# AI Education for K-12: Connecting AI Concepts to the High School Math Curriculum

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## Abstract

Artificial intelligence is increasingly becoming an integral part of our daily lives. It is transforming and redefining the way today's students will live and work in the future. Foundational knowledge of AI could become essential, like the science and math courses taught in K-12 classrooms today, to succeed in a future society of human-AI alliances. Recently, discussions of how to help K-12 students build the skills and values of AI have gained much interest world-wide. Such discussions have highlighted the need for research into how to integrate AI education in K-12 classrooms. In this paper, we discuss our pilot work on connecting the US high school math curriculum to AI concepts taught in higher education classrooms, in order to identify AI concepts that can be accessible to high school students. The results will feed into the design of game-based learning environments to help high school students learn the foundations of AI.

## 1 Introduction

From expert systems assisting doctors in making medical diagnoses, to autonomous robots assembling cars and building houses, artificial intelligence (AI) is redefining the future of work in terms of human-machine alliances [Evans-Greenwood *et al.*, 2017]. Proficiency in the language of AI is key to a data-capable workforce that will continue to innovate and to support the AI-powered technology infrastructure and eco-system. All of today's students will go on to live a life heavily influenced by AI, and many will work in fields that involve or are influenced by AI. It is no longer sufficient to wait until students are in college to introduce AI concepts. Foundational knowledge of AI will become essential to students, like the science and math subjects taught in K-12 (kindergarten through 12th grade) classrooms today. Students must begin to work with AI algorithmic problem solving and computational methods and tools in K-12.

One of the first questions researchers and practitioners need to address is what level of AI knowledge is suitable for students from different grades in K-12. K-12 AI curriculum design is a challenge for both AI and learning science researchers. Given the packed course schedule of K-12 students, being able to connect AI learning to existing Science, technology, engineering and mathematics (STEM) subjects beomes a more realistic approach to embed AI education in K-12 classrooms. On the other hand, AI is built on a foundation of philosophy, psychology, and mathematics, and centers around using algorithms to solve real-world problems [Russell and Norvig, 2016]. It offers a rich context to learn scientific and mathematical concepts already taught in K-12 and to apply them to problem-solving. By illustrating how math concepts, for example, can be used in powerful AI tools to solve problems, learning math through AI can be a motivational vehicle to illustrate the pathway from K-12 STEM education, to post-secondary STEM education, and later to STEM careers.

In this paper, we discuss our preliminary work in designing AI problem-solving in a game-based learning environment for high schools in the United States. We take the approach of linking the US high school math curriculum to AI concepts taught in higher education, to determine what AI concepts are suitable for high school in a way thatl students can not only use the AI tools, but also understand the AI concepts. This AI problem-solving will later be implemented in a game-based learning environment to support interactive and personalized learning where students can use, modify, and even create AI entities (e.g., a simulated robot) in a simulated environment [Council, 2010].

## 2 Related Work

AI is increasingly becoming an integral part of how we live and work. This has in turn raised awareness of AI's central role in the future of work. Much discussion has been carried out on the AI skills and values needed for the future workforce. For example, the United Nations Education, Science and Culture Organization (UNESCO) has recently started a series of conferences for nations to come together and discuss topics such as ethics in AI and AI and education, including skills needed to successfully cope in the AI era [UNESCO, 2019b; UNESCO, 2019a]. While AI has been the cornerstone of the computer science curriculum in higher education for decades, discussions on how to approach AI education for the K-12 population have only just begun in the

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US [Touretzky *et al.*, 2019], Europe, and much of the rest of the world, with the exception of China [Youjun *et al.*, 2018; Yukun and Tang, 2018], which has already developed a series of seven AI textbooks for elementary, middle, and high schools. Discussions on how to integrate AI into the existing K-12 curriculum (e.g., computer science education [Gardner-McCune *et al.*, 2019]) are heating up as well. Overall however, more research on how AI relates to the existing K-12 curriculum, such as science and math curricula, is needed. Such research can inform the readiness for AI at each grade level. And more importantly, it can bring awareness to the K-12 population regarding the role AI plays in existing and future STEM careers.

On the technology front, there has been effort, particularly from industry, to build demonstrations and tools to help the public learn about AI, particularly machine learning (for review, see [Gardner-McCune *et al.*, 2019]). There has also been a lot of recent work in AI to make the decision-making process of AI algorithms more transparent, so that they are humanly understandable. The goal of explainable AI (XAI) research is mostly to facilitate human decision-making, e.g., examine the quality of the AI decisions. The explanations generated from XAI system are not aimed at helping someone understand the AI algorithm, because often very little about details of the algorithms are included. Rather, only the components related to human decision-making, such as probability and utility, as part of decision theory, are extracted from the underlying algorithm, and included in the explanation. Nevertheless, XAI systems can be used to design interactive tools to help teach AI algorithms.

## 3 Math in Artificial Intelligence

From search to machine learning, from logic to probabilistic reasoning, artificial intelligence is the science and engineering process of building intelligent entities [Russell and Norvig, 2016]. AI builds on ideas, viewpoints, and techniques from ancient times to modern days, including philosophy, cognitive psychology, economics, neuroscience, linguistics, and perhaps most important of all, mathematics. AI builds upon mathematical formalizations in three fundamental areas: logic, computation, and probability [Russell and Norvig, 2016]. Logic is used both for formally representing the world around us and making decisions based on such representations through deduction and inference. Computation is often considered as computing an answer giving the input, employing mathematical constructs like Turing Machines [Shannon, 1956] to precisely define processes by which a machine can intelligently solve problems. Probability, a means to represent possible outcomes, allows AI entities to quantify uncertain measures and reason over incomplete theories and knowledge.

While most AI courses are introduced in post-secondary education, in colleges and universities, many of the mathematical concepts that AI algorithms build upon are in the core curriculum of middle and high school. For example, linear algebra is key to understanding not only the fundamental algorithms in machine learning (e.g., logistic regression, Support Vector Machines (SVMs)), but also the basic "cost" functions (e.g., the time and computer memory needed) for all such algorithms. Calculus and Algebra, courses that teach basic concepts that prepare students for linear algebra, are both part of the curriculum of the Common Core State Standards for Mathematics in the US [Association and others, 2010]. Additionally, statistics and probability are key to some of the most used AI algorithms, such as Bayesian networks and Markov Decision Processes, and are also part of the Common Core State Standards for Mathematics for high school students in the United States. Given the uncertain nature of the real-world environments AI algorithms operate in, the critical role of probability-based decision-making, and the prevalence of statistic and probability courses in US high schools, there could be a good connection between high school mathematical concepts of probability to algorithms and decision-making in AI.

### 3.1 High School Math Curriculum in the US

There is an abundance of AI textbooks, tutorials, and online courses for higher education. Our goal is to ensure that the AI concepts taught through our game-based learning environments are accessible to high school students. Given the role that math plays in AI, we have decided to start with a high school math curriculum in an effort to identify the AI concepts suitable for high school students, based on the foundational math knowledge needed to understand the AI concepts. If the math involved in an AI concept is not taught in high school, such a concept will not be included in our game-based learning environment. We specifically focus on the high school population for two reasons. First, integration of our game-based AI education for the entire K-12 population requires a significant undertaking that is beyond the scope of our project. Second, our goal is not just to help students learn what the AI algorithms can do, but also understand the algorithms themselves. Such understanding may require the math knowledge taught in only high school classrooms in the US.

In the US, the Common Core State Standards for Mathematics defines the knowledge and skills students need to be prepared for mathematics in college, career, and life [Association and others, 2010]. Such standards are used in US K-12 classrooms nationwide. Each state in the US can define its own standards on math for K-12 as well, based on the Common Core. Since our game-based learning environment will be piloted in schools in the state of California and Virginia, we also researched the math standards for these two states [of Education, 2013; Board of Education, 2016]. A second resource we employed is the math textbooks used by the teachers from our partner schools in California and Virginia. The primary math subjects covered in the partner schools are pre-calculus, calculus, algebra (I & II), and geometry, which are aligned with both the state and nationwide standards. Concepts in statistics and probability, such as estimating the outcome of a single event and building a histogram, are taught throughout K-12. More advanced concepts such as conditional probability and using probability to make decisions are often introduced only in high school, grades 10 through 12.

### 3.2 AI Concepts

One of the mostly commonly used textbooks for AI in higher education is "Artificial Intelligence: A Modern Approach" [Russell and Norvig, 2016]. This textbook is used both for undergraduate- and graduate-level AI courses, often for computer science or related majors around the world. The textbook covers foundational knowledge in AI from search algorithms to logic, to machine learning. It was one of the resources we used to survey the topics of AI to be covered in our game-based learning. A second resource we used is the curriculum of AI and machine learning for non- computer science and related majors in higher education. With the growing public interest in AI, there has been an increasing demand for AI education, particularly machine learning methods used in data science, for students from non-computer science disciplines in higher education. Many universities have developed courses and curriculum to fulfill this demand. Because the students in these courses have mainly completed math education at a US high school level, the curriculum on computer science (CS), data science, and even math for students from non-CS or non-math majors can help us identify what AI topics are suitable for high school students. Based on the subjects discussed in the AI textbook [Russell and Norvig, 2016] and what we have learned from the US high school math curriculum, we selected a number of candidate AI concepts in search (classical search, local search, adversarial search, and constraint satisfaction problems), propositional logic (inference with truth tables), probabilistic reasoning (conditional probability and Bayesian networks), and learning (decision trees, linear models, and clustering). This is by no means a comprehensive list of AI concepts that are suitable for high school. In other words, it also does not mean that the AI concepts not included in the list are necessarily unsuitable for high school. This is a starting point for the design of our game-based learning environment, based on our survey of the high school math curriculum and AI textbooks.

### 3.3 Connecting AI and High School Math

Based on the candidate AI concepts we selected, we identified the math skills needed to understand these concepts, and how those skills are covered in the high school math curriculum.

- *Classical Search*: Example classical search algorithms are breath-first, depth-first, and A search algorithms. The instructional goals primarily focus on how to search through the search tree, how to use heuristics to guide such search, and how to estimate the complexity of the algorithms. Permutations (Algebra I) are often used to estimate the size of the search space. Expressions and Functions (Algebra I) are used in the design of heuristics to guide the search for algorithms such as A .
- *Local Search*: The Hill Climbing algorithm is a representative local search algorithm. Here, the AI instructional goals include assessing the quality of a state/solution and generating and choosing a successor state. Again, Expressions and functions (Algebra I) are used in heuristic design for estimating how desirable a state is or how good the current solution is. When choosing to move from a state to one of its "successor" states, the rate of change formula, or "rise over run", is used to evaluate which option offers the best change in score. This requires understanding of Slope (Algebra I).
- *Adversarial Search*: Minimax and alpha-beta pruning are exemplar adversarial search algorithms. Here, the AI instructional goal is primarily to help students understand the reasoning of their opponent's moves. To design functions to differentiate winning vs. losing final game states requires knowledge of expressions and functions (Algebra I).
- *Propositional Logic*: While there are many inference algorithms illustrated in propositional logic, we have decided to start with the basic inference procedure through truth tables. However, logic is not a subject formally taught in K-12 classrooms in the US.
- *Constraint Satisfaction Problem*: Constraint Satisfaction Problems search is a type of search where we reduce the the search space by identifying variable and value combinations that violate the constraints. Building on the knowledge of basic search algorithms, the key instructional point here is how to reason about the constraints among variables to reduce the search space. In addition to the math concepts required for classical search algorithms, Polynomials (Algebra I) are required to estimate the complexity of the arc consistency algorithm, which is used to reduce the search space.
- *Probabilistic Reasoning*: On this subject, the primary instructional goals for AI are to help students understand independent and conditional probability and to illustrate those concepts through Bayesian networks. To understand independent and conditional probability and Bayesian networks, the same topics covered in Algebra I will be required.
- *Decision Tree*: Decision trees are one of the simplest yet most successful forms of machine learning. A decision tree represents a function that takes a vector of attribute values as input and returns a "decision". A decision tree reaches its decision by performing a sequence of tests. To construct a decision tree, students need to know how to interpret the frequencies of outcomes as probabilities. To construct an efficient decision tree, students need to know how to estimate the information gain. These requires knowledge in Probability (Algebra I) and Logarithmic Functions (Algebra II).
- *Linear Models*: One of the simplest case of learning with linear models is regression with a univariate linear function, otherwise known as "fitting a straight line". Mathematical Modeling and Variation (Precalculus) is needed to calculate a linear regression line for a set of $(x, y)$ numerical data and the fitness of this line using Sum of Square Differences.
- *Clustering*: Clustering is a good algorithm to illustrate unsupervised learning. The goal of unsupervised clustering is to discern multiple categories in a collection of objects. Knowledge of Functions as graphs (Algebra I), Mean (Algebra I), and Distance formula (Geometry I)

is needed to create and interpret $x$–$y$ plots of numerical data, and understand centroid and distance to centroid.

## 4 Discussion

In this paper, we discussed a preliminary effort to design AI problem-solving for a game-based learning environment for high school students. Based on the foundational role math plays in AI, we researched the US high school math curriculum to identify candidate AI concepts that might be suitable for high school AI education. There are a few lessons we have learned so far. First, logic is often not a subject taught in US K-12 classrooms. Because knowledge engineering and planning often build upon foundational knowledge in logic, such topics may be distant to high school student without introductory courses on logic. While logic is not part of K-12 curriculum, there has been on-going effort to develop courses that are suitable for high schoolers (e.g., [Genesereth, 2019]). Additionally, through the process of identifying math concepts in the most foundational concepts of AI, we found that most of the math knowledge required is covered in the K-12 math curriculum. However, while the math skills are needed to understand parts of the algorithms, such as estimating the complexity, it is not all. More importantly it is perhaps the computational thinking [Wing, 2006], which involves a process of abstraction, automation, and analysis [Lee *et al.*, 2011], that is critical to grasping the core of AI problem-solving. For example, abstraction is often one the first steps of AI problem solving, whether in how to define features for machine learning or in how to express knowledge written in natural language as First-Order Logic expressions. AI problem-solving often involves the process of creating a well-defined abstraction of a problem, knowing when and how to apply different algorithms, and analyzing, modifying, and improving the results. While math is part of the K-12 curriculum, computational thinking (CT) is usually not. However, efforts are underway in integrating CT education in K-12. This provides an exemplar and perhaps pathway on how AI education can be integrated in K-12. For our efforts, the immediate next steps are to evaluate the AI problem-solving at the partner schools, to gather feedback on them from teachers and instructors, and to implement them in a game-based learning environment.

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