The Multifaceted Impact of Chess: Cognitive Enhancement, Educational Applications, and Technological Innovations

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Abstract. Chess is a board game that has been played throughout many centuries. Beyond the board game, it has shown its impact during the Cold War as a battle of intellect between the United States and Soviet Union. This paper reviewed research done on chess's cognitive impacts on students and those studies have shown chess's enhancements of cognitive abilities such as creativity, intelligence, and persistence. The technological advancements in chess engines have led to an adoption of a variety of different Artificial Intelligence (AI) and machine learning methods. Chess engines like AlphaZero and Maia have showcased techniques such as deep neural networks and human-like move prediction. Additionally, the paper explores the usage of chess in higher education where teachers have used chess as a tool to teach computer science concepts. The author suggests personalized, AI chess tutors for future development where technology, education, and chess intersect. The paper showcases the variety of influences chess has beyond the board.

Keywords: Artificial Intelligence; Chess; Machine Learning.

1. Introduction

Chess has been enjoyed around the world for many centuries. Although the rules may be simple, mastery of the game requires complex strategies and intellectual agility. Historically, the game of chess has applications beyond board. During the Cold War, chess was used as an intellectual battleground between the United States and the Soviet Union [1]. A recent resurgence during the COVID-19 pandemic has led chess to be popular with the public once again [2].

Due to the widespread belief that chess is an intellectual and cognitively beneficial game, researchers explored the validity of such beliefs in educational settings. Scientific interest in the benefits of chess have been explored for many decades.

Along with chess educational developments, chess became a hotbed for artificial intelligence and machine learning applications through the developments of chess engines. Development of chess engines has led to improvements in new chess openings and gameplay [3].

This paper will explore the intellectual and cognitive benefits of chess by examining existing research on chess's impact on student cognitive improvements. Along with chess's technological applications, and its impact on education. These findings may show how chess can create a more effective learning environment for students.

2. Chess for Cognitive Enhancement

It is widely believed that playing chess improves a person's intellectual abilities, fosters creative thinking, and enhances logical thinking. To further quantify and verify these cognitive benefits, researchers have conducted a series of studies.

In a summary of chess research studies by Dr. Robert Ferguson found that chess students scored higher on the Torrance Test of Creative Thinking (TTCT) and the Watson-Glaser Critical Thinking Appraisal (WGCTA) [4]. TTCT aims to test the creativity of a child while WGCTA tests critical thinking and reasoning [5, 6]. Ferguson believes the reason for this is due to the properties of chess. These include (1) Quick results of success and failure. (2) Players are forced to consider various solutions to positions. (3) Competitiveness. (4) Variety of different game positions. (5) Children's preference for games.

Ferguson performs a small study of 15 students to analyze the creativity improvement of programs that aim to improve creativity. Ferguson found that chess outperformed other groups in creativity, especially in the originality aspect [4].

Research done by Aciego, Garcia, and Betancort studies both intellectual and social development [7]. The goal was to determine whether chess had an impact on students' intelligence and social skills. The study had 170 participants which were students from 5 Primary and 3 Secondary schools in which they had chess programs. The participants were between the ages of 6 to 16 with a total of 170. The study had 70 students act as a comparison group by having them select basketball or soccer as their extracurricular activity. The researchers used the Wechsler Intelligence Scale for Children (WISC-R) which measures intelligence and cognitive abilities [8]. To measure sociability, the researchers used the Multifactor Self-Assessment Test of Child Adjustment (TAMAI) which has portions that allowed students to self-assess as well as observations made by the teacher. Pre and post testing were done using these assessments.

In the WISC-R pre-posttest contrast, the researchers found that although both groups had significant improvements in many of the tests, the chess group had a significantly better result in tests such as Object Assembly, Block Design, and Mazes.

In the student self-rated portion of TAMAI, it was found that the soccer and basketball players had improvements in problem solving but showed no improvement in terms of personal, academic, and social portions of the assessment. The chess group saw an improvement in personal happiness as well as academic performance but no significant improvement in sociability. However, the teachers' assessment of the students showed a contrast in the results of sociability. The teachers' observations found that chess students were more tolerant to criticism and persistent in the face of difficulties [7].

The improvement of academics for chess students from Aciego et al. were supported by research done by Rosholm, Mikkelsen, and Gumede which looked at the impact of chess on math test scores [9]. The participants of the study were 482 students ranging from grades 1 to 3. Of the 482 students, 323 students had their 1 of their 4 weekly math classes replaced with chess lessons. The rest of the 159 students served as a control group by having no changes to their weekly class schedule. A math assessment was administered to the students right before the start of the study, and a grade higher math assessment was administered at the end of the study. In each of the assessments, students were also asked to rate their general happiness as well as boredom in school. The results show that the chess students had a small improvement in math test scores with around 0.10-0.18 standard deviations. The authors claimed that the small improvement was due to their treatment method as a similar study had 0.38 standard deviations for math test scores when researchers added chess lessons on top of students' regular math schedule [10]. It was found that most of the math improvements came from students that were unhappy or bored in school. Though the study also indicated that there were no significant changes to feelings of happiness or boredom from the students [9].

These findings suggest that chess could be an educational tool used for enhancing students' creativity, intellectual abilities, and academic performances. Chess could also provide social improvements as it supports persistence and acceptance of criticism. Further research would need to be conducted in order to support the results of the above works and its benefits to various educational settings.

3. AI-based Chess Engines

Chess's impact is not only in the cognitive realm but extends into the realm of technological advancements. Chess engines are great examples of artificial intelligence and machine learning applications they use a variety of technologies, new and old. Development of chess engines has led to advancements in decision-making algorithms. The following works will showcase the diversity in algorithm usage in modern chess engines.

Currently, the strongest chess engine is Stockfish with a chess rating of 3806 in blitz [11]. Chess has a few variants used for competition. Blitz is a quick variant of chess that typically allows for 3

minutes of play for each player [12]. For reference, the highest ranked chess player is Magnus Carlsen with a blitz rating of 2888 [13].

Stockfish is characterized through the usage of expert curated features. Experts assign values to certain features such as the value of each piece, the position, and such for the position to be evaluated [14]. Stockfish uses a minimax evaluation method in which the algorithm considers the best moves for the current position via alpha-beta pruning. Then the algorithm explores the best current moves up to a certain depth. At the end, the algorithm will propagate back up to the original position and select the final best move [14, 15].

Another engine is AlphaZero which utilizes a deep convolutional neural network as its main algorithm. The input into the neural network is the current position on the board. The neural network will output the strengths of the position and the strength of the next possible moves [16]. Besides the neural network portion of AlphaZero, a unique feature of AlphaZero is that it only contains knowledge of the rules of chess and no other feature knowledge [14]. The neural network is trained using reinforcement learning which repeatedly makes the neural network play chess games against itself. In doing so, it allows the neural network to discover patterns and movements that are beyond human understanding [16]. Once the neural network is trained, AlphaZero uses a custom Monte Carlo tree search to search through the best moves for the current position [14, 16].

There have been several improvements after AlphaZero's release. One such improvement comes from an open-source version of AlphaZero called Leela Chess Zero. In earlier iterations of Leela, it uses similar convolutional neural network architecture as AlphaZero. A problem involving the architecture is that Leela had trouble finding moves that involve squares far away from each other [17]. To remedy this, Leela has begun to experiment with newer neural network technologies, namely transformers. Transformers were first introduced by Vaswani et al. are being used in recent technological breakthroughs in large language models such as ChatGPT [18, 19]. Leela's best transformer model is almost 300 rating stronger than their best convolution neural network model which shows a promising adaptation of new technology [17].

Both methods used by Stockfish and AlphaZero have the problem of performing in-human moves which can cause confusion for players trying to use chess engines to analyze their games [20]. Maia attempts to remedy this issue by using a similar architecture to AlphaZero except without reinforcement learning for training [20]. Instead, Maia uses a convolutional neural network to train on human games. This allowed Maia to be able to match more closely with moves made by humans [20].

The development of chess engines showcases the applications of artificial intelligence and machine learning. There's diverse usage of different algorithms and methods with Stockfish using minimax and alpha-beta pruning and AlphaZero with neural networks. Leela chess with its experimentation in transformer technology has shown promising performance improvements. Maia chess has developed to mimic human play shows the chess community's willingness to go beyond the board game. These diverse approaches to chess engine development shows the evolution of chess engine technology and its potential outside of the game.

4. Effectiveness of Chess in Higher Education

Beyond chess's cognitive benefits and technological applications, chess has also found applications in higher education. Computer science teachers have found chess to be a great teaching tool for computer science concepts and topics. The following examples demonstrate the integration of chess and higher education.

Professor Gusev utilized chess as a medium to teach computer programming in his classes [21]. In the author's introduction to programming course, the author teaches students how to run files and use features of an integrated development environment (IDE). The author created an assignment in which students had to run a chess engine called Cfish and utilize a chess interface called Arena to play against the chess engine.

In the author's Principles of Programming II course, the author taught students programming in C++. The author had students complete various functions derived from Stockfish and Kaissa chess engines. In the author's Object-Oriented Application Development course, he utilized a chess interface to have students create functionality to it such as adding timers to players [21].

Chess can also be used to teach computer science concepts. Holly et al. used chess to teach students about the concept of state machines [22]. State machines are a model of a computer that, when given an input, will perform a state transition and produce an output [23]. The authors used a 3D simulation of different chess puzzles and had students add new states and rules to accomplish the goal of completing the chess puzzle. The participants were 35 students in which they had varying exposure to the topic of state machines.

Students found that the chess puzzle was a good addition to the learning curriculum to better understand computer science concepts. Though the authors noted students that haven't been exposed to the state machines before had trouble understanding the concept through the chess puzzle [22].

Chess has found itself to be a useful tool for students to learn and interact with course concepts as shown by the works above. Further testing and experimentation with chess in higher education curriculum might reveal the potential of chess in education.

5. Discussion

Chess has a positive impact on cognitive improvements, technological applications, and education. Chess can improve creativity as shown by Dr. Ferguson due to chess's innate properties such as competition and variety of game positions [4]. Thanks to research done by Aciego et al. and Rosholm et al., there are quantitative results of chess improving intelligence, sociability, and mathematical skills of young students [7, 9].

There has been utilization of new technologies such as the usage of artificial intelligence techniques in Stockfish, deep learning techniques in AlphaZero, and transformers in Leela Chess Zero [14-17]. Mcllroy-Young et al. created a chess engine Maia that can better mimic human moves in order to make it easier for chess players to analyze chess games [20].

Chess has been utilized in higher education to act as a medium to teach course concepts. Professor Gusev integrates chess into his computer programming courses. Students are tasked with reimplementing functionalities of chess engines and creating new features for chess interfaces [21]. Holy et al. utilize chess puzzles to provide students with an interactive medium in order to foster understanding of computer science concepts.

Most chess engines are created to play the best chess possible. AI technology has advanced significantly over the years which is why modern chess engines are practically unbeatable for the human players. Though human chess players have benefited greatly from the existence of such a skilled opponent due to chess engines ability to be able to find in-human moves and patterns as supported by Gaessler and Piezunka [24]. The development of human-like chess engines like Maia chess gives rise to the notion of the integration of human-like chess engines with chess education [15]. As pointed out by Gaessler and Piezunka, traditional chess engines are incredibly consistent in their moves which makes them have a different feel compared to humans. They found AI simulations that included more human-like moves tend to produce better results in training humans [24]. The creation of a human-like chess bot could solve certain limitations from previous researchers.

The studies done by Aciego et al. and Rosholm et al. had the limitation of classroom time being the only consistent exposure of chess for students [7, 9]. With the introduction of a human-like chess bot, there can be more points of exposure and practice for students as there is no down time for a bot. The bots can be equipped with communication capabilities which can be augmented by large language models (LLM) like ChatGPT. The LLM can provide feedback and give a personality to the chess bot. The idea of a chess bot having stylistic play has been implemented by Chess.com, a popular online chess platform [25]. There are also short prompts from the bots regarding performance but it doesn't have the fluidity and personality a LLM can provide. Chess.com's bots are run with the

Komodo chess engine, which still has the issue of playing in-human moves [26]. The combination of a LLM and human-like chess engine such as Maia could act as a human-like training partner or mentor for students.

6. Conclusion

Chess has positively impacted cognitive development in students, led to technological innovations, and as a teaching tool for higher education. Empirical evidence from Ferguson, Aciego et al., and Rosholm et al. regarding the cognitive development of students using chess has shown to improve creativity, intelligence, sociability, and academic performance. Innovations in machine learning and artificial intelligence processes have led to the development of chess engines that use comparatively different algorithms. Namely, Stockfish and AlphaZero's methodologies have led them to become extremely powerful chess engines. Development of chess engines has not only led to stronger engines but also engines that can mimic human players such as Maia chess. Chess has been shown to be used as an education tool in computer science through its capabilities of teaching course concepts. Development of the integration with chess, technology, and education can lead to better and more diverse forms of learning. The combination of human-like chess engines and LLMs could create personalized chess tutors which provide consistent practice and learning for the students. Future research could explore the creation of personalized chess tutors and the effectiveness of these tutors in education. A limitation from previous chess studies was that the experiments were limited to the student's classroom time. A personalized chess tutor could provide more data for researchers as students could use it whenever they want. Chess interacts with many different fields from cognition, machine learning, and education. Such interaction leads to many future research opportunities to study human learning and technological development.

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