

## Mathematics III Introduction<sup>1</sup>



It is in the Model Mathematics III course that students integrate and apply the mathematics they have learned from their earlier courses. This course is comprised of standards selected from the high school **conceptual categories**, which were written to encompass the scope of content and skills to be addressed throughout grades 9–12 rather than through any single course. Therefore, the complete standard is presented in the model course, with clarifying footnotes as needed to limit the scope of the standard and indicate what is appropriate for study in this particular course. Standards that were limited in Model Mathematics I and Model Mathematics II no longer have those restrictions in Model Mathematics III.

For the high school Model Mathematics III course, instructional time should focus on four critical areas: (1) apply methods from probability and statistics to draw inferences and conclusions from data; (2) expand understanding of functions to include polynomial, rational, and radical functions; (3) expand right triangle trigonometry to include general triangles; and (4) consolidate functions and geometry to create models and solve contextual problems.

- (1) Students see how the visual displays and summary statistics they learned in earlier grades relate to different types of data and to probability distributions. They identify different ways of collecting data— including sample surveys, experiments, and simulations—and the roles that randomness and careful design play in the conclusions that can be drawn.
- (2) The structural similarities between the system of polynomials and the system of integers are developed. Students draw on analogies between polynomial arithmetic and base-ten computation, focusing on properties of operations, particularly the distributive property. Students connect multiplication of polynomials with multiplication of multi-digit integers, and division of polynomials with long division of integers. Students identify zeros of polynomials and make connections between zeros of polynomials and solutions of polynomial equations. Rational numbers extend the arithmetic of integers by allowing division by all numbers except zero. Similarly, rational expressions extend the arithmetic of polynomials by allowing division by all polynomials except the zero polynomial. A central theme of the Model Mathematics III course is that the arithmetic of rational expressions is governed by the same rules as the arithmetic of rational numbers. This critical area also includes exploration of the Fundamental Theorem of Algebra.
- (3) Students derive the Laws of Sines and Cosines in order to find missing measures of general (not necessarily right) triangles. They are able to distinguish whether three given measures (angles or sides) define 0, 1, 2, or infinitely many triangles. This discussion of general

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<sup>1</sup> Massachusetts Department of Elementary and Secondary Education, *Massachusetts Curriculum Framework for Mathematics*, 2011, p. 147–148.

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triangles opens up the idea of trigonometry applied beyond the right triangle, at least to obtuse angles. Students build on this idea to develop the notion of radian measure for angles and extend the domain of the trigonometric functions to all real numbers. They apply this knowledge to model simple periodic phenomena.

- (4) Students synthesize and generalize what they have learned about a variety of function families. They extend their work with exponential functions to include solving exponential equations with logarithms. They explore the effects of transformations on graphs of diverse functions, including functions arising in an application, in order to abstract the general principle that transformations on a graph always have the same effect regardless of the type of the underlying function. They identify appropriate types of functions to model a situation, they adjust parameters to improve the model, and they compare models by analyzing appropriateness of fit and making judgments about the domain over which a model is a good fit. The description of modeling as “the process of choosing and using mathematics and statistics to analyze empirical situations, to understand them better, and to make decisions” is at the heart of this Model Mathematics III course. The narrative discussion and diagram of the modeling cycle should be considered when knowledge of functions, statistics, and geometry is applied in a modeling context.

The Standards for Mathematical Practice complement the content standards so that students increasingly engage with the subject matter as they grow in mathematical maturity and expertise throughout the elementary, middle, and high school years.

## Number and Quantity

### The Complex Number System

- Use complex numbers in polynomial identities and equations.

## Algebra

### Seeing Structure in Expressions

- Interpret the structure of expressions.
- Write expressions in equivalent forms to solve problems.

### Arithmetic with Polynomials and Rational Expressions

- Perform arithmetic operations on polynomials.
- Understand the relationship between zeros and factors of polynomials.
- Use polynomial identities to solve problems
- Rewrite rational expressions.

### Creating Equations

- Create equations that describe numbers or relationships.

### Reasoning with Equations and Inequalities

- Understand solving equations as a process of reasoning and explain the reasoning.
- Represent and solve equations and inequalities graphically.

## Functions

### Interpreting Functions

- Interpret functions that arise in applications in terms of the context.
- Analyze functions using different representations.

### Building Functions

- Build a function that models a relationship between two quantities.
- Build new functions from existing functions.

## Mathematical Practices

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.
7. Look for and make use of structure.
8. Look for and express regularity in repeated reasoning.

### Linear, Quadratic, and Exponential Models

- Construct and compare linear, quadratic, and exponential models and solve problems.

### Trigonometric Functions

- Extend the domain of trigonometric functions using the unit circle.
- Model periodic phenomena with trigonometric functions.

## Geometry

### Similarity, Right Triangles, and Trigonometry

- Apply trigonometry to general triangles.

### Expressing Geometric Properties with Equations

- Translate between the geometric description and the equation for a conic section.

### Geometric Measurement and Dimension

- Visualize relationships between two-dimensional and three-dimensional objects.

### Modeling with Geometry

- Apply geometric concepts in modeling situations.

## Statistics and Probability

### Interpreting Categorical and Quantitative Data

- Summarize, represent, and interpret data on a single count or measurement variable.

### Making Inferences and Justifying Conclusions

- Understand and evaluate random processes underlying statistical experiments.
- Make inferences and justify conclusions from sample surveys, experiments, and observational studies.

### Using Probability to Make Decisions

- Use probability to evaluate outcomes of decisions.

★ Indicates a modeling standard linking mathematics to everyday life, work, and decision-making

(+) Indicates additional mathematics to prepare students for advanced courses

## Number and Quantity

### The Complex Number System

N-CN

**Use complex numbers in polynomial identities and equations.** [Polynomials with real coefficients; apply N.CN.9 to higher degree polynomials.]

8. (+) Extend polynomial identities to the complex numbers.
9. (+) Know the Fundamental Theorem of Algebra; show that it is true for quadratic polynomials.

## Algebra

### Seeing Structure in Expressions

A-SSE

**Interpret the structure of expressions.** [Polynomial and rational.]

1. Interpret expressions that represent a quantity in terms of its context. ★
  - a. Interpret parts of an expression, such as terms, factors, and coefficients. ★
  - b. Interpret complicated expressions by viewing one or more of their parts as a single entity.
2. Use the structure of an expression to identify ways to rewrite it.

**Write expressions in equivalent forms to solve problems.**

4. Derive the formula for the sum of a finite geometric series (when the common ratio is not 1), and use the formula to solve problems. *For example, calculate mortgage payments.* ★

### Arithmetic with Polynomials and Rational Expressions

A-APR

**Perform arithmetic operations on polynomials.** [Beyond quadratic.]

1. Understand that polynomials form a system analogous to the integers, namely, they are closed under the operations of addition, subtraction, and multiplication; add, subtract, and multiply polynomials.

**Understand the relationship between zeros and factors of polynomials.**

2. Know and apply the Remainder Theorem: For a polynomial  $p(x)$  and a number  $a$ , the remainder on division by  $x - a$  is  $p(a)$ , so  $p(a) = 0$  if and only if  $(x - a)$  is a factor of  $p(x)$ .
3. Identify zeros of polynomials when suitable factorizations are available, and use the zeros to construct a rough graph of the function defined by the polynomial.

**Use polynomial identities to solve problems.**

4. Prove polynomial identities and use them to describe numerical relationships. *For example, the polynomial identity  $(x^2 + y^2)^2 = (x^2 - y^2)^2 + (2xy)^2$  can be used to generate Pythagorean triples.*
5. (+) Know and apply the Binomial Theorem for the expansion of  $(x + y)^n$  in powers of  $x$  and  $y$  for a positive integer  $n$ , where  $x$  and  $y$  are any numbers, with coefficients determined for example by Pascal's Triangle<sup>1</sup> ★

**Rewrite rational expressions.** [Linear and quadratic denominators.]

6. Rewrite simple rational expressions in different forms; write  $a(x)/b(x)$  in the form  $q(x) + r(x)/b(x)$ , where

<sup>1</sup> The Binomial Theorem may be proven by mathematical induction or by a combinatorial argument.

$a(x)$ ,  $b(x)$ ,  $q(x)$ , and  $r(x)$  are polynomials with the degree of  $r(x)$  less than the degree of  $b(x)$ , using inspection, long division, or, for the more complicated examples, a computer algebra system.

7. (+) Understand that rational expressions form a system analogous to the rational numbers, closed under addition, subtraction, multiplication, and division by a nonzero rational expression; add, subtract, multiply, and divide rational expressions.

## Creating Equations

A-CED

**Create equations that describe numbers or relationships.** [Equations using all available types of expressions including simple root functions.]

1. Create equations and inequalities in one variable **including ones with absolute value** and use them to solve problems. *Include equations arising from linear and quadratic functions, and simple rational and exponential functions.* CA ★
2. Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. ★
3. Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or non-viable options in a modeling context. *For example, represent inequalities describing nutritional and cost constraints on combinations of different foods.* ★
4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

## Reasoning with Equations and Inequalities

A-REI

**Understand solving equations as a process of reasoning and explain the reasoning.** [Simple radical and rational.]

2. Solve simple rational and radical equations in one variable, and give examples showing how extraneous solutions may arise.

**Represent and solve equations and inequalities graphically.** [Combine polynomial, rational, radical, absolute value, and exponential functions.]

11. Explain why the  $x$ -coordinates of the points where the graphs of the equations  $y = f(x)$  and  $y = g(x)$  intersect are the solutions of the equation  $f(x) = g(x)$ ; find the solutions approximately, e.g., using technology to graph the functions, make tables of values, or find successive approximations. Include cases where  $f(x)$  and/or  $g(x)$  are linear, polynomial, rational, absolute value, exponential, and logarithmic functions. ★

## Functions

### Interpreting Functions

F-IF

**Interpret functions that arise in applications in terms of the context.** [Include rational, square root and cube root; emphasize selection of appropriate models.]

4. For a function that models a relationship between two quantities, interpret key features of graphs and tables in terms of the quantities, and sketch graphs showing key features given a verbal description of the relationship. *Key features include: intercepts; intervals where the function is increasing, decreasing, positive, or negative; relative maximums and minimums; symmetries; end behavior; and periodicity.* ★
5. Relate the domain of a function to its graph and, where applicable, to the quantitative relationship it describes. ★

6. Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. Estimate the rate of change from a graph. ★

**Analyze functions using different representations.** [Include rational and radical; focus on using key features to guide selection of appropriate type of model function.]

7. Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. ★
- Graph square root, cube root, and piecewise-defined functions, including step functions and absolute value functions. ★
  - Graph polynomial functions, identifying zeros when suitable factorizations are available, and showing end behavior. ★
  - Graph exponential and logarithmic functions, showing intercepts and end behavior, and trigonometric functions, showing period, midline, and amplitude. ★
8. Write a function defined by an expression in different but equivalent forms to reveal and explain different properties of the function.
9. Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions).

## Building Functions

F-BF

**Build a function that models a relationship between two quantities.** [Include all types of functions studied.]

- Write a function that describes a relationship between two quantities. ★
  - Combine standard function types using arithmetic operations. *For example, build a function that models the temperature of a cooling body by adding a constant function to a decaying exponential, and relate these functions to the model.* ★

**Build new functions from existing functions.** [Include simple, radical, rational, and exponential functions; emphasize common effect of each transformation across function types.]

- Identify the effect on the graph of replacing  $f(x)$  by  $f(x) + k$ ,  $kf(x)$ ,  $f(kx)$ , and  $f(x + k)$  for specific values of  $k$  (both positive and negative); find the value of  $k$  given the graphs. Experiment with cases and illustrate an explanation of the effects on the graph using technology. *Include recognizing even and odd functions from their graphs and algebraic expressions for them.*
- Find inverse functions.
  - Solve an equation of the form  $f(x) = c$  for a simple function  $f$  that has an inverse and write an expression for the inverse. *For example,  $f(x) = (x + 1)/(x - 1)$  for  $x \neq 1$ .*

## Linear, Quadratic, and Exponential Models

F-LE

**Construct and compare linear, quadratic, and exponential models and solve problems.**

- For exponential models, express as a logarithm the solution to  $ab^{ct} = d$  where  $a$ ,  $c$ , and  $d$  are numbers and the base  $b$  is 2, 10, or  $e$ ; evaluate the logarithm using technology. ★ [Logarithms as solutions for exponentials.]
  - 4.1. Prove simple laws of logarithms. CA ★**
  - 4.2 Use the definition of logarithms to translate between logarithms in any base. CA ★**
  - 4.3 Understand and use the properties of logarithms to simplify logarithmic numeric expressions and to identify their approximate values. CA ★**

## Trigonometric Functions

F-TF

**Extend the domain of trigonometric functions using the unit circle.**

1. Understand radian measure of an angle as the length of the arc on the unit circle subtended by the angle.
2. Explain how the unit circle in the coordinate plane enables the extension of trigonometric functions to all real numbers, interpreted as radian measures of angles traversed counterclockwise around the unit circle.

**2.1 Graph all 6 basic trigonometric functions. CA**

**Model periodic phenomena with trigonometric functions.**

5. Choose trigonometric functions to model periodic phenomena with specified amplitude, frequency, and midline. ★

## Geometry

## Similarity, Right Triangles, and Trigonometry

G-SRT

**Apply trigonometry to general triangles.**

9. (+) Derive the formula  $A = 1/2 ab \sin(C)$  for the area of a triangle by drawing an auxiliary line from a vertex perpendicular to the opposite side.
10. (+) Prove the Laws of Sines and Cosines and use them to solve problems.
11. (+) Understand and apply the Law of Sines and the Law of Cosines to find unknown measurements in right and non-right triangles (e.g., surveying problems, resultant forces).

## Expressing Geometric Properties with Equations

G-GPE

**Translate between the geometric description and the equation for a conic section.**

- 3.1 Given a quadratic equation of the form  $ax^2 + by^2 + cx + dy + e = 0$ , use the method for completing the square to put the equation into standard form; identify whether the graph of the equation is a circle, ellipse, parabola, or hyperbola, and graph the equation.** [In Mathematics III, this standard addresses circles and parabolas only.] CA

## Geometric Measurement and Dimension

G-GMD

**Visualize relationships between two-dimensional and three-dimensional objects.**

4. Identify the shapes of two-dimensional cross-sections of three-dimensional objects, and identify three-dimensional objects generated by rotations of two-dimensional objects.

## Modeling with Geometry

G-MG

**Apply geometric concepts in modeling situations.**

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder). ★
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot). ★
3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios). ★

## Statistics and Probability

### Interpreting Categorical and Quantitative Data

S-ID

**Summarize, represent, and interpret data on a single count or measurement variable.**

4. Use the mean and standard deviation of a data set to fit it to a normal distribution and to estimate population percentages. Recognize that there are data sets for which such a procedure is not appropriate. Use calculators, spreadsheets, and tables to estimate areas under the normal curve. ★

### Making Inferences and Justifying Conclusions

S-IC

**Understand and evaluate random processes underlying statistical experiments.**

1. Understand statistics as a process for making inferences to be made about population parameters based on a random sample from that population. ★
2. Decide if a specified model is consistent with results from a given data-generating process, e.g., using simulation. *For example, a model says a spinning coin falls heads up with probability 0.5. Would a result of 5 tails in a row cause you to question the model?* ★

**Make inferences and justify conclusions from sample surveys, experiments, and observational studies.**

3. Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each. ★
4. Use data from a sample survey to estimate a population mean or proportion; develop a margin of error through the use of simulation models for random sampling. ★
5. Use data from a randomized experiment to compare two treatments; use simulations to decide if differences between parameters are significant. ★
6. Evaluate reports based on data. ★

### Using Probability to Make Decisions

S-MD

**Use probability to evaluate outcomes of decisions.** [Include more complex situations.]

6. (+) Use probabilities to make fair decisions (e.g., drawing by lots, using a random number generator). ★
7. (+) Analyze decisions and strategies using probability concepts (e.g., product testing, medical testing, pulling a hockey goalie at the end of a game). ★