Introduction
The Ohio Department of Education’s Office of Learning and Instructional Strategies is in the process of revising Ohio’s Model Curriculum for Computer Science.

The State Board of Education adopted Ohio’s Learning Standards and Model Curriculum for Computer Science in December 2018. Implemented in the 2019-2020 (FY2020) school year, the purpose of Ohio’s Learning Standards and Model Curriculum for Computer Science is to provide guidance to schools and districts. Ohio educators, many of whom engage daily with Ohio students, led the process to create Ohio’s Learning Standards and Model Curriculum for Computer Science.

The review and revision process presents an opportunity for families, computer science professionals, community members and other educators, to provide suggestions for improving the model curriculum through a public comment survey, open March 2 through March 18.

In the Fall of 2021, the public was invited to provide comments on the current standards and model curriculum. Advisory group members, who have an educational background or professional experience in computer science, met several times to discuss the public comment and make suggestions for revisions. The advisory group then provided direction and guidance to the working groups of Ohio educators, who worked to write the revisions.

The following is a draft of the revised model curriculum available for viewing and public comment. This document contains the revisions to the model curriculum for the Artificial Intelligence (AI) strand. This model curriculum addresses new proposed standards and therefore new content.

In your review, please focus on the content of the statements. All materials will be going through additional technical edits, but because of the timeline outlined in HB110, the Department wanted to make these drafts available for public comment at this time.

To see the model curriculum adopted by the Ohio State Board of Education in 2018 please visit the Model Curriculum for Computer Science.
Overview of the Computer Science Standards Framework

Ohio’s Computer Science Standards are organized by strands, topics and content statements.

Grades 9-12 - Content statements are organized by grade band into two levels – Foundational and Advanced. Foundational level standards are targeted at students who have limited or no experience in Computer Science. **Foundational level courses ask students to demonstrate competency of one or more subsets of the standards.** Advanced standards are targeted at students demonstrating mastery at the foundational level. See an example of a content statement for high school and its corresponding content statement code below. This content statement addresses the topic of Networking within the Networks and the Internet strand, at the Foundational Level.

**Content Statement:** Evaluate and select networking devices to establish scalable communications.

**Content Statement Code:** NI.N.9-12.F.a
### Expectations for Learning

**LEARNING PROGRESSION**

By the end of grade 8:
Students explain the difference between training and using a reasoning model to identify how a machine learns.

In the grade 9-12 Foundational Level:
Students will illustrate what happens during each of the steps required when using machine learning to construct a classifier or predictor.

In the grade 9-12 Advanced Level:
Students will evaluate a dataset used to train a real Artificial Intelligence (AI) system by considering the size of the dataset, the way that the data were acquired and labeled, the storage required and the estimated time to produce the dataset. Artificial Intelligence (AI), is the science and engineering of making intelligent machines and computer programs.

**IMPORTANT CONCEPTS**
- Deciding a problem to want to solve
- Discovering where to obtain the training data
- Choosing a feature set
- Discovering how to label the data
- Running the learning algorithm
- Using a cross-validation set to decide when training should stop
- Using a test set to measure performance

**KEY SKILLS/PROCEDURES**
- Outline the steps of machine learning and elaborate on what is happening
  - How the machine learns the information
  - How the information is being stored
  - How the machine changes or modifies its existing algorithm
## Content Elaborations

### CLARIFICATIONS

The cross-validation set is used to avoid overfitting. The test set consists of examples that were not used during training or for cross-validation, so it provides an unbiased prediction of the reasoner's performance on new inputs.

### CONTENT FOCUS

- The origins of the dataset
- How the data is being used
- How the machine will make decisions or modify the existing algorithm as it "learns" more information

### COMPUTER SCIENCE PRACTICES

*Practice 3.1* Identify complex, interdisciplinary, real-world problems that can be solved computationally. At any level, students should be able to identify problems that have been solved computationally.
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### Expectations for Learning

#### LEARNING PROGRESSION

- **By the end of grade 8:**
  Students will train a classification or prediction model using machine learning on a tabular dataset to evaluate the quality of the dataset.

- **In the grade 9-12 Foundational Level:**
  Students will use either a supervised or unsupervised learning algorithm to train a model on real-world data, then evaluate the results.

- **In the grade 9-12 Advanced Level:**
  Students will investigate imbalances in training data in terms of gender, age, ethnicity or other demographic variables that could result in a biased model by using a data visualization tool.

#### IMPORTANT CONCEPTS

- The supervised learning model is trained on a training set to produce the correct labels for labeled data. Students should evaluate the results by measuring the percent of items in a test set that are labeled correctly.

- The unsupervised learning model is trained to assign each input to a cluster of similar inputs. The clusters are determined by the learning algorithm since there are no labels attached to the training data. Students should evaluate the results by examining the clusters to see if they capture useful distinctions in the dataset.

#### KEY SKILLS/PROCEDURES

**Supervised Learning Algorithm**

*Example:* Sort animal images into categories and teach a machine how to sort the images. Then, expose the machine to new images and quantify the results based on how many correct labels were applied to the new images.

**Unsupervised Learning Algorithm**

*Example:* Teach the machine to sort images into clusters based on useful distinctions, such as two legs, long tails, etc. Do not assign the images to distinct categories. Quantify the results by evaluating the contents of each cluster.
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**Content Elaborations**

**CLARIFICATIONS**

Supervised and unsupervised learning algorithms find patterns in data. In supervised learning, the "pattern" is the relationship between feature values and class labels. In unsupervised learning, the pattern is the way that data is grouped into clusters. Real-world data sets are now widely available on the web. In earlier grade bands, students might test their trained models on a few new data points, but in this grade band, students are asked to quantitatively measure the performance of a trained model on a nontrivial test set.

**CONTENT FOCUS**

Using a search engine, conduct a search for 'machine learning tools'. Choose one that is free and compatible with the 1:1 devices used in the classroom. Model how the tool is used, and have the students try to train the tool in various manners.

**COMPUTER SCIENCE PRACTICES**

*Practice 3.1* Identify complex, interdisciplinary, real-world problems that can be solved computationally. At any level, students should be able to identify problems that have been solved computationally.
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<tr>
<td>AI.NI.9-12.F.a</td>
<td>Construct context-free grammars to parse simple languages and use language processing tools to construct a chatbot. Use sentiment analysis tools to extract emotional tone from text.</td>
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**Expectations for Learning**

**LEARNING PROGRESSION**

By the end of grade 8:
Students will create a program, individually and collaboratively, that implements a language processing algorithm to create a functional chatbot.

In the grade 9-12 Foundational Level:
Students will construct context-free grammars to parse simple languages, use language processing tools to construct a chatbot and use sentiment analysis tools to extract emotional tone from text.

In the grade 9-12 advanced level:
Students will identify and debate the issues of AI and consciousness.

**IMPORTANT CONCEPTS**

- Context-free grammars (CFGs) are a set of recursive rules used to generate patterns of strings and to describe context-free languages. CFGs can describe all regular languages and more, but they cannot describe all possible languages.
- Sentiment analysis (or opinion mining) is a natural language processing (NLP) technique used to determine whether data is positive, negative or neutral.

**KEY SKILLS/PROCEDURES**

- Describe Context-Free Grammar (CFG) and how the weighted and probabilistic extensions handle the ambiguity of natural language.
- Write an algorithm to create a chatbot.
- Incorporate a sentiment analysis tool into an algorithm to allow the machine to determine whether the data is positive, negative or neutral to generate its response.

**Content Elaborations**

**CLARIFICATIONS**

Context-free grammars (CFGs) are a set of recursive rules used to generate patterns of strings and to describe context-free languages. CFGs can describe all regular languages and more, but they cannot describe all possible languages. Sentiment analysis (or opinion mining) is a natural language processing (NLP) technique used to determine whether data is positive, negative or neutral.
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**CONTENT FOCUS**
Create a Chatbot that will respond to inputs based on sentiment of inputed data. After students have gained experience testing (P6.2), debugging and revising (P6.1), they should begin to evaluate and refine their computational artifacts.

**COMPUTER SCIENCE PRACTICES**
*Practice 6.3* Evaluate and refine a computational artifact multiple times to enhance its performance, reliability, usability and accessibility.
### Expectations for Learning

#### LEARNING PROGRESSION

By the end of grade 8:
Students will create a program, individually and collaboratively, that implements a language processing algorithm to create a functional chatbot.

In the grade 9-12 Foundational Level:
Students will demonstrate how sentence parsers handle ambiguity

#### IMPORTANT CONCEPTS
- Parsing is an NLP task to assign syntactic structures to sentences according to grammar

#### KEY SKILLS/PROCEDURES
- Differentiate between how humans and AI learn language ambiguities

#### Content Elaborations

#### CLARIFICATIONS
This was mentioned under AI Perceptions with the differences between written and spoken language. Students should begin to evaluate and refine their computational artifacts after they have gained experience testing, debugging and revising.

#### CONTENT FOCUS
Machine learning can overcome language ambiguities.

#### COMPUTER SCIENCE PRACTICES

*Practice 6.3 Evaluate and refine a computational artifact multiple times to enhance its performance, reliability, usability and accessibility.*
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| AI.NI.9-12.F.c Describe how artificial intelligence drives many software and physical systems. |

### Expectations for Learning

#### LEARNING PROGRESSION

By the end of grade 8:
Students critically analyze and discuss features that make an entity “intelligent”, including discussing differences between human, animal and machine intelligence to identify how machine intelligence varies from natural intelligence.

In the grade 9-12 Foundational Level:
Students describe how artificial intelligence drives many software and physical systems.

#### IMPORTANT CONCEPTS
- AI is a component of smart homes, smartwatches and smartphones

#### KEY SKILLS/PROCEDURES
- Brainstorm areas where AI exists in student’s everyday encounters
- Students will choose one area and present to the class how AI is used in that area

### Content Elaborations

#### CLARIFICATIONS
Examples include digital ad delivery, self-driving cars and credit card fraud detection.

#### CONTENT FOCUS
AI is everywhere.

#### COMPUTER SCIENCE PRACTICES

*Practice 6.3 Evaluate and refine a computational artifact multiple times to enhance its performance, reliability, usability and accessibility. After students have gained experience testing (P6.2), debugging, and revising (P6.1), they should begin to evaluate and refine their computational artifacts.*
## Expectations for Learning

### LEARNING PROGRESSION

By the end of grade 8:
Students explain how sounds and images are represented digitally in a computer to explain how sensor data is stored in a computer.

In the grade 9-12 Foundational Level:
Students will explain how radar, lidar, GPS and accelerometer data are represented.

In the grade 9-12 Advanced Level:
Students will describe some of the technical difficulties in making computer perception systems function well for diverse groups.

### IMPORTANT CONCEPTS

- Radar and lidar do depth imaging; each pixel is a depth value
- GPS triangulates position using satellite signals and gives a location as longitude and latitude
- Accelerometers measure acceleration in three-orthogonal dimensions

### KEY SKILLS/PROCEDURES

- Define radar, lidar, GPS and accelerometers
- Determine if this data is a string, numeric as integer or decimal or boolean
- Choose one sensor device to research how the data is stored on the computer
- Students should report findings to the whole class
- Students should know how to explain the complex concepts in simple language and should add to their report based on questions from the class

### Content Elaborations

### CLARIFICATIONS

Radar and lidar measure distance as the time for a reflected signal to return to the transceiver. GPS determines position by triangulating precisely timed signals from three or more satellites. Accelerometers use orthogonally oriented strain gauges to measure acceleration in three dimensions.
**CONTENT FOCUS**
Teachers should focus on deconstruction activities that help students analyze and interpret how sensors operate and how the computer stores data. The AI components of the sensors will make decisions based on the information.

**COMPUTER SCIENCE PRACTICES**
*Practice 5.3* Modify an existing artifact to improve or customize it. At all grade levels, students should be able to examine existing artifacts to understand what they do.
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**AI.P.9-12.F.b** Describe the limitations and advantages of various types of computer sensors.

## Expectations for Learning

### LEARNING PROGRESSION

**By the end of grade 8:**

Students will describe how a vision system might exhibit cultural bias if it lacked knowledge of objects not found in the culture of the people who created it to create inclusive and equitable data sets.

**In the grade 9-12 Foundational Level:**

Students will describe the limitations and advantages of various types of computer sensors.

**In the grade 9-12 Advanced Level:**

Students will illustrate the abstraction hierarchy for speech understanding, from waveforms to sentences, showing how knowledge at each level is used to resolve ambiguities in the levels below.

### IMPORTANT CONCEPTS

- Sensors are devices that measure physical phenomena such as light, sound, temperature or pressure

### KEY SKILLS/PROCEDURES

- Brainstorm types of computer sensors and the type of data they collect
- Create a table, Venn diagram or another graphic organizer to illustrate the advantages and disadvantages of each type of sensor
- Troubleshoot one sensor to provide a possible solution to a disadvantage

### Content Elaborations

### CLARIFICATIONS

Cameras have limited resolution, dynamic range and spectral sensitivity. Microphones have limited sensitivity and frequency response. Signals may be degraded by noise, such as a microphone in a noisy environment. Some sensors can detect things that people cannot like infrared or ultraviolet imagery or ultrasonic sounds.
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**CONTENT FOCUS**

The focus is on cultural bias of programmers, ethics and limited datasets.

**COMPUTER SCIENCE PRACTICES**

*Practice 5.3* Modify an existing artifact to improve or customize it. At all grade levels, students should be able to examine existing artifacts to understand what they do.
### Expectations for Learning

#### LEARNING PROGRESSION

By the end of grade 8:
- Students will categorize problems as classification, prediction, combinatorial search or sequential decision problems.

In the grade 9-12 Foundational Level:
- Students will categorize real-world problems as classification, prediction, sequential decision problems, combination search heuristic search, adversarial search, logical deduction or statistical inference.

#### IMPORTANT CONCEPTS

- Reasoning problems can be categorized based on:
  - Types of inputs supplied
  - Types of outputs to be produced
  - Characteristics of the search space, if applicable

#### KEY SKILLS/PROCEDURES

- Define combination search, heuristic search, adversarial search, logical deduction and statistical inference as it relates to computer science
- Give students examples of different real-world problems to categorize
- Students will justify their reasoning based on their knowledge of the categories

### Content Elaborations

#### CLARIFICATIONS

Heuristic search is needed when the state space is too large to examine all possible states. It uses a rule of thumb (heuristic) to limit the search by focusing on the most promising states. In adversarial search, used in game playing, the algorithm alternates between finding the best move for the player and the best response for the opponent, which would be the worst move from the player’s perspective. Adversarial search may require heuristics if the game is complex such as chess or go. In logical deduction, the reasoner starts with a set of facts and derives new facts by applying inference rules. Logical deduction can be done using formal logic such as propositional or predicate logic, or ad hoc
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Inference rules used with semantic networks or the IF-THEN rules found in expert systems. Statistical inference involves reasoning with probabilities.

**CONTENT FOCUS**

Reasoning problems can be categorized based on the types of inputs supplied, the types of outputs to be produced, and the characteristics of the search space, if applicable.

**COMPUTER SCIENCE PRACTICES**

*Practice 3.1* Identify complex, interdisciplinary, real-world problems that can be solved computationally. At any level, students should be able to identify problems that have been solved computationally.
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**AI.RR.9-12.F.c** Describe the differences between types of search algorithms.

### Expectations for Learning

#### LEARNING PROGRESSION

By the end of grade 8:
Students will model the process of solving a graph search problem using breadth-first search to draw a search tree.

In the grade 9-12 Foundational Level:
Students will describe the differences between types of search algorithms.

In the grade 9-12 Advanced Level:
Students will illustrate breadth-first, depth-first and best-first search algorithms to grow a search tree.

### Important Concepts

- There are multiple algorithms for generating a search tree, each with its own advantages

### Key Skills/Procedures

- Categorizing problems
- Predicting outcomes
- Defining and using the various algorithms

### Content Elaborations

#### Clarifications

Some algorithms may be easier to implement in a particular programming language, work faster, require less memory to store data and be applicable in a wider variety of situations than other algorithms. Algorithms used to search and sort data are common in a variety of software applications. Encryption algorithms are used to secure data, and compression algorithms make data storage more efficient. At this level, the analysis may involve simple calculations of steps. Analysis using sophisticated mathematical notation to classify algorithm performance like Big-O notation is not expected.

#### Content Focus

There are multiple algorithms for generating a search tree, each with its own advantages. Students should begin to evaluate and refine their computational artifacts after they have gained experience testing, debugging and revising.
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**COMPUTER SCIENCE PRACTICES**

*Practices 6.3* Evaluate and refine a computational artifact multiple times to enhance its performance, reliability, usability, and accessibility.
# Artificial Intelligence

## Societal Impacts

**AI.SI.9-12.F.a** Critically explore the positive and negative impacts of an AI system.

### Expectations for Learning

#### LEARNING PROGRESSION

- **By the end of grade 8:**
  Students will identify and explain how the composition of training data affects the outcome of a supervised artificial intelligence system.

- **In the grade 9-12 Foundational Level:**
  Students will critically explore the positive and negative impacts of an AI system.

- **In the grade 9-12 Advanced Level:**
  Students will design an AI system to address social issues or explain how AI could be used to address a social issue.

### IMPORTANT CONCEPTS

- Weak AI vs strong AI
- Robots replacing humans in the workforce
- Overcoming the innate bias of creating AI
- Ethics debates based on “just because we can, should we?”

### KEY SKILLS/PROCEDURES

- Investigate and propose solutions to ethical and societal AI issues in a variety of settings like public safety, finance, social media marketing or government use)
- Discuss issues of bias and accessibility in the design of existing technologies
- Using a web tool that trains a machine learning model without coding, investigate examples of bias and identify solutions
- Identify and analyze examples of legal policies related to AI, including why and how they were or are being developed
- Analyze real-world AI scenarios to determine the ethical and legal implications
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## Content Elaborations

### Clarifications

**Positives:**
- less time
- solves problems that humans cannot

**Negatives:**
- ethics of using biased datasets
- loss of jobs
- price of the technology

### Content Focus

Students can have an ethical debate about AI. It is important to discuss the impacts that AI is having on our society and develop criteria for the ethical design and deployment of AI-based systems.

### Computer Science Practices

*Practices 3.1 Identify complex, interdisciplinary, real-world problems that can be solved computationally. At any level, students should be able to identify problems that have been solved computationally.*
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**AI.ML.9-12.A.a** Evaluate a dataset used to train a real AI system by considering the size of the dataset, the way that the data were acquired and labeled, the storage required and the estimated time to produce the dataset.

### Expectations for Learning

#### LEARNING PROGRESSION

**By the end of grade 8:**
Students will illustrate how objects in an image can be segmented and labeled to construct a training set for object recognition.

**In the grade 9-12 Foundational Level:**
Students will illustrate what happens during each of the steps required when using machine learning to construct a classifier or predictor.

**In the grade 9-12 Advanced Level:**
Students evaluate a dataset used to train a real AI system by considering the size of the dataset, the way that the data were acquired and labeled, the storage required and the estimated time to produce the dataset.

#### IMPORTANT CONCEPTS

- A large dataset is typically required to capture the diversity of a complex domain and narrow down the range of possible reasoner behaviors
- There are multiple ways to construct, clean and verify a dataset
- There can be large costs associated with creating the dataset and processing the data
- Labeling training data is labor intensive and may require specialized expertise like spotting disease in x-rays
- Bias can be introduced during each step of the dataset creation

#### KEY SKILLS/PROCEDURES

- An activity can be done with common machine learning datasets found in repositories or publicly available demographic, economic or environmental datasets

#### Content Elaborations

#### CLARIFICATIONS

Datasets for real-world problems may involve many features, and the defining characteristics of a class may involve complex relationships among these features. To narrow down the class to be learned and distinguish it from millions of other possible classes, the learning algorithm must see many examples.
## Computer Science Model Curriculum: Artificial Intelligence, Grade 9-12 DRAFT

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### CONTENT FOCUS
- Uses of Big Data
- Analysis of Datasets
- Bias of datasets

### COMPUTER SCIENCE PRACTICES

*Practice 3.1* Identify complex, interdisciplinary, real-world problems that can be solved computationally. At any level, students should be able to identify problems that have been solved computationally.
# Computer Science Model Curriculum: Artificial Intelligence, Grade 9-12 DRAFT

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<td><strong>AIIML.9-12.A.b</strong></td>
<td>Investigate imbalances in training data in terms of gender, age, ethnicity, or other demographic variables that could result in a biased model, by using a data visualization tool.</td>
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## LEARNING PROGRESSION

**By the end of grade 8:**
Students will explain how the choice of training data shapes the behavior of the classifier to identify how bias can be introduced if the training set is not properly balanced.

**In the grade 9-12 Foundational Level:**
Students will use either a supervised or unsupervised learning algorithm to train a model on real-world data, then evaluate the results.

**In the grade 9-12 Advanced Level:**
Students will investigate imbalances in training data in terms of gender, age, ethnicity or other demographic variables that could result in a biased model by using a data visualization tool.

### IMPORTANT CONCEPTS
- Machine learning algorithms will take advantage of any imbalances or correlations in the training set that help lower the error rate
- If the dataset is not representative, correlations can be misleading

### KEY SKILLS/PROCEDURES
- Brainstorm limitations to data
- Research current events that illustrate bias in AI facial recognition software

## Content Elaborations

### CLARIFICATIONS
Data exploration to help students uncover imbalances or correlations can be done using histograms in spreadsheet software, or using any number of data visualization tools.

### CONTENT FOCUS

**Sources of bias in datasets**
Imbalances of datasets from historical data like police databases from 1900 - 2000, due to race or gender bias. For example, in the 1970s, women needed a male cosigner (father or husband) to apply for a credit card.
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**COMPUTER SCIENCE PRACTICES**

*Practices 3.1* Identify complex, interdisciplinary, real-world problems that can be solved computationally. At any level, students should be able to identify problems that have been solved computationally.


## Expectations for Learning

### LEARNING PROGRESSION

By the end of grade 8:
Students will critically analyze and discuss features that make an entity “intelligent”, including discussing differences between human, animal and machine intelligence to identify how machine intelligence varies from natural intelligence.

In the grade 9-12 Foundational Level:
Students will construct context-free grammars to parse simple languages and use language processing tools to construct a chatbot. Use sentiment analysis tools to extract emotional tone from text.

In the grade 9-12 Advanced Level:
Students will identify and debate the issues of AI and consciousness.

### IMPORTANT CONCEPTS

- AI consciousness affects those who interact with it.
- Bias, as an inherent human condition, is coded into the functionality of AI
- Can computers "think"?

### KEY SKILLS/PROCEDURES

- Identify examples of issues related to bias, perception, privacy and accuracy in artificial intelligence

### Content Elaborations

**CLARIFICATIONS**

Alan Turing’s paper “Computing Machinery and Intelligence” published in 1950 started the debate and the Strong AI Hypothesis. Edsger Dijkstra, in a 1984 paper, compared the question of whether machines can think with questions, such as “can submarines swim?” or “can airplanes fly?”. Most will agree that airplanes can, in fact, fly but submarines can’t swim.
### Strand: Artificial Intelligence  
**Topic: Natural Interaction**

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<th>CONTENT FOCUS</th>
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<tr>
<td>• Define the word &quot;thinking&quot;</td>
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<td>• Research how computers think</td>
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<td>• Research how reliable computer decisions are</td>
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**COMPUTER SCIENCE PRACTICES**

*Practice 3.1 Identify complex, interdisciplinary, real-world problems that can be solved computationally. At any level, students should be able to identify problems that have been solved computationally.*
## Computer Science Model Curriculum: Artificial Intelligence, Grade 9-12 DRAFT

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### Expectations for Learning

**LEARNING PROGRESSION**

By the end of grade 8:
- Students will describe how a vision system might exhibit cultural bias if it lacked knowledge of objects not found in the culture of the people who created it to create inclusive and equitable data sets.

In the grade 9-12 Foundational Level:
- Describe the limitations and advantages of various types of computer sensors.

In the grade 9-12 Advanced Level:
- Students will describe some of the technical difficulties in making computer perception systems function well for diverse groups.

### IMPORTANT CONCEPTS

- Facial Recognition software is only reliable on white males
- Digital cameras are limited on their ability to create contrast on darker objects, limiting their ability to distinguish features

### KEY SKILLS/PROCEDURES

- Discuss bias created by programmers’ limitations of datasets
- Explore technological articles on why corporations are moving away from facial recognition software
- Debate the ethics of whether or not historical data should be used in locating high-crime areas to increase police presence

### Content Elaborations

**CLARIFICATIONS**

- Dark or low contrast facial features are harder to recognize than bright, high contrast features.
- Children’s speech is in a higher register and less clearly articulated than adult speech.

**CONTENT FOCUS**

- The focus is on the cultural bias of programmers, ethics and limited datasets.
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**COMPUTER SCIENCE PRACTICES**

*Practice 5.3* Modify an existing artifact to improve or customize it. At all grade levels, students should be able to examine existing artifacts to understand what they do.
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**AI.P.9-12.A.b** Illustrate the abstraction hierarchy for speech understanding, from waveforms to sentences, showing how knowledge at each level is used to resolve ambiguities in the levels below.

**Expectations for Learning**

**LEARNING PROGRESSION**

By the end of grade 8:
Students will illustrate how sequences of words can be recognized as phrases, even if some of the words are unclear, by looking at how the words fit together to create a text recognition program.

In the grade 9-12 Advanced Level:
Students will illustrate the abstraction hierarchy for speech understanding, from waveforms to sentences, showing how knowledge at each level is used to resolve ambiguities in the levels below.

**IMPORTANT CONCEPTS**

The spoken language hierarchy is:
- waveforms
  - articulatory gesture
    - sounds
  - morphemes
    - words
      - phrases
      - sentences

**KEY SKILLS/PROCEDURES**

- Demonstrate how an intelligent agent can misunderstand spoken words if you change the tone or pitch of your voice
- Explain how written punctuation placement determines the meaning of a statement
  - Example: "Let's eat, grandma." vs "let's eat grandma".
- Discuss how spoken language take this into account

**Content Elaborations**

**CLARIFICATIONS**

To go from noisy, ambiguous signals to meaning requires recognizing structure and applying domain knowledge at multiple levels of abstraction. A classic example: the sentences "How to recognize speech" and "How to wreck a nice beach" are virtually identical at the waveform level.
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**CONTENT FOCUS**

How do chatbots determine responses to oral language vs. written language? Students are familiar with their smart devices such as phones and watches. They can ask these devices various questions changing tone and accent.

**COMPUTER SCIENCE PRACTICES**

*Practice 3. Recognizing and Defining Computational Problems*

The ability to recognize appropriate and worthwhile opportunities to apply computation is a skill that develops over time and is central to computing. Solving a problem with a computational approach requires defining the problem, breaking it down into parts, and evaluating each part to determine whether a computational solution is appropriate.

By the end of Grade 12, students should be able to:

- Identify complex, interdisciplinary, real-world problems that can be solved computationally
- Decompose complex real-world problems into manageable subproblems that could integrate existing solutions or procedures
- Evaluate whether it is appropriate and feasible to solve a problem computationally
### Artificial Intelligence

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</table>

**AI.RR.9-12.A.a** Write code to create an algorithmic search.

### Expectations for Learning

#### LEARNING PROGRESSION

By the end of grade 8:
Students will model the process of solving a graph search problem using breadth-first search to draw a search tree.

In the grade 9-12 Foundational Level:
Students will list an algorithm that could be used to solve a problem for each of these types of reasoning problems: classification, prediction, sequential decision making, combinatorial search, heuristic search, adversarial search, logical deduction and statistical inference.

In the grade 9-12 Advanced Level:
Students will write code to create an algorithmic search.

#### IMPORTANT CONCEPTS
- There are multiple algorithms for generating a search tree, each with its own advantages

#### KEY SKILLS/PROCEDURES
- Categorizing problems
- Predicting outcomes
- Defining and using the various algorithms

### Content Elaborations

#### CLARIFICATIONS
Some algorithms may be easier to implement in a particular programming language, work faster, require less memory to store data and be applicable in a wider variety of situations than other algorithms. Algorithms used to search and sort data are common in a variety of software applications. Encryption algorithms are used to secure data, and compression algorithms make data storage more efficient. At this level, the analysis may involve simple calculations of steps. Analysis using sophisticated mathematical notation to classify algorithm performance, like Big-O notation, is not expected.

#### CONTENT FOCUS
The focus of this content is on using code to create an algorithmic search.
### Computer Science Model Curriculum: Artificial Intelligence, Grade 9-12 DRAFT

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**COMPUTER SCIENCE PRACTICES**

*Practice 6.3* Evaluate and refine a computational artifact multiple times to enhance its performance, reliability, usability and accessibility.
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<tr>
<td><strong>AI.RR.9-12.A.b</strong></td>
<td>Illustrate breadth-first, depth-first and best-first search algorithms to grow a search tree</td>
</tr>
</tbody>
</table>

**Expectations for Learning**

**LEARNING PROGRESSION**

By the end of grade 8:
Students will model the process of solving a graph search problem using breadth-first search to draw a search tree.

In the grade 9-12 Foundational Level:
Students will categorize real-world problems as classification, prediction, sequential decision problems, combination search heuristic search, adversarial search, logical deduction or statistical inference.

In the grade 9-12 Advanced Level:
Students will illustrate breadth-first, depth-first and best-first search algorithms to grow a search tree.

**IMPORTANT CONCEPTS**

- Breadth-first search finds shallow solutions quickly if they exist, but requires lots of memory
- Depth-first search is better than breadth-first for cases where the number of nodes at each level grows exponentially because it uses less memory
- A Binary Tree follows one simple rule that each parent node has no more than two child nodes, whereas, a Binary Search Tree is just a variant of the binary tree that follows a relative order to how the nodes should be organized in a tree

**KEY SKILLS/PROCEDURES**

- Illustrate breadth-first, depth-first and best-first search algorithms to grow a search tree for tic-tac-toe
- Illustration is done by drawing the tree. Writing code is appropriate for advanced students (AP CSA/CSP)
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**Content Elaborations**

**CLARIFICATIONS**
There are multiple algorithms for generating a search tree, each with its own advantages.

**CONTENT FOCUS**
Students should begin to evaluate and refine their computational artifacts after they have gained experience testing, debugging and revising.

**COMPUTER SCIENCE PRACTICES**
*Practice 6.3* Evaluate and refine a computational artifact multiple times to enhance its performance, reliability, usability and accessibility.
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<td>Societal Impacts</td>
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<tr>
<td>AI.SI.9-12.A.a</td>
<td>Design an AI system to address social issues (or explain how AI could be used to address a social issue).</td>
</tr>
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</table>

**Expectations for Learning**

**LEARNING PROGRESSION**

By the end of grade 8:
- Students will understand tradeoffs in the design of AI systems and how decisions can have unintended consequences in the function of a system.

In the grade 9-12 Foundational Level:
- Students will critically explore the positive and negative impacts of an AI system.

In the grade 9-12 Advanced Level:
- Students will design an AI system to address social issues or explain how AI could be used to address a social issue.

**IMPORTANT CONCEPTS**

- What Can AI Do?
- Find trends, patterns and associations
- Discover inefficiencies
- Execute plans
- Learn and become better
- Predict future outcomes based on historical trends
- Inform fact-based decisions

**KEY SKILLS/PROCEDURES**

- Identify and research projects from organizations focusing on social issues and design potential solutions to the problems identified
- Create an algorithm to address a social issue identified in student research that will solve the issue
## Content Elaborations

**CLARIFICATIONS**

Technology has helped societies all over the world to battle the most pressing issues and solve social problems. By promising faster technological advancement, artificial intelligence (AI) promises to provide answers to questions relating to the environment, security and society that we are all exploring today.

**CONTENT FOCUS**

- Research how to solve societal issues
- Students can explore fact-checking AI
- Consider how computers make our work easier or harder

**COMPUTER SCIENCE PRACTICES**

*Practice 6.3* Evaluate and refine a computational artifact multiple times to enhance its performance, reliability, usability and accessibility. After students have gained experience testing (P6.2), debugging, and revising (P6.1), they should begin to evaluate and refine their computational artifacts.
## Expectations for Learning

### LEARNING PROGRESSION

By the end of grade 8:
Students will model the process of solving a graph search problem using breadth-first search to draw a search tree.

In the grade 9-12 Foundational Level:
Students will list an algorithm that could be used to solve a problem.

In the grade 9-12 Advanced Level:
Students will illustrate breadth-first, depth-first and best-first search algorithms to grow a search tree.

### IMPORTANT CONCEPTS

- AI includes a wide variety of reasoning algorithms for solving different types of reasoning problems. Some algorithms use symbolic representations like search trees. Others are numerical in nature, such as neural nets operating on feature vectors.

### KEY SKILLS/PROCEDURES

- Categorizing problems
- Predicting outcomes
- Defining and using the various algorithms

### Content Elaborations

### CLARIFICATIONS

Different algorithms can be used to tie shoes or decide which path to take on the way home from school. While the end results may be similar, they may not be the same. In the example of going home, some paths could be faster, slower or more direct depending on varying factors, like time or obstacles, such as a barking dog. Algorithms can be expressed in noncomputer languages, including natural language, flowcharts and pseudocode.

### CONTENT FOCUS

AI includes a wide variety of reasoning algorithms for solving different types of reasoning programs. Some use symbolic representations while others are numerical in nature.
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**COMPUTER SCIENCE PRACTICES**

*Practice 3.1* Identify complex, interdisciplinary, real-world problems that can be solved computationally. At any level, students should be able to identify problems that have been solved computationally.