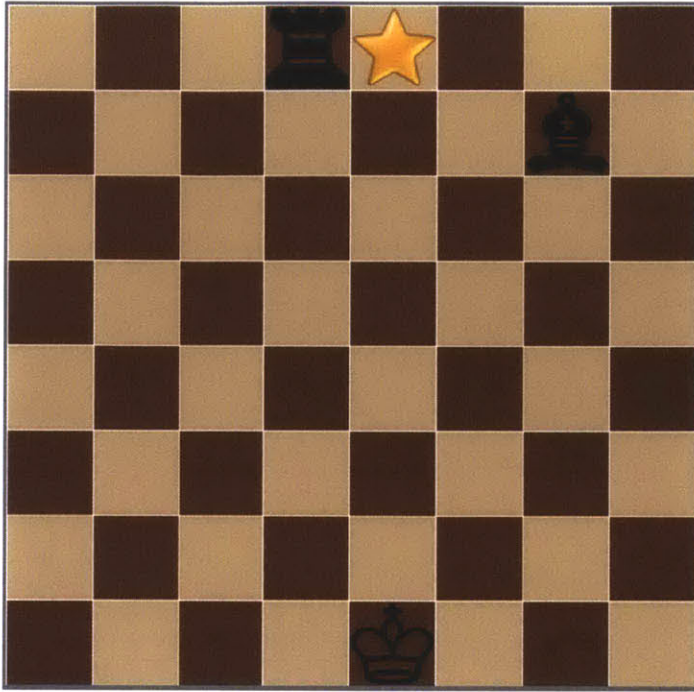
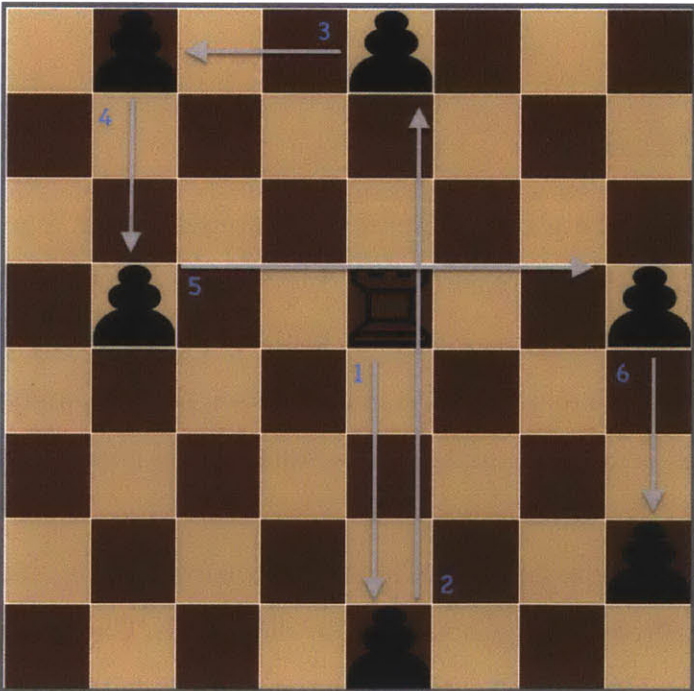Figure 2-2: An example of ChessMaze

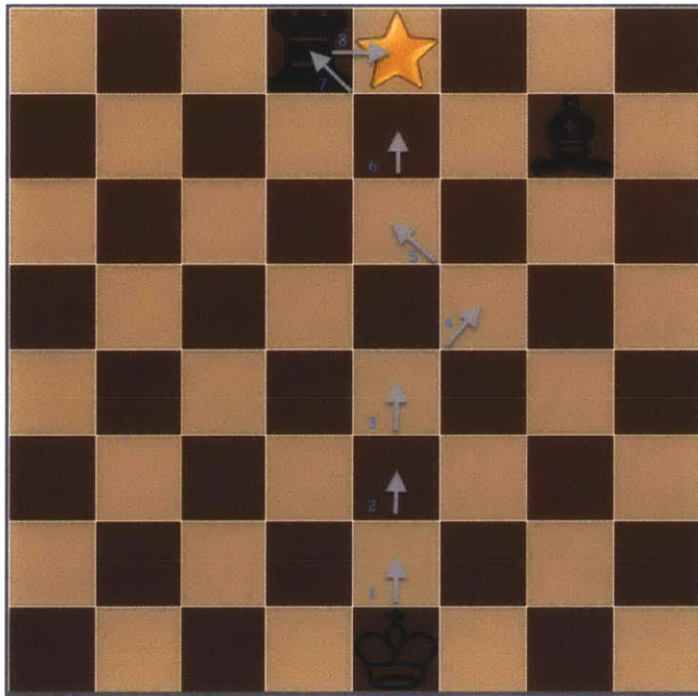Figure 2-3: Solution to the Pawn Mower example in Figure 2-1

Figure 2-4: Solution to the ChessMaze example in Figure 2-2

Chapter 3

Design of the Social Learning Network

In essence, MOOCs heavily resemble PLATO when the system interacts with a student individually in terms of features or methods provided. The continuity of the user experience is partially due to and also in turn proves the effectiveness of such methods, it is also unfortunately doomed by the natural limitation of computer intelligence at current stage. The artificial intelligence is still better fitted to routine tasks, systematic or linear curriculum delivery - like the way behaviorist believed in how human learning works, rather than tasks that require cognitive thinking.

Thus, to provide different user experience, and hopefully better engagement and better learning result, one should seek help from the cognitive learning theories. Three different methods of team interactions are hence designed, largely inspired by Lev Vygotsky's Zone of Proximity Development, in the context of chess learning. They are as follows.

3.1   EnLighten Me + Pawn Mower

As pointed out by Skinner, constructive feedback helps the learner get a better idea of his current learning stage. A good teacher almost always observe his students and subtly guide through the course, and similarly, an alert learner also get hints from

the environment pretty fast. In both cases, the learner has the information to make necessary adjustment.

One of the weapons held by the online learning community over the traditional classroom education is instant feedback, which from the system's perspective guarantees that learners being treated equal: they don't need to compete for the instructor's attention, nor do they need to be aware of their own behavior in order to interpret it into 'How well am I doing'. However, the provided instant feedback almost exclusively depends on some preset algorithms, and can be rather rigid.

It is necessary then, to include human intelligence in the evaluation, to provide the type of instant feedback as if it is from your helpful classmate who is always keen on your progress, and EnLighten Me is designed to this end. It works on top of Pawn Mower, and allows the player to ask for help once he find the puzzle challenging. Instantly, a hint provided by his real human teammate, assume that one is available, will be fed back to the help seeker.

Many existing social games or social learning platforms provide similar functionality, most of which are in the form of text chatting, some advanced platform would also allow voice-over chatting. For example, many games marketed by Zygna^{TM} allow user to chat via text with his friends to get a better strategy for the game. One problem with that is, either text or voice, chatting as a communication's method can contain much less irrelevant information, or as in Communication Theory's terms, is with high SNR (Signal to Noise Ratio). People might feel rude if he just gives his friend what he thinks to be a good answer without saying 'hi' or 'here's what I think', while in fact the politeness is useless in terms of boosting the player's playing skills.

To avoid that, EnLighten Me is designed to only transfer relevant information, which in Pawn Mower is only the corresponding square the helper deems to be a good choice. The communication is conveniently indicated through the square's color changing, or 'lighten up', to be more connected with the name title.

Specifically, whenever a player is connected to the server, he is to be presented two chess boards. The one on the left is for his own Pawn Mower game; and the other for displaying his teammate's board whenever there is help request. For illustration

convenience, suppose there are only two players, one is the helper seeker and the other, the helper. Their roles are self-explanatory.

Figure 3-1 shows the initial state of the helper's board when he first starts. While the helper is playing, (and hopefully learning through thinking), the seeker joins the team. He gets connected to the server and is presented with two boards as well.
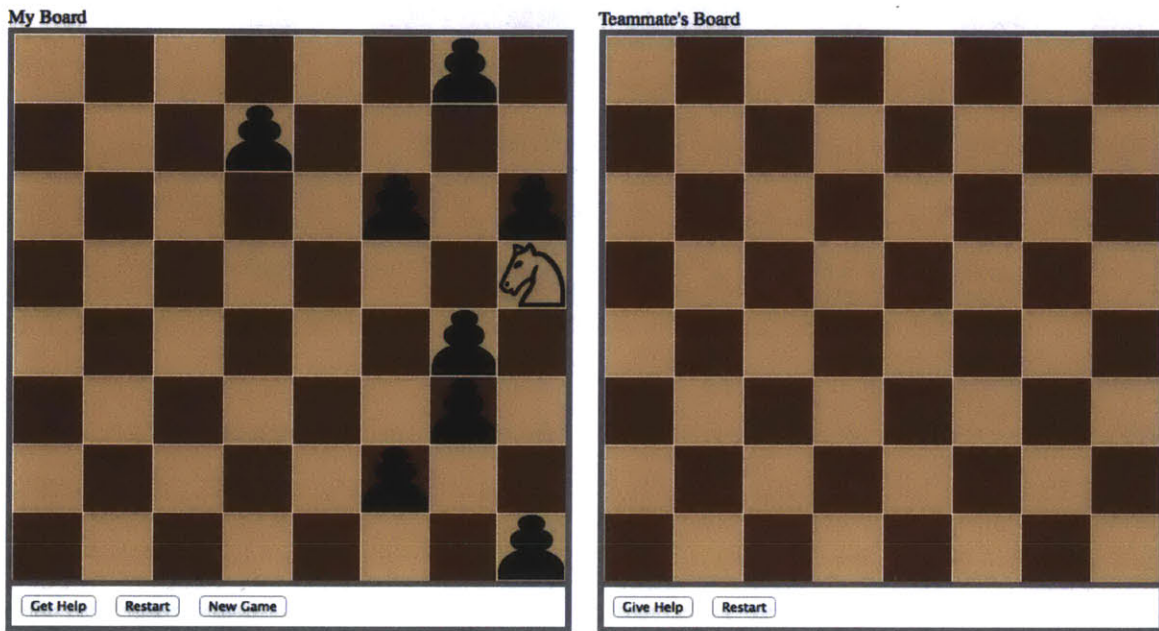
Figure 3-1: EnLighten Me - the helper's initial boards

The seeker then starts to play on his own board too, as shown in Figure 3-2, but only to find overwhelmed by so many pawns on the board. He now can choose to send a 'Help' request to the whole team. The seeker's 'Help' request is sent to all the remaining team members, and presented on their right-hand side chess board, which is labeled as 'Teammate's board', as shown in See Figure 3-3.

Whoever is free and confident to help can pick up the request. In our simplified example, let it also be the helper. He provides help by playing the move he had in mind on the 'Teammate's board', as if it were his own game, and in this case, move the rook in 'c1', as shown in Figure 3-4.

When finished, the helper hits the 'Send Help' button, and on the other side of the tunnel, the square that is the end-position of the helper's suggested move will

Figure 3-2: EnLighten Me - the seeker's initial boards

Figure 3-3: EnLighten Me - the helper's boards after receiving help request

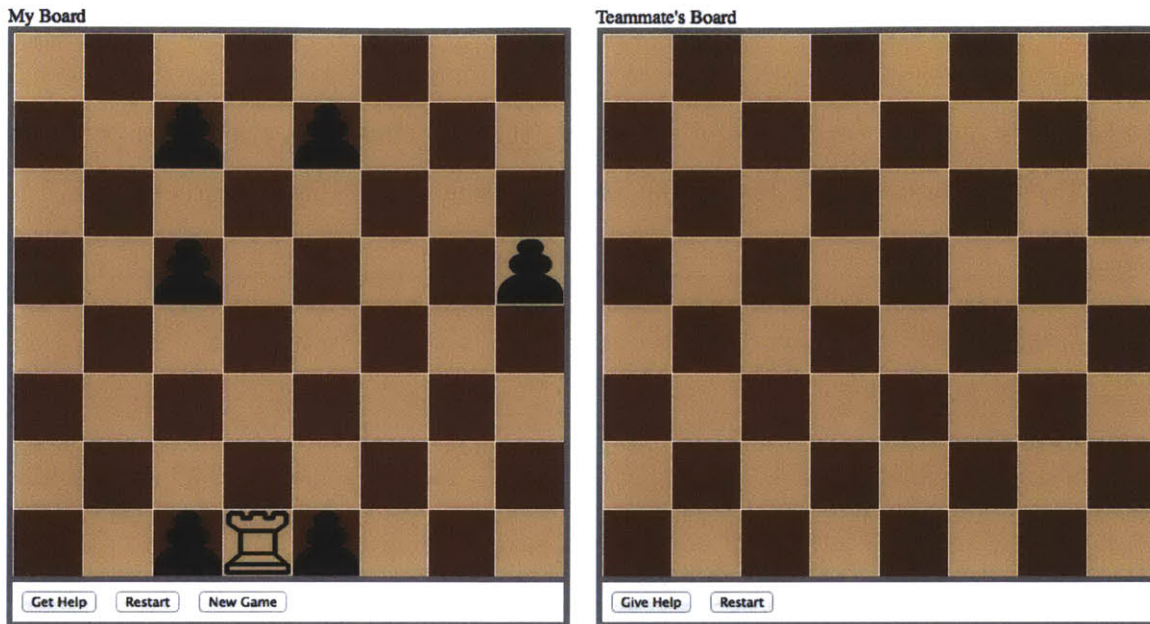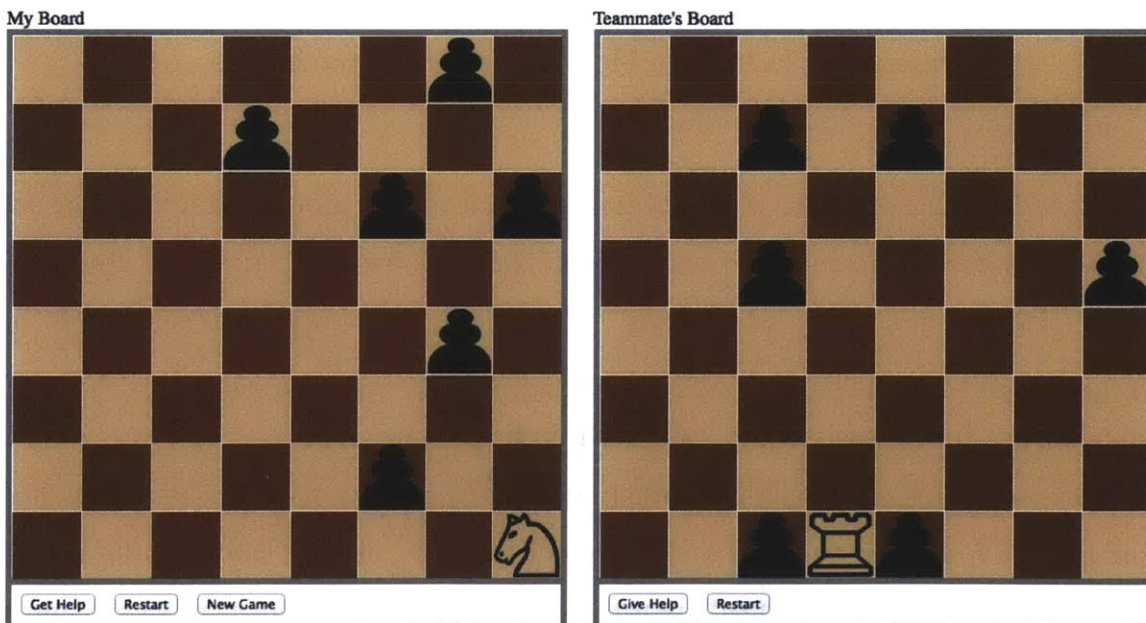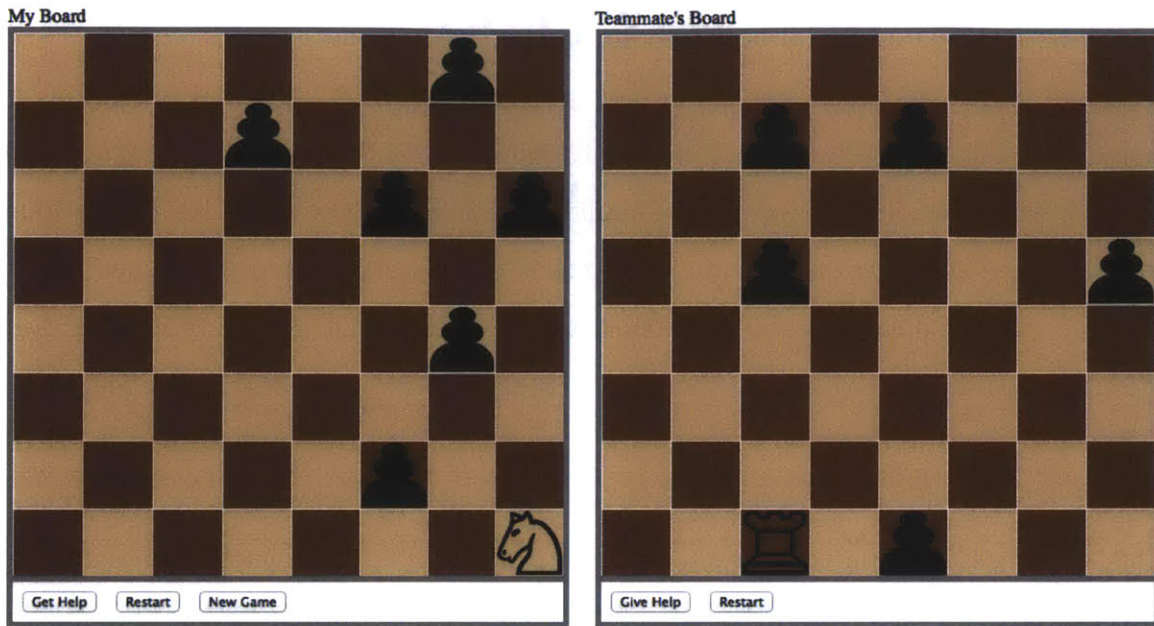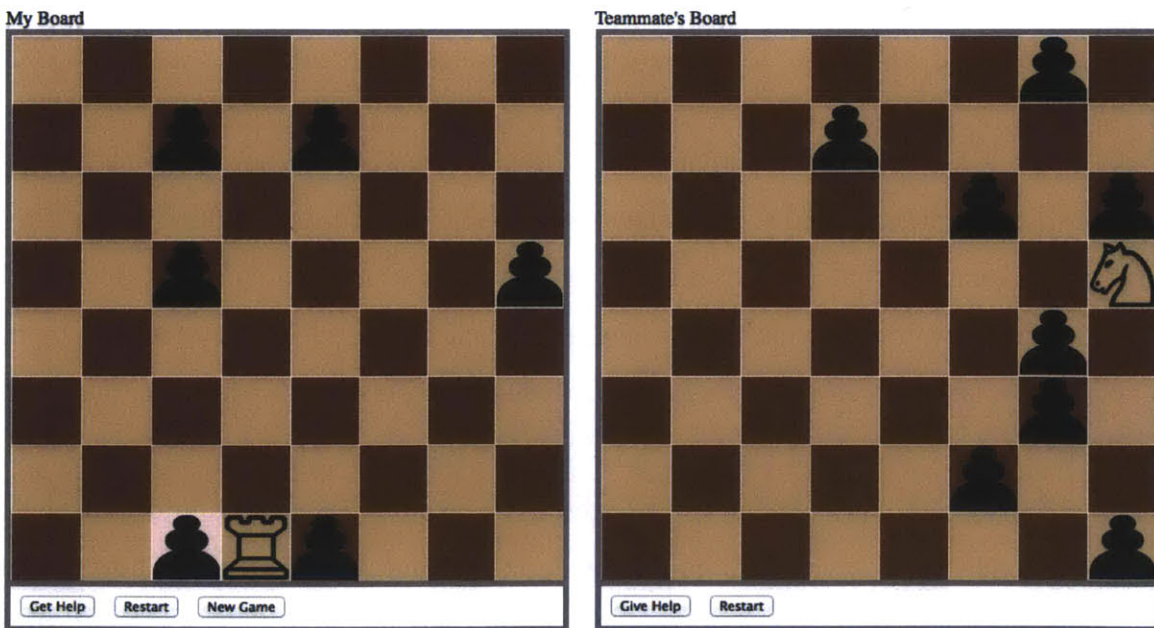Figure 3-4: EnLighten Me - the helper's boards after completing help request

Figure 3-5: EnLighten Me - the seeker's boards after help request is answered

light up on the seeker's board, as shown in Figure 3-5. The seeker then can be free to follow the suggestion and hopefully finish the puzzle game.

Some additional remarks on the design: the entire information exchange is anonymous-based, and the help seeker is not obliged to follow or reject any suggestion provided by his teammates. In the case where multiple helpers and seeker exists, the system will pair the two solely on the time stamp that the players entered the game.

Two assumptions are required for this system to work. The first is that, whenever the help request is sent out to the team, there are always someone to answer the call, which sometimes can be unrealistic, especially when the team size is small, or when it's made of international players and most of who have different time zones. The second assumption is inherent from the Pawn Mower game itself. For the game instance, there is only one feasible solution. Thus, for EnLighten Me to work as expected, the help seeker has to know the good moment to ask for help, which is sometimes the gem of the game to begin with. To cater for this two situations, a different design is explored.

3.2 Peers' Peek + ChessMaze

Peers' Peek is a team learning environment designed to allow an user to see what his teammates had chosen to do when they were facing his situation, and how well are they progressing in the course. Once in this mode, the team member is presented at once with the information of the aggregated choices made by a group of team players automatically, as well as a leader board showing the front runners' status and progress.

In some sense a complement to EnLighten Me, which delivers the information of the move made by an active individual player on demand, Peers' Peek 1) allows team members make non-synchronizing communication, 2) offers virtual help in every step along the learning process, and 3) adds the element of competition while promoting collaborative learning at the same time. The first feature is realized via a database that stores past information so no real time selection of teammates' choices is required,

the second feature is realized via deviating from Pawn Mower and selecting ChessMaze as the base skill builder, the reason for the switch will be clearer after the system description, and the third feature is obviously done through the leaderboard.

Shown in Figure 3-6 is a snapshot of ChessMaze + Peers' Peek. The chess board integrates past users' information with the present. Throughout the course of the game, whenever the user turns on Peers' Peek mode, the squares that had been chosen by his teammates in the past to be their next move are to be filled in with the corresponding teammates' avatars, to indicate that it is been chosen and by whom it is been chosen. The leader board simply shows the best players and their progress in real time.
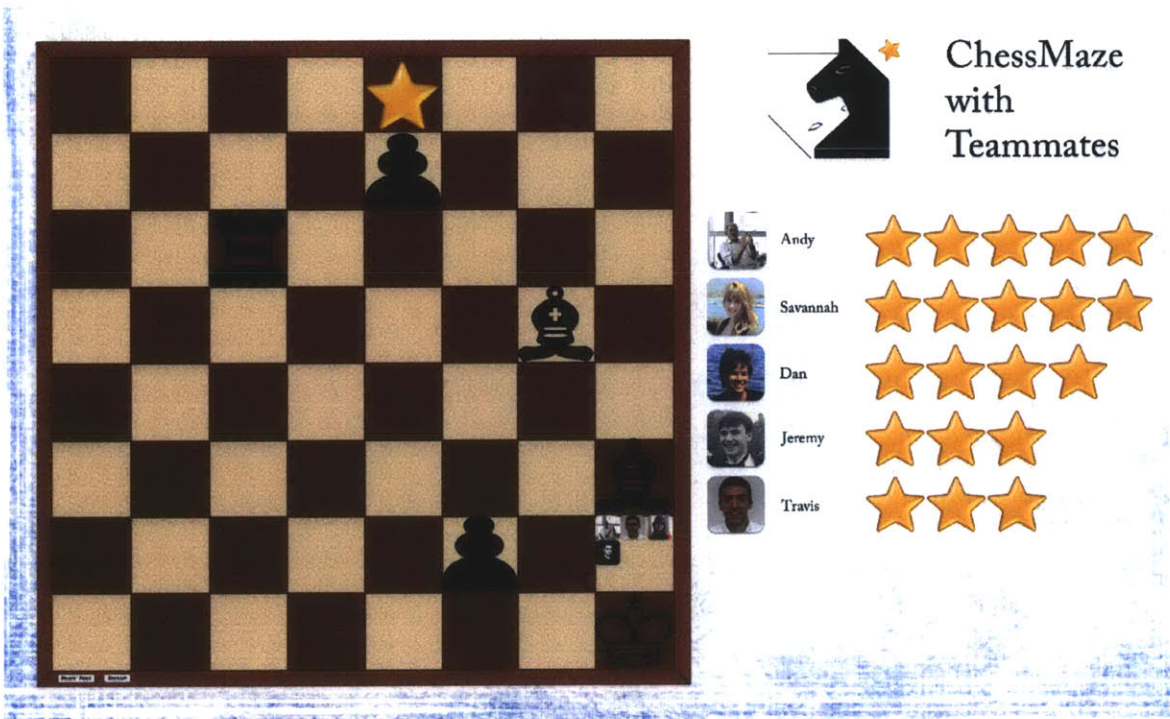
Figure 3-6: A snapshot of Peers' Peek + ChessMaze

The inspiration for Peers' Peek comes from the simple belief that people like to see what their peers are doing, both in real life and online. It gives them a sense of belonging, as well as stimulates their engagement in the activity. For example, after seeing the voting result, more people would like to express their own opinion. They are more inclined to share such information within the trusted environment as well.

In a parallel activity that's closely related to learning, explores would leave marks on trees for his teammates or precedence to avoid danger, and the ones come later would proactively search for such marks.

Within the learning environment, such psychological tendency is often shown as the behavior of peeking. Having been working as a teaching assistant for three semesters at MIT EECS department, I myself have noticed that students like to look over to see the approaches their classmates took to solve the questions during my tutorial sessions or office hours, and more often than not get inspired by their peer's solution. Like most of them I did not realize I also had this habit when I was an undergraduate, but the observation relates to my own feeling at the time. We look for peers' solution not because we want to cheat or avoid individual and independent thinking, but rather because we would like to get reassurance and support. We are willing to offer such good feelings to our peers as well, proven by that we actually do not mind being peeked at either.

On the other hand, noticing how fast the classmates solve the same problem creates healthy pressure on the students as well. This is especially true under a casual and friendly environment, in another word, when there is no instant rewards related to the performance, like an exam. So a public and healthy competition is also a good and natural addition if a simulated team environment is desired.

Based on these first hand observations, as well as Lev Vygotsky's very intuitive ZPD theory that a team as a whole helps an individual overcome hurdle, Peers' Peek utilizes the collective behavior of the group to offer help through the chess board at one hand, and impose pressure at the same time through the leader board. A similar design was used in RalliSport Challenge, a 2002 rally racing video game on Xbox. In the game's time attacks mode, a ghost of the driver's best lap is loaded, saved or played every time one undertakes that race. The best player's profile and record is stored locally in the game console, and will return to the racing game with any new player as if they were racing against each other. The stored data get replaced once a new player beats the incumbent ghost. The difference between Peers' Peek and RalliSport's phantom mode lies in that: 1) A group of precedences' data are collected,

rather than single player, 2) instead of playing against, the new player is guided by his precedences, and 3) The precedence's data are stored remotely not locally.

Peers' Peek pairs better with ChessMaze than with Pawn Mower, because the letter has only one feasible solution. Not only does this imply that the players need to know which one is the key step, it also subtly means that the choices made by all past team players tend to converge very soon. They either converge to the right answer or one that most got wrong and soon reach a dead end. As a result, paring Peers' Peek with Pawn Mower would be like feeding the right answer generated by a computer algorithm and hence lacks the human touch, which sometimes is in the form of imperfection. Luckily ChessMaze allows such imperfection. Even with several step not being the optimal move, players still may possibly finish the game, and the divergence in choices also motivates the player to think harder as he is implicitly facing the choice of whether to follow a past move and if so, which one.
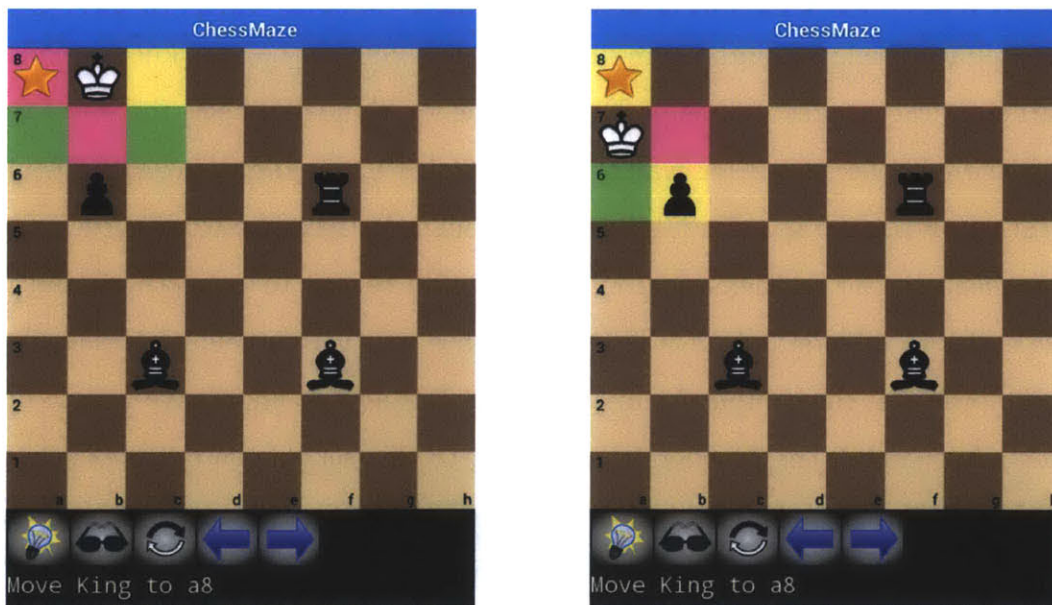
3.3   Heat Map + ChessMaze

Figure 3-7: Two snapshots of Heat Map + ChessMaze

Heat Map is a step up from EnLighten Me. It still presents the player with data collected from past instances, but instead of showing avatars of the players on the next

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move square, it changes the corresponding squares' colors according to its popularity, which is calculated by how many past players have chosen this move. Because of the same benefit explained at the end of Section 3.2, Heat Map also pairs with ChessMaze.

Figure 3-7 shows how Heat Map + ChessMaze works. The player enters the game with Heat Map turned on, he is about to make a move and based on past data, at his position, all legal moves have been chosen among the team members. The most popular one is with red color, and in the instance is the square to the left and the one below current position. (There exists a systematic way to indicate the squares on the board, which will be described later in Section 4.1.1.) Similarly, medium popularity is indicated by yellow, and the least popular ones are with green. The player in the instance chooses to move to his lower left, a decision made either by his own judgment or influenced by the heat map, and then he is presented with the updated heat map for that position.

3.3.1 Information, Visualization, and Transformation

Standing behind the idea of Heat Map is the belief that a good visualization transforms useful information into a pre-digested form. One of the best known examples of mathematical visualization is perhaps the one for Mandelbrot set, the set of values of c in the complex plane for which the orbit of 0 under iteration of the complex quadratic polynomial $z_{n+1} = z_n^2 + c$ remains bounded. Here, the wording description is equivalent to the mathematical expression with regard to correctness, but is of course easier to understand for a learner who has yet the mathematical maturity to fully comprehends the complexity of such a set. But a more impressive way to depict the set is to plot all the numbers that belong to this set on the complex plane, as shown in Figure 3-8.

Apart from the aesthetic appeal, the still image also has the fractal property. The images display an elaborate boundary that reveals progressively ever-finer recursive detail at increasing magnifications. The set's boundary also incorporates smaller versions of the main shape, so the fractal property of self-similarity applies to the entire set, and not just to its parts. A close up look of Figure 3-8 is shown below in
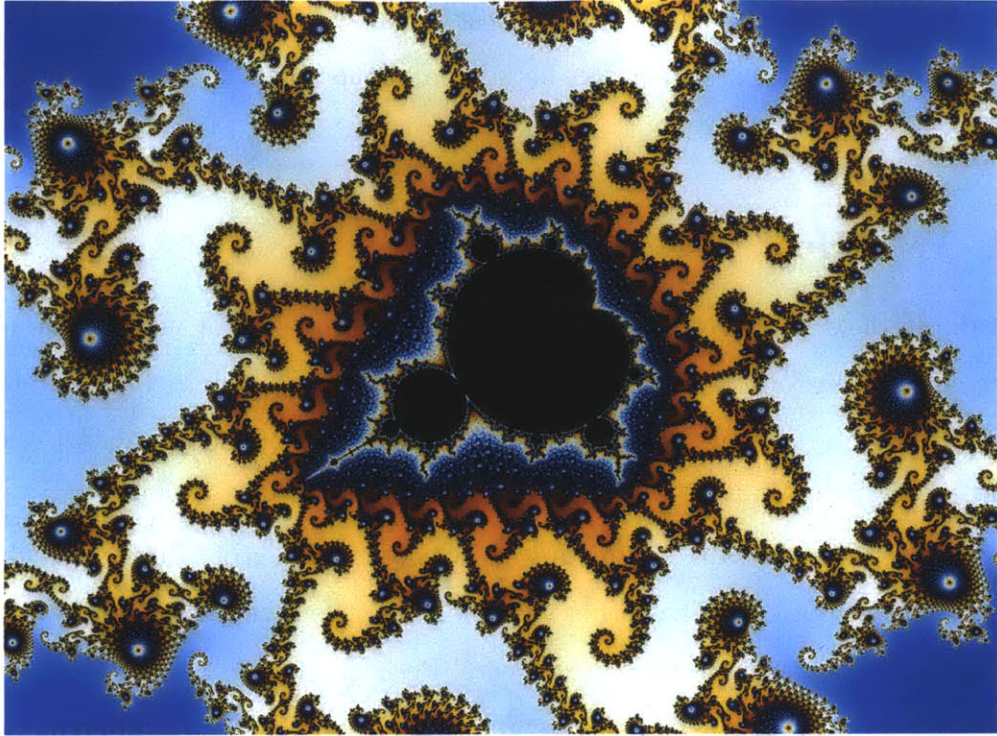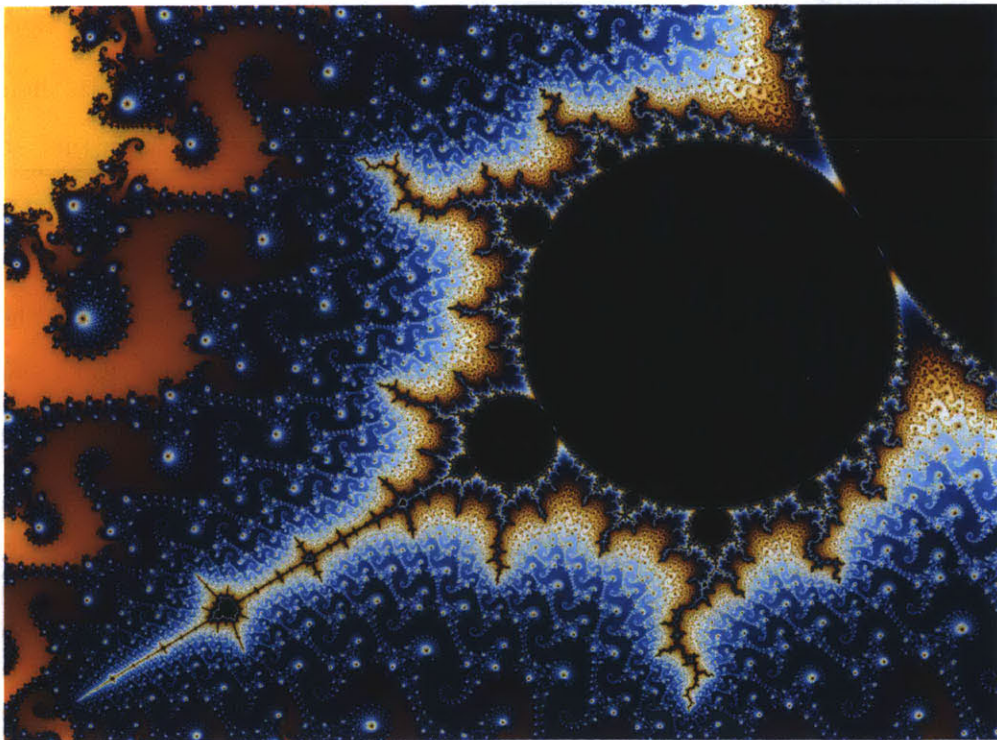
Figure 3-8: Mandelbrot set visualization

Figure 3-9: Magnified Mandelbrot set visualization

Figure 3-9. This property is however not best visualized through a set of still images, but rather an animation, which can be seen at `http://en.wikipedia.org/wiki/Mandelbrot_set`.

3.3.2 Why Heat Map

The example of Mandelbrot set demonstrates that one form of visualization excels another, depending on the nature of the information needed to be delivered. A straightforward question then to ask is, is Peers' Peek the best visualization for the grouped message?

Possibly no under certain circumstances: when the team is of a large size, when the team members do not know each other very well, and when the team members do know each other very well. In the first case, Peers' Peek doesn't scale very well. Because at any given position of the ChessMaze game, there are at most 8 different possible moves chosen by past team members (based on the rule, see Section 2.2). Even if each of these 8 squares are chosen by the team members equally, it still will be overcrowded if the team size is at the scale of hundreds, let alone that one square may be extremely popular and itself alone needs to accommodate the whole team avatars. In the second case, showing the avatars does not give out any more information than just showing maybe the number of team members chosen this square. Because no identity is yet established, no one trusts or cares about any one's behavior more than the rest of the team, and the avatar stands for no more than just one person. Ironically, in the third case, Peers' Peek doesn't work very well either. The reason being that, when the community is well established, certain player has a better reputation of being good at the game, and their choices often times have too much influence over the later comers. Thus, displaying these players' avatars would have the effect of overriding the popularity, the unbiased popularity, which again, should be based simply on head count.

The idea of using a heat map comes from recognizing colors as being good at categorizing information and give obvious and direct view at a glance. There are abundant examples for this point, especially in the office setting. Color-coding flags

have been helpful in taking notes, and organizing files for example.

Using color as indicator of different categories has an additional advantage of being a universally spoken language. For instance, Tokyo city has a Metro system so complex that even the locals would need to refer to the map for exact information, thus color codes were introduced to indicate individual line more clearly, as shown in Figure 3-10. Even non-English and non-Japanese speaking tourists would have no trouble getting the basic idea of the direction of each individual line.
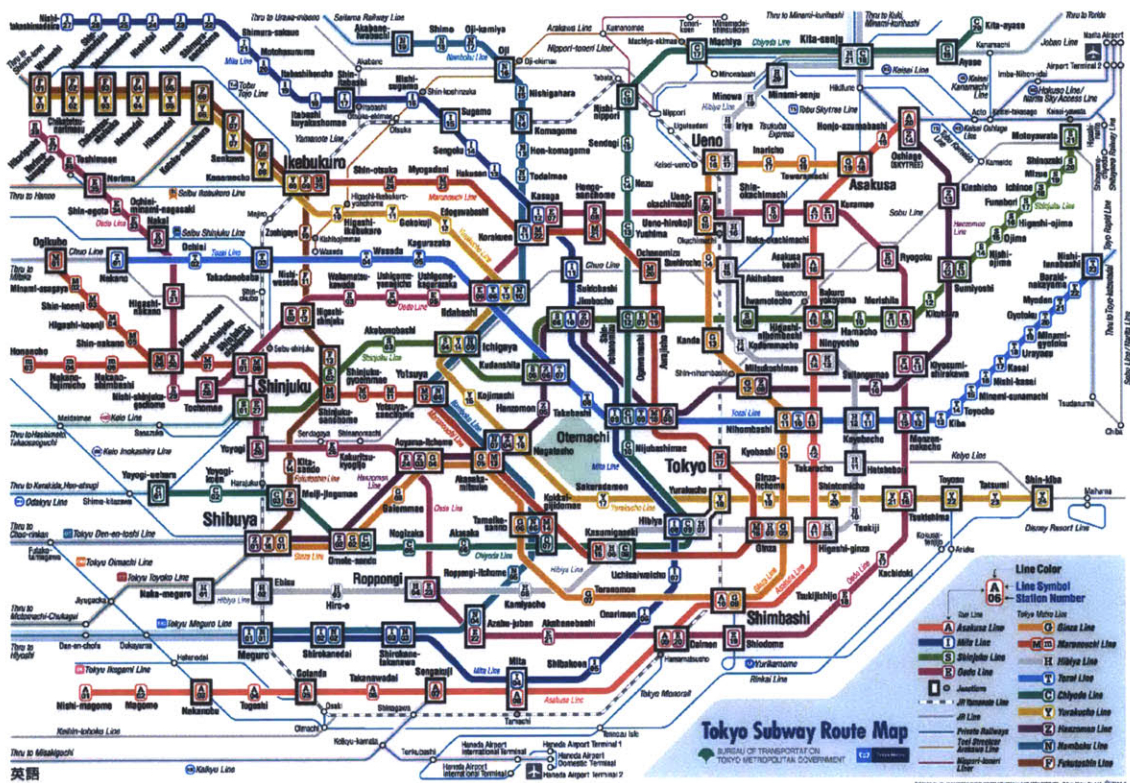
Figure 3-10: Tokyo metro map

The proposed Heat Map visualization is similar to the Metro map in the sense that the group of players chosen the same move aggregately forms a subway line, and each individual of them is a single stop on the line. Under the three above mentioned circumstances, a player is better off to be presented a birds-view image. But when they need more details they could still turn on Peers' Peek, just like how they would be able to zoom in and see the details of each subway station.

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As a communication channel, the Heat Map is lightweight - no extra input like typing or speaking, and effective - a good move is obvious and self-explanatory, and we think it's applicable to other board games and even other disciplines as long as discrete choice is involved.

Chapter 4

Implementation

4.1 Stand-alone Applications

As described in Section 2.2, Pawn Mower and ChessMaze are chess variations: they originate from chess but are not quite the same. Hence, off-the-shelf chess programs can not be used directly, several modifications are necessary. These modifications are rather minor, in the sense that they do not affect the programming architect. Therefore, a typical architect of design for a computer chess program is adopted for the particular implementation of the skill builders, as shown in Figure 4-1.

On the front end is the board component, which consists of the chess board, the pieces, and individual piece movement, and on the back end are the game logic and temporary data storage. A string-type notation called FEN bridges the front and back end. Each part is introduced in detail below.

4.1.1 Board Representation

The traditional chess board serves as the playground for the game, and since the skill builders and chess share the same board, nothing needs to be tweaked here. The board consists of 64 squares, eight rows, called ranks, times eight columns, called files. The squares are alternating dichromatic, light or white, and dark or black squares, on ranks as well on files. Ranks are labeled from 1 to 8, the files from A to H (or
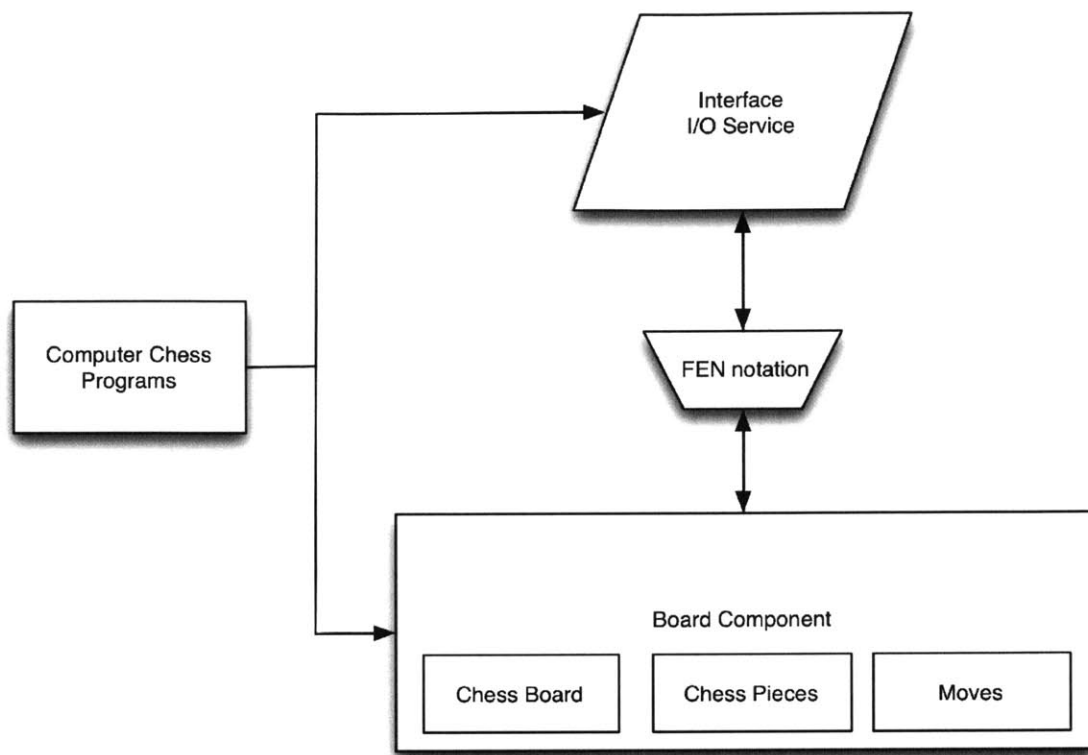
Figure 4-1: Typical computer chess program framework

with lower case letters a to h), so that each square can be uniquely addressed via concatenated file and rank labels. The lower left square with the "Address" a1 is dark. The diagonals are the north-east directed.

There exists many different methods to represent the board, and each of those has their own advantage. For instance, Bitboard method is a 64-bit sequence of bits (0 or 1), which indicates the absence or presence (false or true) of some state about each place on the board. It enables bit parallel operations upon the 64-bit entities instead of iteration to manipulate and derive information about the state of the board. This makes maximal use of the hardware available, especially as 64-bit processors have become mainstream.

We however, chooses an 8x8 two-dimensional array representation, one dimension for the ranks, and the other for the files. Albeit not the most computation-efficient, this method is one of the simplest and most intuitive representation. The 8x8 two-

dimensional array is sometimes equivalently translated into a 64 one-dimensional array, to better accommodate the validation of whether a particular move is legal under the rules of the two puzzles, see Section 4.1.3 for details.

4.1.2 FEN Notation

Forsyth—Edwards Notation (FEN) is a standard notation for describing a particular board position of a chess game. The purpose of FEN is to provide all the necessary information to restart a game from a particular position. Because it is an one-line ASCII-string, it widely accepted as a standard for computer chess applications.

A FEN record contains six fields, which are separated pair-wise by a space. The FEN needed for the two puzzles are much simplified as follows:

1. Piece placement on squares. Each type of piece is identified by a letter, black pieces use lower-case letters and the white ones use capital letters. Specifically, FEN uses "p" for pawn, "n" for knight, "q" for queen, "r" for rook, "k" for king, and "b" for bishop. The consecutive blank squares are counted for each row, and denoted by the count digits, 1-8. Between each row, a "/" is used to separate ranks.

Additionally, a new type of piece is introduced in ChessMaze, that is, the given destination square where the player needs to move the white King to. The given destination square is identified with a capital "D", standing for "Destination", and is an important flag in the course of the game. Once it is been taken by the white King, the game finishes and the player wins.

2. Active color. "w" means white moves next, "b" means black. Per the rules of the puzzles, this field is always set to "w" and does not get updated.

3. Castling availability. Either "-" if no side can castle or a letter (K,Q,k,q) for each side and castle possibility. Per the rules of the puzzles, this field is always set to "-" and does not get updated.

4. En passant. Target square in algebraic notation or "-". Per the rules of the puzzles, this field is always set to "-" and does not get updated.

5. Halfmove clock. This is the number of halfmoves since the last pawn advance or capture.

6. Fullmove number: The number of the current full move.

These simplifications are summarized in Table 4.1.

Field	Value
Piece placement	Piece by letter, blank by number
Active color	Fixed as "w"
Castling availability	Fixed as "-"
En passant	Fixed as "-"
Halfmove clock	Number
Fullmove number	Number

Table 4.1: FEN simplifications for the puzzles

For example, for a Pawn Mower with the opening as shown in Figure 2-1, its FEN notation would be "1p2p3/8/8/1p2R2p/8/8/7p/4p3 w - - 1 1"; and if a new ChessMaze game starts with the position shown in Figure 2-2, its FEN notation would be "3rD3/6b1/8/8/8/8/8/4K3/8 w - - 1 1".

4.1.3 Rules of the Skill Builders

Inheriting from the numerical representation of the board, either one or two dimensional, the implementations for the rules of puzzles are also in the form of mathematical expression. The program first parse the current FEN notation to get the piece position, and then return the list of legal squares' addresses based on preset movelist conditions. Take a Rook for instance, its current position, which consists of two numerical values, one for the rank and one for the file, gets fed into a function which generates the list of legal squares the Rook can land on in the next move, which is the squares that share either the rank or the file with the Rook's current square.

Fortunately, most of the off-the-shelf chess programs come with such implementation, and to convert the skill builders into a computer/mobile program,

See Table 4.2 for rules modifications detail:

	Pawn Mower	ChessMaze
Rules Removed	Initial piece setup	
	Alternating black/white playing	
	Castling	
	En passant	
	Pawn promotion	
	Check and Checkmate	
Rules Added	Pawn capture rule	Destination piece is static
Winning Flag	All black pawns captured	White King takes down Destination

Table 4.2: Rules modification for skill builders from traditional chess

4.2 Browser-based Applications

Two team modes are built into browser-based applications, EnLighten Me and Peers'
Peek. Each of them is paired with the corresponding skill builder, as described in
Chapter 3. The majority of the stand-alone part implementation is adopted from
open-source web project "p4wn" [1], and the integration with team modes are described
as follows.

4.2.1 The Workflows

EnLighten Me's implementation work flow is as shown in Figure 4-2. It is centered
around a server that handles users' real time service requests, including rendering the
game instance, accepting help request, pair team members, pushing back help result,
and temporary data storage.

The effect of each step shown in the work flow corresponds to the commands made
by the user as described in Chapter 3. When the help seeker enters the system, he
is being assigned a random ID, recorded entering time stamp, and rendered a new
game by the server. The connection is then cut, meaning the user can play the game
without talking to the server. Then at Step 1, a new connection is established. The
user sends another request, a help request. The server distributes the request to other
existing players in the system, according to their respective time stamps in Step 2.

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[1] http://p4wn.sourceforge.net

In Step 3, player number 2 is the first to respond, and his helping result will be first send back to the server in Step 4 and then to the help weaker in Step 5. Note that the players don't get consistent ID each time they enters the system, and no direct talk is established between two users.

The implementation work flow for Peers' Peek is as shown in Figure 4-3. A data base is added to the server to store data when the connection is cut between the client and the server. It stores every player's identity, every move from every game, and their victory/failure. Now when a new player enters the system, he talks with the server bi-literally, meaning that he needs to have the internet connected to enjoy Peers' Peek.

Specifically, the user enters the system, with identity recognized, time stamps recorded, and game instance rendered. Then once he turns on Peers' Peek, his every position would be sent to the server, compared and matched with previous games played by his team mates, and then the pre-sorted data of who has played which move when they were facing his position would be push back to the user. The user's
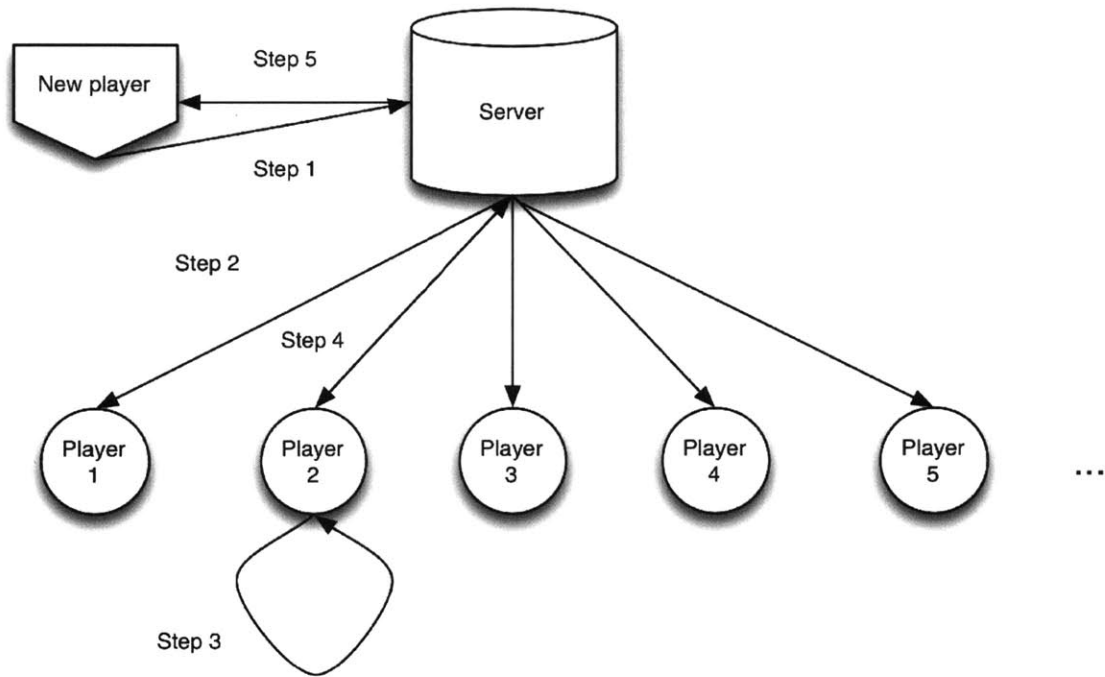

Figure 4-2: EnLighten Me work flowchart

own move selection would also be stored and sorted to update the data base for future use.

4.2.2 Web Framework

A python-based MVC web framework called Tornado is used. Although it is less popular than say, Django, which has many off the shelf examples and open source projects which can be easily tweaked to cater for the specific purpose designed in our case, Tornado is more lightweight. It is also more suitable to handle responsive and live interactions, one of the reasons that it is chosen for collaborative browser applications such as Google docs or social networks at large scale such as Facebook.

4.2.3 Web Sockets

Conventional HTTP communications were first considered. But soon it's been clear that, since the application requires real-time communication and is event-driven, a
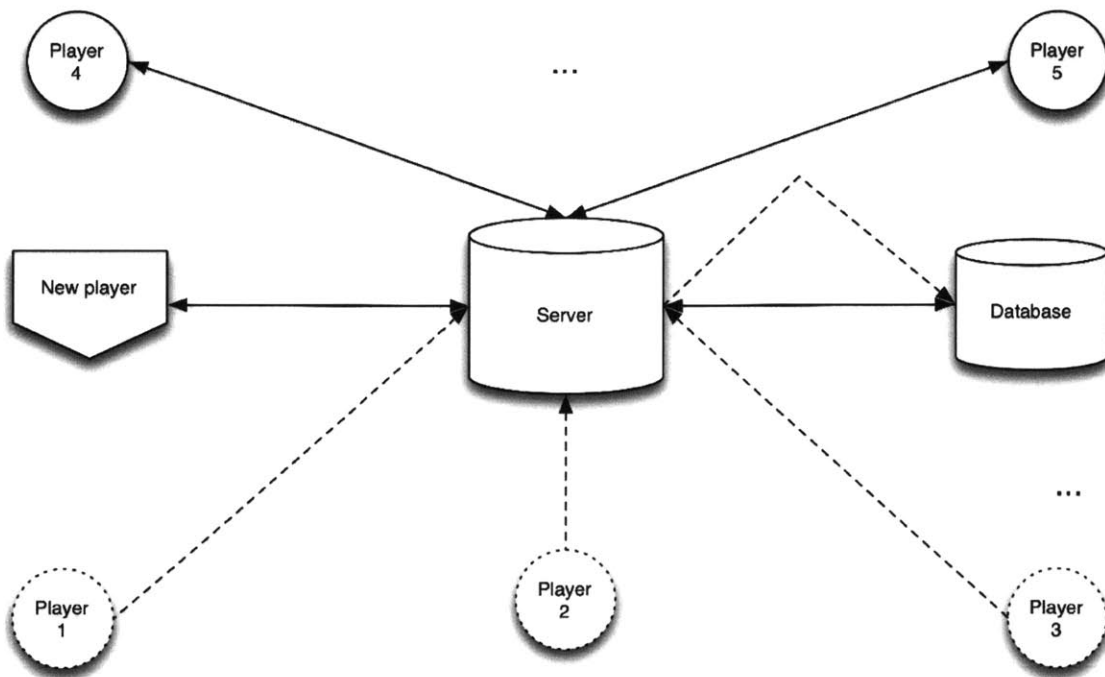
Figure 4-3: Peers Peek, work flowchart

better solution would be web sockets.

Web Socket is a new protocol providing full-duplex communications channels over a single TCP connection. The WebSocket protocol makes possible more interaction between a browser and a web site, facilitating live content and the creation of real-time games. The most distinguishing character between web sockets and traditional HTTP POST and GET methods is that web socket allows persistent connection while the traditional technology is called on demand. As a result, web socket provides a faster response under the synchronizing environment.

This is made possible by providing a standardized way for the server to send content to the browser without being solicited by the client, and allowing for messages to be passed back and forth while keeping the connection open. In this way a two-way (bi-directional) ongoing conversation can take place between a browser and the server. A similar effect has been achieved in non-standardized ways using stop-gap technologies such as Comet.

Web Sockets allows the application such as Peers' Peek to keep an open connection between the server and client at a relatively low cost, while renders faster response should an event triggers data exchange between the two.

4.2.4   Database

No particular requirement is imposed on the type of database needed. Both SQL database and non-SQL ones have been tested, but for the browser-based applications, final decision goes to MongoDB, which is a non-SQL database that integrates better with Tornado and responds faster among webpages.

4.3   Mobile Application

Heat Map is brought to the portable devices as a mobile application, because mobile devices such as smartphones and tablets have had significantly increasing share of internet traffic since 2010. According to CNN Money, mobile devices accounted

for 55% of Internet usage in the United States in January 2014 [2]. In the learning community, mobile devices also have the advantage of squeezing into whatever small chunk of time window the user has, and handles small tasks efficiently and nicely. For example, many mobile applications have helped users save valuable time by allow them learn on-the-go, like reciting index card and browse lecture text.

4.3.1 Android Platform

Android system is chosen as the platform for the mobile-based experiment. Because any conclusion drawn from these designs are only valuable when the experiment is conducted in a large scale, and Android has the leading market share among all the mobile operating systems. According to IDC, a leading global market intelligence firm shows that in the third quarter of 2013, Android made up 81 percent of devices shipped worldwide.[3]

4.3.2 The Workflow

The mobile-based system is designed to provide both solo and team mode, as shown in Figure 4-4. The functions provided are very much what the names imply.

The app mainly focuses on a team-mode where anonymous many-to-one help are offered through a heat map that visualizes the team's effort. The app also works as a stand-alone ChessMaze gaming platform with create-your-own game feature that we call Shape and Share.

4.3.3 Solo Mode

The mobile application is by large tweaked from an open source project called Droid-Fish, [4]and it works first as an offline ChessMaze game. Two additional features called Hint Map and Shape and Share were added along the way for the offline solo playing mode.

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[2]http://money.cnn.com/2014/02/28/technology/mobile/mobile-apps-internet/
[3]http://www.idc.com/getdoc.jsp?containerId=prUS24442013
[4]http://web.comhem.se/petero2home/droidfish/

Hint Map

Hint map is a feature not originally planned, but rather added to the app based on feedbacks from the initial demos. Some testers asked if little hint can be provided by the system when there's bad internet connection or when they really get stuck and want somewhat better direction than suggestions given by their teammates.

It then is natural to give out what is definitely wrong in the game as hint, that is, per ChessMaze rule, the squares guarded by the black pieces. By explicitly change the colors of these squares, a hint map is presented to the player as shown in Figure 4-5.

Shape and Share

Shape and Share is added to 'ChessMaze with Teammates', after hearing from the Lego fans about how much they love about that there can be so many interesting and different structures to DIY using the most basic bricks.

Thus, the similar functionally is offered in our app. A mediate level player who have a relatively good command of the game could create his own puzzle game, and
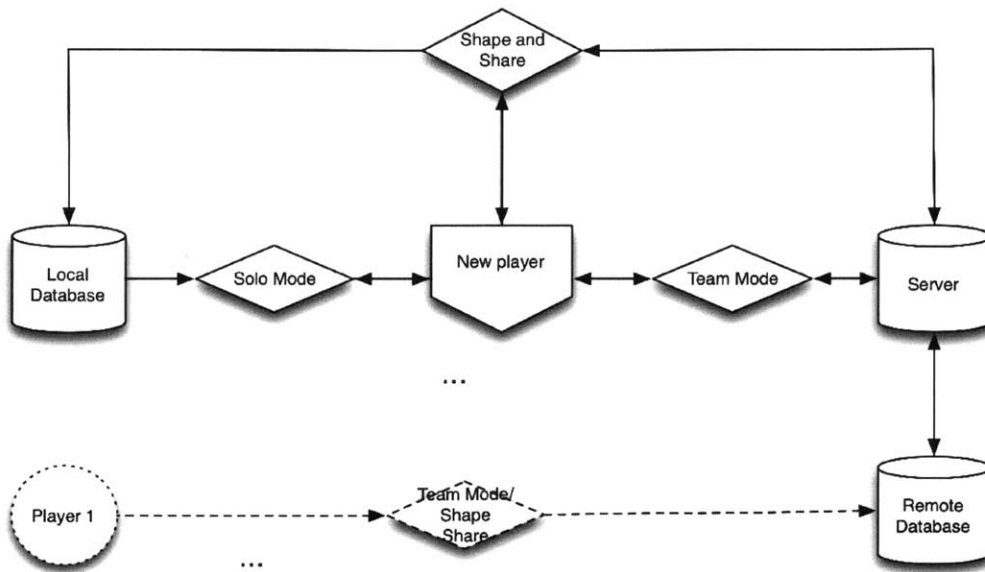

Figure 4-4: Android App flow chart
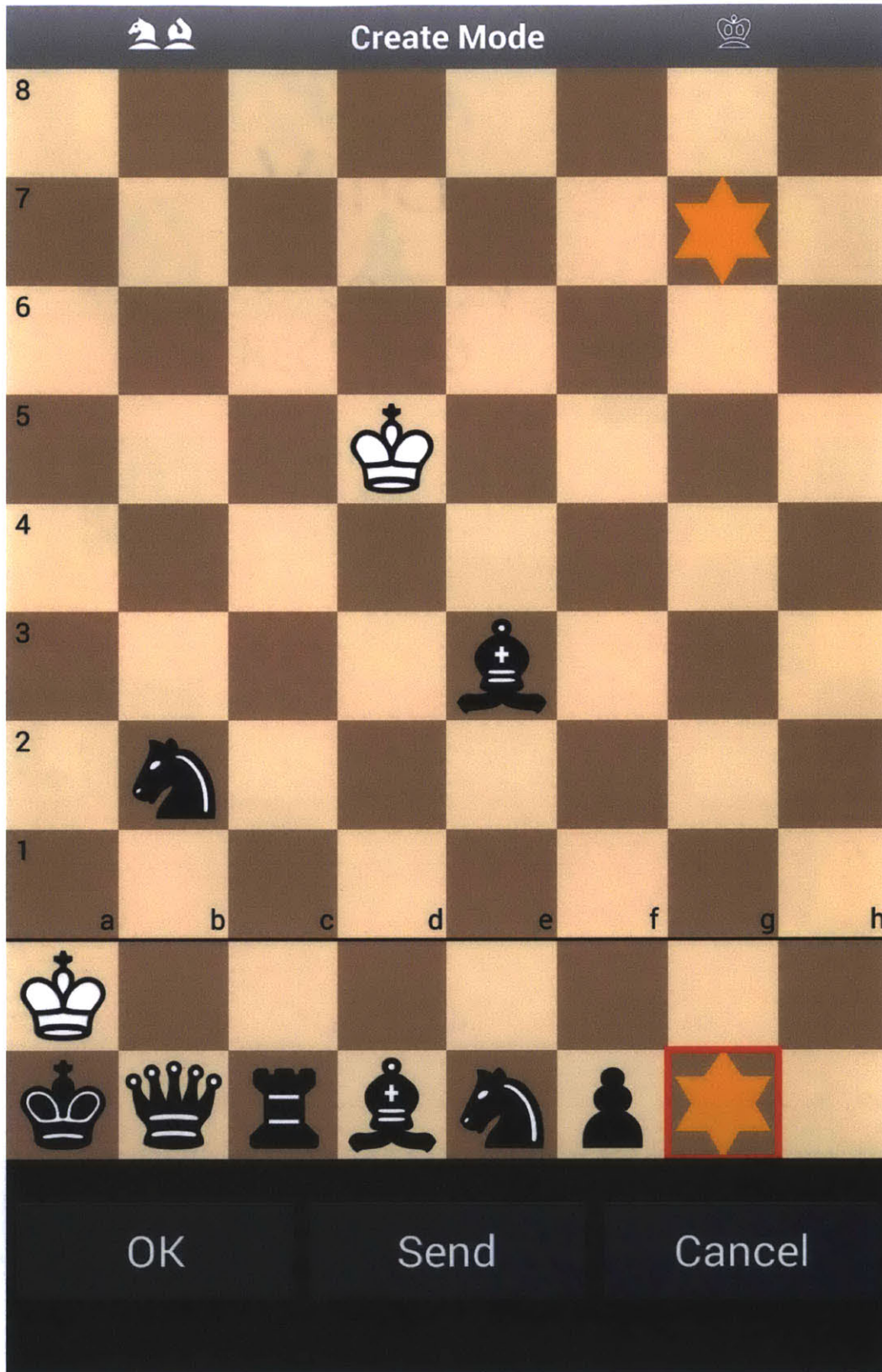
Figure 4-5: Hint-map is turned on

Figure 4-6: Snapshot of Shape and Share Mode

save it locally to his device, or upload to the server and share with or challenge his teammates. The player is presented with a slightly different board where it starts with an empty chess board, below which are the pieces needed for a ChessMaze puzzle game.

4.3.4 Heat Map

Heat Map is realized by combing much of the web server's implementation with the stand alone Android application. Specifically, the web server built for Peers' Peek is almost preserved to be used here, with the only tweak that, the number of users chosen for each square would be sent back to the user, instead of an array of users' identities.

The number then gets translated into RGB color codes by using basic heatmap algorithms. Also, the game instances created by users on their own in Shape and Share can be uploaded into the remote database. Unlike in the browser based implementation where MongoDB is chosen to serve as the database, mySQL is chosen here for the mobile application instead, for it is supported natively by Android SDK.
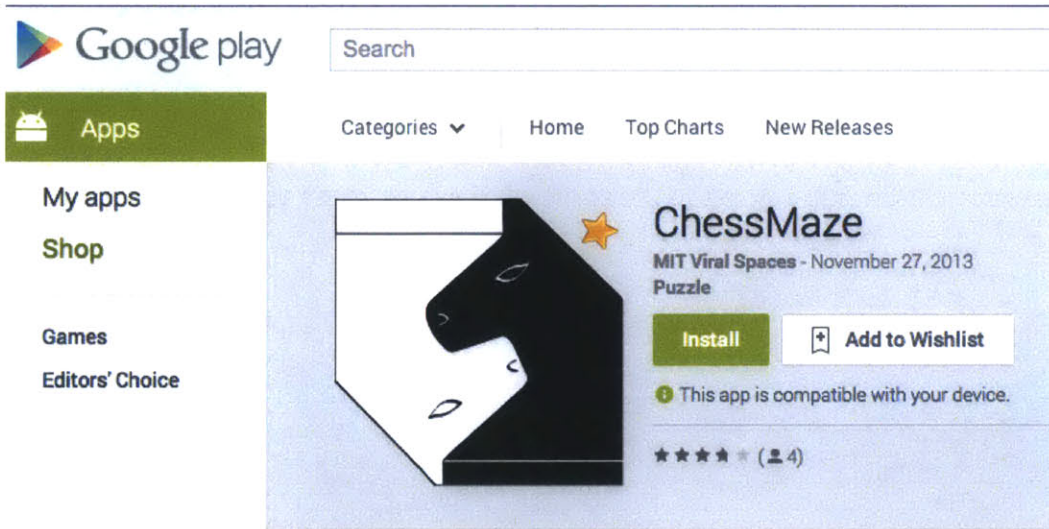

Figure 4-7: ChessMaze with Teammates at Google Playstore

The end result is an app named 'ChessMaze with Teammates', and it is available on the Google Play Store through the link https://play.google.com/store/apps/

`details?id=edu.mit.viral.shen`, Figure 4-7 shows its current status.

Chapter 5

Evaluation

The effectiveness of the designs in Chapter 3, which are largely based on intuitive belief and past inspirations, needs to be scientifically proven. The evaluation is done through experiments where hard data (numerical values) are collected, and demos where soft data (user experience and user feedback) are observed. Both hard and soft data are valuable in understanding the strength and weakness of the social learning network design, and the hard data is heuristically interpreted in Section 5.2, and the soft one in Section 6.2

5.1 Experiment Design

5.1.1 Learning Experiment Definitions

First, let's introduce three terms used by the experts in learning theories' experiments: operational definition, dependent variable, and independent variable. The following introduction is quoted and paraphrased from the book by Matthew Olson [8]:

"A theoretical statement or practical design of the learning process needs to be converted into rems of identifiable and repeatable activities or experimental performances, to verify its effectiveness. This way of measurably defining is called an operational definition. A common operational definition of learning rate is trials to criterion, which is the number of times an experimental subject needs to experience

the martial to be learned before being able to perform at some specified level. Once researches operationally define their theoretical terms, they're ready to experiment.

The dependent variable is something involved in the experiment whose changes are measured. For example, common dependent variables include scores on tests, running speed, rate of responding, time to solution, number of errors etc.

The independent variables are something the experimenter manipulates or controls to see its effect on the dependent variable. Common independent variables include sex difference, age differences, intelligence, interaction with other tasks and so go."

5.1.2   Comparative Experiment

In our specific case, the experiment is designed as shown in Table 5.1, where OD stands for Operational Definition, IV stands for Independent Variable, and DV is short for Dependent Variable.

	Pawn Mower	ChessMaze
OD	Successfully complete the game	Steps made before win or game over
IV	Level of familiarity with the skill builders	
	Team mode turned on or not	
DV	Number of wins out of 10 games	Average survival steps out of 10 games

Table 5.1: Experiment design

A small scale comparative experiment is conducted among 18 persons. 10 of them either have never before played chess let alone Maurice's skill builders, or barely know the basic chess rules, and they are in the amateurs' group. The rest 8, most of who helped beta testing the implementations, are categorized as professionals. All 18 persons are presented with the same 30 skill builders games, 10 Pawn Mower games on testing EnLighten Me, and 20 ChessMaze games, where the first half 10 will be used on Peers' Peek, and the rest 10 on Heat Map.

Within the amateurs and professionals group, only half the testers are allowed to turn team modes on, that is, they are allowed to communicate through EnLighten Me, Peers' Peek, and Heat Map.Therefore they form the treatment group. The other

half can only work on their own, and hence they belong to the control group.

5.2 Result and Discussion

Shown in Table 5.2 is the result of data collected from the amateurs. The EnLighten Me row shows the number of wins out of 10 Pawn Mower games, averaged per person, from the treatment group and the control group respectively. Treatment group turns EnLighten Me mode on, while control group does not. Peers' Peek row shows the number of steps the user can make before the game ends or he wins out of 10 Chess-Maze games, first averaged over the 10 games, and then averaged over the testers. Heat Map row's data is generated similarly to ChessMaze row.

	Treatment Group	Control Group
EnLighten Me	6	5
Peers' Peek	56	34
Heat Map	77	30

Table 5.2: Amateurs group comparative experiments result

The results from the professionals are shown in Table 5.3, and each cell shows similar meaning as their counterparts in Table 5.2

	Treatment Group	Control Group
EnLighten Me	9	7
Peers' Peek	79	57
Heat Map	98	60

Table 5.3: Professional group comparative experiments result

As expected, the treatment group has on average better performance than the control group, both among amateurs and among professionals. Some additional interpretations can be drawn from the data:

1) The results from Peers' Peek and Heat Map can be compared since they both are paired with ChessMaze. Within each group, the increase of survival steps are more noticeable under Heat Map mode than under Peers' Peek. Specially, for amateurs,

turning on Peers' Peek increases the performance from 24 to 56, 133% better, while turning on Heat Map increases the performance from 30 to 77, 156% better. The two numbers for the professionals group are 38% increase (from 57 to 79), and 63% better (from 60 to 98);

2) Using the same numbers in 1), notice that professionals are less influenced by their teammates' ideas. This is consistent with intuition that they have more experience with the game, and expectedly won more games and thus built more confidence.

5.3 Demos

All three designs are also experimented at several demo sessions at the Media Lab. EnLighten Me was demoed in members meeting in April 2013. Peers' Peek was officially demoed in members meeting in October 2013. ChessMaze with Teammates was officially demoed in Director's Fellows week held at Media Lab in July 2013, and Director's Fellows Outing in New York City in November 2013.

The feedback from the sponsors are mostly positive. Also, some of the comments are thought provocative, which are integrated into the discussion for future work in Section 6.2
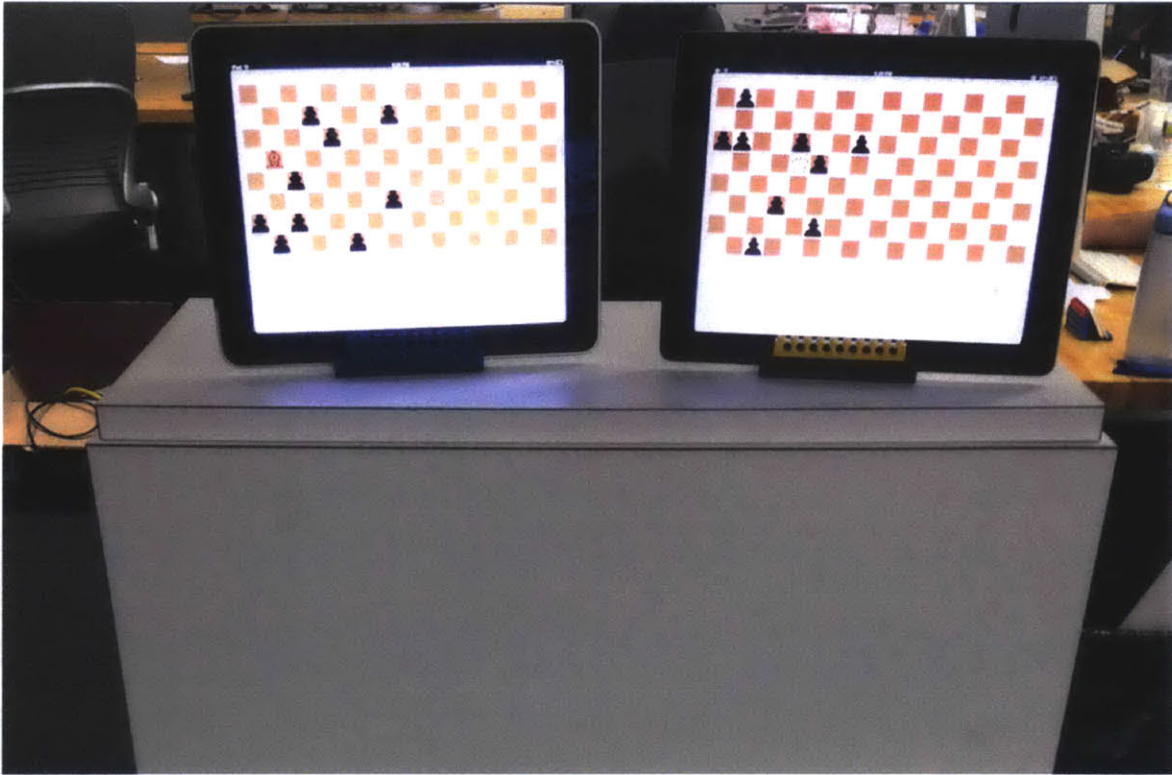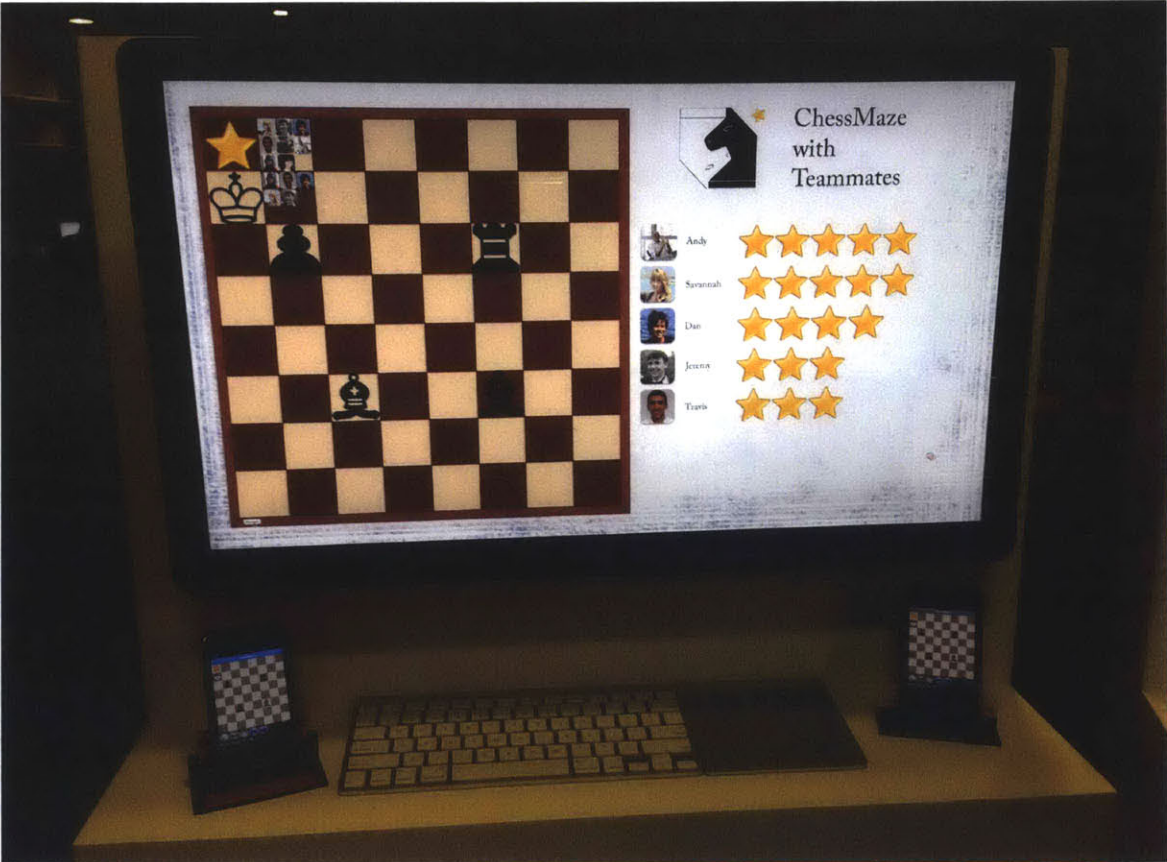
Figure 5-1: EnLighten Me demo

Figure 5-2: Peers' Peek demo

Figure 5-3: ChessMaze with Teammates demo by GM Ashley

Chapter 6

Conclusion and Future Work

6.1 Conclusion

Based on the comparative experiments carried out among various groups of people, the proposed designs are proven to be effective.

6.2 Future Work

Improvements can be lent to the work done in this thesis in three aspect: application where the designs can be used in a broader sense; implementation where the workflow can be more efficient and the system more responsive; and evaluation where the result can be more convincing and more insightful.

6.2.1 Application's Aspect

The natural extension of the work done in this thesis is of course to a broader topic within the education domain. That is, to apply the idea to subjects other than chess, like math, physics, or technology related areas. EnLighten Me can be extended to multiple choices, Peers' Peek and the Heat Map can be extended to any type of questions where the responses are convenient to be grouped together.

It is obvious that the proposed social learning network design does not work well

on subjects like humanity, social study, or arts, which are less fact and logic based but rather require more practice and reading on one's own time. It is not to suggest that social elements does not help in such area, only that the proposed design may not.

Albeit the above limitation, the proposed design of social learning network can actually be extended to many applications outside the education domain, especially the ones with discrete-decision-making involved. For example, as suggested by the Media Lab sponsor from Fidelity Investments, the heat map probably will help a lot for his clients to decide whether or not to make a certain investment, and if so which one to invest on. "It's all about the sense of not in this alone, and heat map can really give a visualization of such abstract feeling", he said.

6.2.2 Implementation's Aspect

For example, in EnLighten Me, all pairing are done purely based on time stamp. This is perfectly fine when the team is of relative small size compared with the server's computation ability, but when the team grows to the extend like the scale of MOOCs, better implementation is in need. The pairing can be optimized by applying Queueing Theory, or by Online Matching Algorithm based on the player's profile.

6.2.3 Evaluation's Aspect

The evaluation can be further perfected in terms of group size and data size. Because of time and resource limitation, the proposed experiment described in Section 5.1 was only conducted among the scale of tens of people, the result would provide much insight into the effectiveness of the design if the experiment is carried out within a larger audience. Also, the types of data that were collected are preliminary, and can be studied further within the education domain to design a better experiment.

Appendix A

Thesis Logo

A byproduct of this thesis is an originally designed logo. While it's not technically innovative, much time and thought has been put into the design, so it seems a shame to leave this out of the thesis.

The inspiration comes from yin-yang, an ancient concept in Chinese philosophy that describes how apparently opposite or contrary forces are actually complementary. While the black versus white stands for the chess players' colors, and signifies the traditional competing relationship between the two, locking together they also reach a balanced state. It is implied that by collaboration a new kind of beauty could be reached. The star on the top right hand corner indicates the destination of ChessMaze, and it also helps break the symmetry.

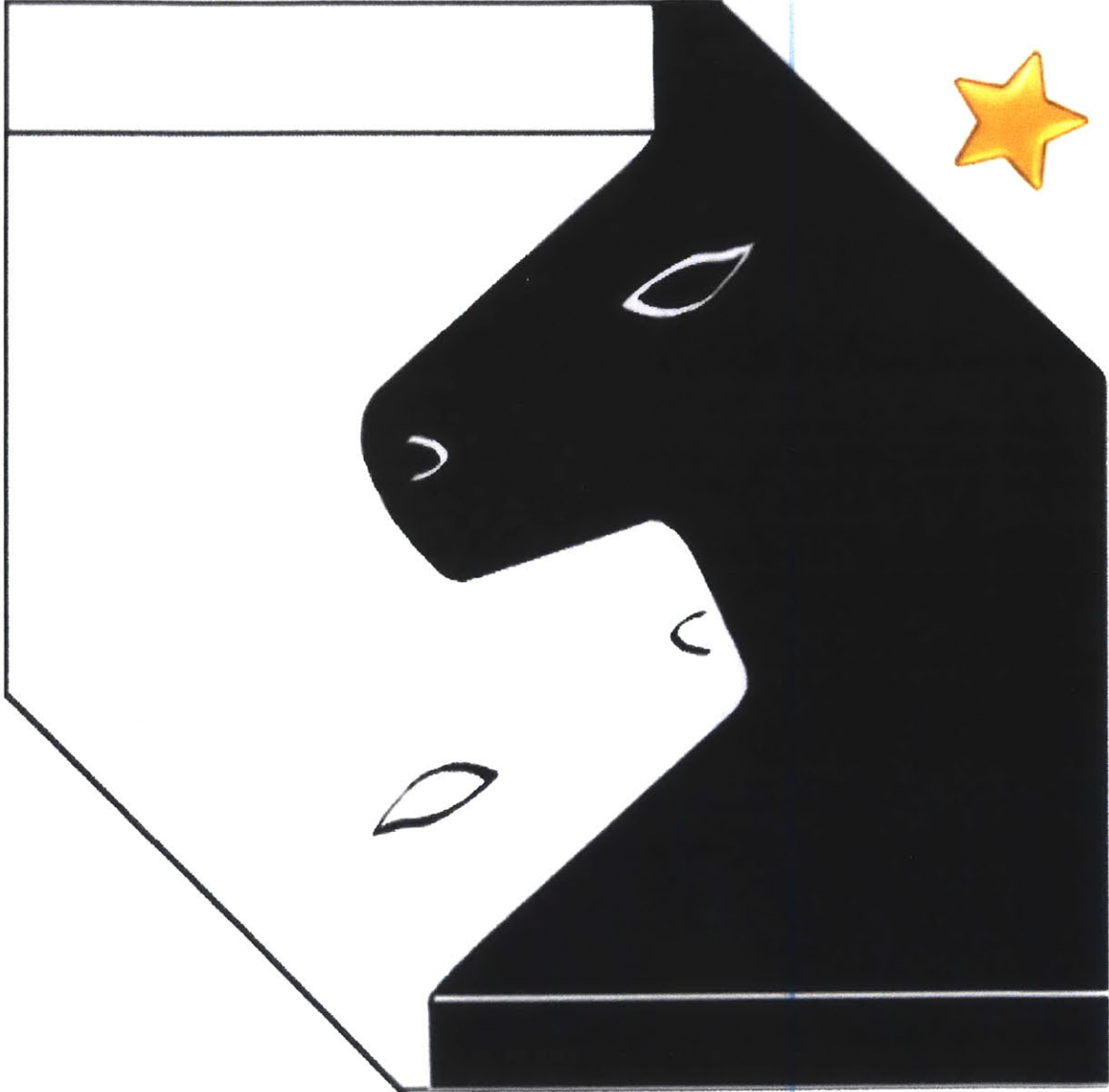Many have pointed out that the logo is the very first reason they liked the app.

Figure A-1: Thesis Logo

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