

ENHANCED HIGH SCHOOL PATHWAY TO CALCULUS

The Enhanced Pathway allows for a motivated student to complete the necessary course work to take Calculus in grade twelve starting with Enhanced Algebra I in grade nine (followed by Enhanced Geometry in grade ten and Enhanced Algebra II in grade eleven).

The Enhanced Pathway is presented as a proof of concept that it is possible to accelerate students starting in grade 9 to reach Calculus by grade 12, without “doubling up” to take multiple math courses in any given year. **Please note that the Enhanced Pathway has not been approved by the Board of Elementary and Secondary Education and is not officially part of the Massachusetts Curriculum Framework for Mathematics.** It is provided as a resource to assist district planning and curriculum development.

Summary of changes to Model courses

In Enhanced Algebra I, the study of complex numbers and operations on polynomials are added to the study of quadratics and exponentials found in Model Algebra I. In Enhanced Geometry the study of analytic geometry is extended through the study of hyperbolas and ellipses (in addition to circles). The Enhanced Algebra II coursework completes the study of algebraic concepts and functions begun in Enhanced Algebra I, including the study of logarithmic, rational, and trigonometric functions.

Several standards in the Model Algebra II course were moved to the Enhanced Algebra I course which made it possible to add standards from the Model Pre-calculus Course to the Enhanced Algebra II course.

In order to ensure that the Enhanced Pathway courses reflect a reasonable amount of content to address in one school year, some standards from the Model courses have been removed from the Enhanced courses. If time permits these standards could be addressed as part of the Enhanced course(s). All standards that have been removed are (+) standards (indicating standards beyond college and career ready), but the topics represented by these standards typically are not pre-requisites for Calculus.

Format of this document

Each Enhanced course (Enhanced Algebra I, Enhanced Geometry, and Enhanced Algebra II) starts with a cover page that notes the “Additional Standards” and the “Standards Removed”. The conceptual category and domain of each standard are listed along with a brief description and/or rationale for why the standard was added or removed. For Enhanced Algebra I, the “Footnotes Removed” are also listed; in most cases the footnotes limited the scope of the standard.

After the cover page of an Enhanced course, the full set of standards are listed. Standards that have been added to the Enhanced course are highlighted with ***bold italic*** font.

Additional Standards:

The concepts in the Model Algebra I course are extended in the Enhanced Algebra I course by introducing additional types of numbers, expressions, equations, and functions that naturally connect with each other (as in the case of extending finding zeros of quadratics to finding zeros of polynomials) and/or organize each other (as in the case of extending the number system to include both real and non-real numbers).

Number and Quantity

Complex Number System

N.CN.1, 2, 7, 8, 9 These standards complement the study of quadratics in Enhanced Algebra I by extending the study of numbers and the study of quadratic equations to include both real and non-real solutions.

Algebra

Seeing Structure in Expressions

A.SSE.4 This standard complements the study of exponential expressions and problem solving in Enhanced Algebra I by connecting the values of exponential expressions to the terms in finite geometric sequences as being equivalent.

Arithmetic with polynomials and rational Expressions

A.APR.MA.1a, 2, 3 In addition to performing operations on polynomials these standards extend the work of factoring to find zeros of quadratic expressions to higher degree polynomial expressions.

Reasoning with equations and Inequalities

A.REI.2 This standard extends the work of reasoning about the solutions for simple equations in one variable to reasoning about extraneous solutions.

Functions

Interpreting Functions

F.IF.7c This standard extends the work of polynomial expressions and equations to polynomial functions.

Standards Removed:

The following standards were removed from Model Algebra I.

Functions

Interpreting Functions

F.IF.7.e The content of this standard is generally advanced and fits with Enhanced Algebra II. Much of the content for Enhanced Algebra I described in this standard is found in standard F-IF.4.

Footnotes Removed:

The following Model Algebra I footnotes were removed for the Enhanced Algebra I. In most cases these footnotes limited the types of functions to which the corresponding standard, cluster, or domain was applicable. Footnote numbers refer to the numbers in the Model Algebra I course.

Footnote 38 This footnote limited the standard A1A-APR.1 to adding and multiplying polynomials. Enhanced Algebra I includes the entirety of this standard. This standard does not re-appear in Enhanced Algebra II as it does in Model Algebra II.

- Footnote 40 This footnote limited the standard A1.A-CED.3 to linear equations and inequalities. Enhanced Algebra I will include linear, quadratic, and exponential equations in this cluster.
- Footnote 41 This footnote limited the standard A1.A-REI.4.b to recognizing non-real roots. The study of non-real solutions and writing complex roots is included in Enhanced Algebra I.
- Footnote 47 The standard related to this footnote, A1.F-IF.7.e was moved to Enhanced Algebra II.
- Footnote 48 The standard related to this footnote, A1.F-IF.7.e was moved to Enhanced Algebra II.
- Footnote 50 This footnote limited the standard A1.F-BF.2 to the study of arithmetic and geometric sequences. Enhanced Algebra I introduces the study of finite geometric series.

Note:

In the list of standards that follow, please note that *larger italicized bold text* refers to standards *added to Enhanced Algebra I*.

Number and Quantity

The Real Number System

N.RN

Extend the properties of exponents to rational exponents.

1. Explain how the definition of the meaning of rational exponents follows from extending the properties of integer exponents to those values, allowing for a notation for radicals in terms of rational exponents. *For example, we define $5^{1/3}$ to be the cube root of 5 because we want $(5^{1/3})^3 = 5^{(1/3)3}$ to hold, so $(5^{1/3})^3$ must equal 5.*
2. Rewrite expressions involving radicals and rational exponents using the properties of exponents.

Use properties of rational and irrational numbers.

3. Explain why the sum or product of two rational numbers is rational; that the sum of a rational number and an irrational number is irrational; and that the product of a nonzero rational number and an irrational number is irrational.

Quantities★

N.Q

Reason quantitatively and use units to solve problems.★

1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. ★
2. Define appropriate quantities for the purpose of descriptive modeling. ★
3. Choose a level of accuracy appropriate to limitations on measurement when reporting quantities★
MA.3a. Describe the effects of approximate error in measurement and rounding on measurements and on computed values from measurements. Identify significant figures in recorded measures and computed values based on the context given and the precision of the tools used to measure. ★

The Complex Number System

N.CN

Perform arithmetic operations with complex numbers.

1. *Know there is a complex number i such that $i^2 = -1$, and every complex number has the form $a + bi$ with a and b real.*
2. *Use the relation $i^2 = -1$ and the commutative, associative, and distributive properties to add, subtract, and multiply complex numbers.*

Use complex numbers in polynomial identities and equations.

7. *Solve quadratic equations with real coefficients that have complex solutions.*
8. (+) *Extend polynomial identities to the complex numbers. For example, rewrite $x^2 + 4$ as $(x + 2i)(x - 2i)$.*
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.¹**

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. *For example, interpret $P(1+r)^n$ as the product of P and a factor not depending on P .*
2. Use the structure of an expression to identify ways to rewrite it. *For example, see $x^4 - y^4$ as $(x^2)^2 - (y^2)^2$, thus recognizing it as a difference of squares that can be factored as $(x^2 - y^2)(x^2 + y^2)$.*

Write expressions in equivalent forms to solve problems.

3. Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression.
 - a. Factor a quadratic expression to reveal the zeros of the function it defines.
 - b. Complete the square in a quadratic expression to reveal the maximum or minimum value of the function it defines.
 - c. Use the properties of exponents to transform expressions for exponential functions. *For example the expression 1.15^t can be rewritten as $(1.15^{1/12})^{12t} \approx 1.012^{12t}$ to reveal the approximate equivalent monthly interest rate if the annual rate is 15%.*
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.**

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. ***MA.1a. Divide 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.***

Creating Equations²**A.CED****Create equations that describe numbers or relationships.**

1. Create equations and inequalities in one variable and use them to solve problems. *Include equations arising from linear and quadratic functions, and simple rational and exponential functions.* ★
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. *For example, rearrange Ohm's law $V = IR$ to highlight resistance R .* ★

¹ In Enhanced Algebra I, expressions are limited to linear, quadratic, polynomial, and Exponential expressions in this cluster.

² In Enhanced Algebra I, equations are limited to linear, quadratic, and exponential equations in this cluster.

Reasoning with Equations and Inequalities**A.REI****Understand solving equations as a process of reasoning and explain the reasoning.**

1. Explain each step in solving a simple equation as following from the equality of numbers asserted at the previous step, starting from the assumption that the original equation has a solution. Construct a viable argument to justify a solution method.
2. *Solve simple rational and radical equations in one variable, and give examples showing how extraneous solutions may arise.*

Solve equations and inequalities in one variable.

3. Solve linear equations and inequalities in one variable, including equations with coefficients represented by letters.
MA.3.a. Solve linear equations and inequalities in one variable involving absolute value.
4. Solve quadratic equations in one variable.
 - a. Use the method of completing the square to transform any quadratic equation in x into an equation of the form $(x - p)^2 = q$ that has the same solutions. Derive the quadratic formula from this form.
 - b. Solve quadratic equations by inspection (e.g., for $x^2 = 49$), taking square roots, completing the square, the quadratic formula and factoring, as appropriate to the initial form of the equation. Recognize when the quadratic formula gives complex solutions and write them as $a \pm bi$ for real numbers a and b .
MA.4.c. Demonstrate an understanding of the equivalence of factoring, completing the square, or using the quadratic formula to solve quadratic equations.

Solve systems of equations.

5. Prove that, given a system of two equations in two variables, replacing one equation by the sum of that equation and a multiple of the other produces a system with the same solutions.
6. Solve systems of linear equations exactly and approximately (e.g., with graphs), focusing on pairs of linear equations in two variables.
7. Solve a simple system consisting of a linear equation and a quadratic equation³ in two variables algebraically and graphically. *For example, find the points of intersection between the line $y = -3x$ and the circle $x^2 + y^2 = 3$.*

Represent and solve equations and inequalities⁴ graphically.

10. Understand that the graph of an equation in two variables is the set of all its solutions plotted in the coordinate plane, often forming a curve (which could be a line).
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. ★
12. Graph the solutions to a linear inequality in two variables as a half-plane (excluding the boundary in the case of a strict inequality), and graph the solution set to a system of linear inequalities in two variables as the intersection of the corresponding half-planes.

³ Enhanced Algebra I does not include the study of conic equations; for this standard include quadratic equations typically included in Algebra I.

⁴ Enhanced Algebra I, functions are limited to linear, quadratic, absolute value, and exponential functions for this cluster.

Functions

Interpreting Functions

F.IF

Understand the concept of a function and use function notation.

1. Understand that a function from one set (called the domain) to another set (called the range) assigns to each element of the domain exactly one element of the range. If f is a function and x is an element of its domain, then $f(x)$ denotes the output of f corresponding to the input x . The graph of f is the graph of the equation $y = f(x)$.
2. Use function notation, evaluate functions for inputs in their domains, and interpret statements that use function notation in terms of a context.
3. Recognize that sequences are functions, sometimes defined recursively, whose domain is a subset of the integers. *For example, the Fibonacci sequence is defined recursively by $f(0) = f(1) = 1$, $f(n+1) = f(n) + f(n-1)$ for $n \geq 1$.*

Interpret functions⁵ that arise in applications in terms of the context.^{6*}

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. *For example, if the function $h(n)$ gives the number of person-hours it takes to assemble n engines in a factory, then the positive integers would be an appropriate domain for the function.* ★
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 functions⁷ using different representations.

7. Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. ★
 - a. Graph linear and quadratic functions and show intercepts, maxima, and minima. ★
 - b. Graph square root, cube root⁸, and piecewise-defined functions, including step functions and absolute value functions. ★
 - c. Graph polynomial functions, identifying zeros when suitable factorizations are available, and showing end behavior. ★
 8. Write a function defined by an expression in different but equivalent forms to reveal and explain different properties of the function.
 - a. Use the process of factoring and completing the square in a quadratic function to show zeros, extreme values, and symmetry of the graph, and interpret these in terms of a context.
 - b. Use the properties of exponents to interpret expressions for exponential functions. *For example, identify percent rate of change in functions such as $y = (1.02)^t$, $y = (0.97)^t$, $y = (1.01)^{12t}$, $y = (1.2)^{t/10}$, and classify them as representing exponential growth or decay.*
- MA.8.c. Translate between different representations of functions and relations: graphs, equations, point sets, and tables.
9. Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions). *For example, given a graph of one quadratic function and an algebraic expression for another, say which has the larger maximum.*

⁵ Limit to interpreting linear, quadratic, and exponential functions.

⁷ In Enhanced Algebra I, only linear, exponential, quadratic, polynomial, absolute value, step, and piecewise functions are included in this cluster.

⁸ Graphing square root and cube root functions is included in Enhanced Algebra II.

Building Functions⁹**F.BF****Build a function that models a relationship between two quantities.**

1. Write a function that describes a relationship between two quantities. ★
 - a. Determine an explicit expression, a recursive process, or steps for calculation from a context. ★
 - b. 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.* ★
2. Write arithmetic and geometric sequences both recursively and with an explicit formula, use them to model situations, and translate between the two forms. ★

Build new functions from existing functions.

3. Identify the effect on the graph of replacing $f(x)$ by $f(x) + k$, $k f(x)$, $f(kx)$, 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.*
4. Find inverse functions.
 - a. 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, $f(x) = 2x^3$ or $f(x) = (x+1)/(x-1)$ for $x \neq 1$.*

Linear, Quadratic, and Exponential Models**F.LE****Construct and compare linear, quadratic, and exponential models and solve problems.**

1. Distinguish between situations that can be modeled with linear functions and with exponential functions. ★
 - a. Prove that linear functions grow by equal differences over equal intervals, and that exponential functions grow by equal factors over equal intervals. ★
 - b. Recognize situations in which one quantity changes at a constant rate per unit interval relative to another. ★
 - c. Recognize situations in which a quantity grows or decays by a constant percent rate per unit interval relative to another. ★
2. Construct linear and exponential functions, including arithmetic and geometric sequences, given a graph, a description of a relationship, or two input-output pairs (include reading these from a table). ★
3. Observe using graphs and tables that a quantity increasing exponentially eventually exceeds a quantity increasing linearly, quadratically, or (more generally) as a polynomial function. ★

Interpret expressions for functions in terms of the situation they model.

5. Interpret the parameters in a linear or exponential¹⁰ function in terms of a context. ★

Statistics and Probability**Interpreting Categorical and Quantitative Data****S.ID****Summarize, represent, and interpret data on a single count or measurement variable.**

1. Represent data with plots on the real number line (dot plots, histograms, and box plots). ★
2. Use statistics appropriate to the shape of the data distribution to compare center (median, mean) and spread (interquartile range, standard deviation) of two or more different data sets. ★
3. Interpret differences in shape, center, and spread in the context of the data sets, accounting for possible effects of extreme data points (outliers). ★

⁹ Functions are limited to linear, quadratic, and exponential in Algebra I.

¹⁰ Limit exponential function to the form $f(x) = b^x + k$.

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.★¹¹

Summarize, represent, and interpret data on two categorical and quantitative variables.¹²

5. Summarize categorical data for two categories in two-way frequency tables. Interpret relative frequencies in the context of the data (including joint, marginal, and conditional relative frequencies). Recognize possible associations and trends in the data. ★
6. Represent data on two quantitative variables on a scatter plot, and describe how the variables are related. ★
 - a. Fit a function to the data; use functions fitted to data to solve problems in the context of the data. *Uses given functions or choose a function suggested by the context. Emphasize linear, quadratic, and exponential models.* ★
 - b. Informally assess the fit of a function by plotting and analyzing residuals. ★
 - c. Fit a linear function for a scatter plot that suggests a linear association. ★

Interpret linear models. ★

7. Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data. ★
8. Compute (using technology) and interpret the correlation coefficient of a linear fit. ★
9. Distinguish between correlation and causation.★

¹¹ Introduce in Algebra I; expand in Algebra II.

¹² Linear focus; discuss as a general principle in Algebra I.

Additional Standards:

The Enhanced Geometry course is the same as the Model Geometry course with the exception of two additional standards (both (+)) from the Geometry conceptual category.

Expressing Geometric Properties with Equations

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

G.GPE.3, MA.3a These standards extend analytic geometry concepts to hyperbolas and ellipses.

Standards Removed:

The Model Geometry course contains eleven standards from the Statistics and Probability conceptual category. For the purpose of creating an Enhanced High School Pathway to Calculus, four standards have been removed from the Enhanced Geometry course. If time permits these standards could be included, but these topics typically are not pre-requisites for Calculus.

Conditional Probability and the Rules of Probability

Use the rules of probability to compute probabilities of compound events in a uniform probability model.

S.CP.8(+),9(+)
These standards introduce the Multiplication Rule and the use of permutations and combinations to compute probabilities.

Using probability to Make Decisions

Use probability to evaluate outcomes or decisions.

S.MD.6(+),7(+)
These standards apply probability concepts to decision making situations

Note:

In the list of standards that follow, please note that ***larger italicized bold text*** refers to standards ***added to Enhanced Algebra I***.

Content Standards

Number and Quantity Quantities

N.Q

Reason quantitatively and use units to solve problems.★

2. Define appropriate quantities for the purpose of descriptive modeling. ★
3. Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.★
 - MA.3.a. Describe the effects of approximate error in measurement and rounding on measurements and on computed values from measurements. Identify significant figures in recorded measures and computed values based on the context given and the precision of the tools used to measure. ★

GEOMETRY

Congruence

G.CO

Experiment with transformations in the plane.

1. Know precise definitions of angle, circle, perpendicular line, parallel line, and line segment, based on the undefined notions of point, line, distance along a line, and distance around a circular arc.
2. Represent transformations in the plane using, e.g., transparencies and geometry software; describe transformations as functions that take points in the plane as inputs and give other points as outputs. Compare transformations that preserve distance and angle to those that do not (e.g., translation versus horizontal stretch).
3. Given a rectangle, parallelogram, trapezoid, or regular polygon, describe the rotations and reflections that carry it onto itself.
4. Develop definitions of rotations, reflections, and translations in terms of angles, circles, perpendicular lines, parallel lines, and line segments.
5. Given a geometric figure and a rotation, reflection, or translation, draw the transformed figure using, e.g., graph paper, tracing paper, or geometry software. Specify a sequence of transformations that will carry a given figure onto another.

Understand congruence in terms of rigid motions.

6. Use geometric descriptions of rigid motions to transform figures and to predict the effect of a given rigid motion on a given figure; given two figures, use the definition of congruence in terms of rigid motions to decide if they are congruent.
7. Use the definition of congruence in terms of rigid motions to show that two triangles are congruent if and only if corresponding pairs of sides and corresponding pairs of angles are congruent.
8. Explain how the criteria for triangle congruence (ASA, SAS, and SSS) follow from the definition of congruence in terms of rigid motions.

Prove geometric theorems.¹³

9. Prove theorems about lines and angles. *Theorems include: vertical angles are congruent; when a transversal crosses parallel lines, alternate interior angles are congruent and corresponding angles are congruent; points on a perpendicular bisector of a line segment are exactly those equidistant from the segment's endpoints.*
10. Prove theorems about triangles. *Theorems include: measures of interior angles of a triangle sum to 180° ; base angles of isosceles triangles are congruent; the segment joining midpoints of two sides of a triangle is parallel to the third side and half the length; the medians of a triangle meet at a point.*
11. Prove theorems about parallelograms. *Theorems include: opposite sides are congruent, opposite angles are congruent, the diagonals of a parallelogram bisect each other, and conversely, rectangles are parallelograms with congruent diagonals.*

¹³ Proving the converse of theorems should be included when appropriate.

MA.11.a. Prove theorems about polygons. Theorems include: measures of interior and exterior angles, properties of inscribed polygons.

Make geometric constructions.

12. Make formal geometric constructions with a variety of tools and methods (compass and straightedge, string, reflective devices, paper folding, dynamic geometric software, etc.). *Copying a segment; copying an angle; bisecting a segment; bisecting an angle; constructing perpendicular lines, including the perpendicular bisector of a line segment; and constructing a line parallel to a given line through a point not on the line.*
13. Construct an equilateral triangle, a square, and a regular hexagon inscribed in a circle.

Similarity, Right Triangles, and Trigonometry

G.SRT

Understand similarity in terms of similarity transformations.

1. Verify experimentally the properties of dilations given by a center and a scale factor:
 - a. A dilation takes a line not passing through the center of the dilation to a parallel line, and leaves a line passing through the center unchanged.
 - b. The dilation of a line segment is longer or shorter in the ratio given by the scale factor.
2. Given two figures, use the definition of similarity in terms of similarity transformations to decide if they are similar; explain using similarity transformations the meaning of similarity for triangles as the equality of all corresponding pairs of angles and the proportionality of all corresponding pairs of sides.
3. Use the properties of similarity transformations to establish the Angle-Angle (AA) criterion for two triangles to be similar.

Prove theorems involving similarity.

4. Prove theorems about triangles. *Theorems include: a line parallel to one side of a triangle divides the other two proportionally, and conversely; the Pythagorean Theorem proved using triangle similarity.*
5. Use congruence and similarity criteria for triangles to solve problems and to prove relationships in geometric figures.

Define trigonometric ratios and solve problems involving right triangles.

6. Understand that by similarity, side ratios in right triangles are properties of the angles in the triangle, leading to definitions of trigonometric ratios for acute angles.
7. Explain and use the relationship between the sine and cosine of complementary angles.
8. Use trigonometric ratios and the Pythagorean Theorem to solve right triangles in applied problems.★

Apply trigonometry to general triangles.

9. (+) Derive the formula $A = \frac{1}{2} ab \sin(C)$ 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).

Circles

G.C

Understand and apply theorems about circles.

1. Prove that all circles are similar.
2. Identify and describe relationships among inscribed angles, radii, and chords. *Include the relationship between central, inscribed, and circumscribed angles; inscribed angles on a diameter are right angles; the radius of a circle is perpendicular to the tangent where the radius intersects the circle.*
3. Construct the inscribed and circumscribed circles of a triangle, and prove properties of angles for a quadrilateral inscribed in a circle.

MA.3.a. Derive the formula for the relationship between the number of sides and sums of the interior and sums of the exterior angles of polygons and apply to the solutions of mathematical and contextual problems.

4. (+) Construct a tangent line from a point outside a given circle to the circle.

Find arc lengths and areas of sectors of circles.

5. Derive using similarity the fact that the length of the arc intercepted by an angle is proportional to the radius, and define the radian measure of the angle as the constant of proportionality; derive the formula for the area of a sector.

Expressing Geometric Properties with Equations

G.GPE

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

1. Derive the equation of a circle of given center and radius using the Pythagorean Theorem; complete the square to find the center and radius of a circle given by an equation.
2. Derive the equation of a parabola given a focus and directrix.
3. (+) *Derive the equations of ellipses and hyperbolas given the foci, using the fact that the sum or difference of distances from the foci is constant.*

MA.3a (+) Use equations and graphs of conic sections to model real-world problems.

Use coordinates to prove simple geometric theorems algebraically.

4. Use coordinates to prove simple geometric theorems algebraically. *For example, prove or disprove that a figure defined by four given points in the coordinate plane is a rectangle; prove or disprove that the point $(1, \sqrt{3})$ lies on the circle centered at the origin and containing the point $(0, 2)$.*
5. Prove the slope criteria for parallel and perpendicular lines and use them to solve geometric problems (e.g., find the equation of a line parallel or perpendicular to a given line that passes through a given point).
6. Find the point on a directed line segment between two given points that partitions the segment in a given ratio.
7. Use coordinates to compute perimeters of polygons and areas of triangles and rectangles, e.g., using the distance formula.★

Geometric Measurement and Dimension

G.GMD

Explain volume formulas and use them to solve problems.

1. Give an informal argument for the formulas for the circumference of a circle, area of a circle, volume of a cylinder, pyramid, and cone. *Use dissection arguments, Cavalieri's principle, and informal limit arguments.*
2. (+) Give an informal argument using Cavalieri's principle for the formulas for the volume of a sphere and other solid figures.
3. Use volume formulas¹⁴ for cylinders, pyramids, cones, and spheres to solve problems. ★

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). ★

MA.4. Use dimensional analysis for unit conversions to confirm that expressions and equations make sense. ★

¹⁴ Note: The 2011 Massachusetts grade 8 mathematics standards require that students know volume formulas for cylinders, cones, and spheres.

Statistics and Probability**Conditional Probability and the Rules of Probability****S-CP****Understand independence and conditional probability and use them to interpret data.¹⁵**

1. Describe events as subsets of a sample space (the set of outcomes) using characteristics (or categories) of the outcomes, or as unions, intersections, or complements of other events (“or,” “and,” “not”). ★
2. Understand that two events A and B are independent if the probability of A and B occurring together is the product of their probabilities, and use this characterization to determine if they are independent. ★
3. Understand the conditional probability of A given B as $P(A \text{ and } B)/P(B)$, and interpret independence of A and B as saying that the conditional probability of A given B is the same as the probability of A , and the conditional probability of B given A is the same as the probability of B . ★
4. Construct and interpret two-way frequency tables of data when two categories are associated with each object being classified. Use the two-way table as a sample space to decide if events are independent and to approximate conditional probabilities. *For example, collect data from a random sample of students in your school on their favorite subject among math, science, and English. Estimate the probability that a randomly selected student from your school will favor science given that the student is in tenth grade. Do the same for other subjects and compare the results.* ★
5. Recognize and explain the concepts of conditional probability and independence in everyday language and everyday situations. *For example, compare the chance of having lung cancer if you are a smoker with the chance of being a smoker if you have lung cancer.* ★

Use the rules of probability to compute probabilities of compound events in a uniform probability model.¹⁶

6. Find the conditional probability of A given B as the fraction of B 's outcomes that also belong to A , and interpret the answer in terms of the model. ★
7. Apply the Addition Rule, $P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$, and interpret the answer in terms of the model. ★

¹⁵ Link to data from simulations or experiments.

¹⁶ Introductory only.

Additional Standards:

Several standards in the Model Algebra II course were moved to the Enhanced Algebra I course which made it possible to add standards from the Model Pre-calculus Course to the Enhanced Algebra II course. In this way students will be prepared for Calculus after successful completion of Enhanced Algebra II.

Number and Quantity*Complex Number System*

N-CN.3, 4, 5, 6 These standards extend the study of complex numbers begun in Enhanced Algebra I.

Algebra*Reasoning with Equations and Inequalities*

A.REI.8, 9 These standards use matrices to solve systems of linear equations.

Functions*Interpreting Functions*

F.IF.7d This standard extends the work of rational functions to graphing and identifying zeros and asymptotes.

F.IF.MA.10 This standard contains content appropriate for Algebra II coursework

Building Functions

F.BF.1c, 4b, 4c, 4d, 5 These standards extend the work of creating new functions from existing functions that was begun in Enhanced Algebra I.

Trigonometric Functions

F.TF.3, 4, 6, 7, and 9 These standards extend the study of trigonometry to include: the unit circle, proving trigonometric identities, modeling periodic behavior, solving and graphing trigonometric equations.

Standards Removed:

The Model Algebra II course contains several standards from the Statistics and Probability conceptual category. For the purpose of creating an Enhanced High School Pathway to Calculus, two of these standards have not been included in the Enhanced Algebra II course. All of the Vector and Matrix Quantity standards have also been removed. If time permits these standards could be included in the Enhanced Algebra II course, but these topics typically are not pre-requisites for Calculus.

Using Probability to Make Decisions*Use probability to evaluate outcomes or decisions.*

S.MD.6(+), 7(+) These standards apply probability concepts to decision making situations.

Number and Quantity*Vector and matrix quantities.*

N.CN.1(+), 3(+), 6(+), 8(+), 12 (+) These standards are about vectors and matrices.

Note:

In the list of standards that follow, please note that *larger italicized bold text* refers to standards *added to Enhanced Algebra I*.

Number and Quantity

The Complex Number System

N.CN

Perform arithmetic operations with complex numbers.

3. (+) *Find the conjugate of a complex number; use conjugates to find moduli and quotients of complex numbers.*

Represent complex numbers and their operations on the complex plane.

4. (+) *Represent complex numbers on the complex plane in rectangular and polar form (including real and imaginary numbers), and explain why the rectangular and polar forms of a given complex number represent the same number.*
5. (+) *Represent addition, subtraction, multiplication, and conjugation of complex numbers geometrically on the complex plane; use properties of this representation for computation. For example, $(-1 + \sqrt{3}i)^3 = 8$ because $(-1 + \sqrt{3}i)$ has modulus 2 and argument 120° .*
6. (+) *Calculate the distance between numbers in the complex plane as the modulus of the difference, and the midpoint of a segment as the average of the numbers at its endpoints.*

Algebra

Arithmetic with Polynomials and Rational Expressions

A.APR

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.¹⁷

Rewrite rational expressions.

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

1. Create equations and inequalities in one variable and use them to solve problems. *Include equations arising from linear and quadratic functions, and simple rational and exponential functions.* ★
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.* ★

¹⁷ The Binomial Theorem can be proved by mathematical induction or by a combinatorial argument.

Reasoning with Equations and Inequalities**A.REI****Understand solving equations as a process of reasoning and explain the reasoning.**

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

Solve systems of equations.

8. (+) *Represent a system of linear equations as a single matrix equation in a vector variable.*
9. (+) *Find the inverse of a matrix if it exists and use it to solve systems of linear equations (using technology for matrices of dimension 3×3 or greater).*

Represent and solve equations and inequalities graphically.

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.**

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. *For example, if the function $h(n)$ gives the number of person-hours it takes to assemble n engines in a factory, then the positive integers would be an appropriate domain for the function.* ★
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.

7. Graph functions expressed symbolically and show key features of the graph, by hand in simple cases and using technology for more complicated cases. ★
 - b. Graph square root, cube root, and piecewise-defined functions, including step functions and absolute value functions. ★
 - c. Graph polynomial functions, identifying zeros when suitable factorizations are available, and showing end behavior.
 - d. (+) *Graph rational functions, identifying zeros and asymptotes when suitable factorizations are available, and showing end behavior.* ★
 - e. 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.

MA.8c. Translate between different representations of functions and relations: graphs, equations, point sets, and tables.

9. Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions). *For example, given a graph of one quadratic function and an algebraic expression for another, say which has the larger maximum.*
- 10.MA.10. Given algebraic, numeric and/or graphical representations of functions, recognize the function as polynomial, rational, logarithmic, exponential, or trigonometric.**

Building Functions**F.BF****Build a function that models a relationship between two quantities.**

1. Write a function that describes a relationship between two quantities. ★
 - b. 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.* ★
 - c. (+) **Compose functions.** *For example, if $T(y)$ is the temperature in the atmosphere as a function of height, and $h(t)$ is the height of a weather balloon as a function of time, then $T(h(t))$ is the temperature at the location of the weather balloon as a function of time.* ★

Build new functions from existing functions.

3. Identify the effect on the graph of replacing $f(x)$ by $f(x) + k$, $k f(x)$, $f(kx)$, 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.*
4. Find inverse functions.
 - a. 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, $f(x) = 2x^3$ or $f(x) = (x+1)/(x-1)$ for $x \neq 1$.*
 - b. (+) **Verify by composition that one function is the inverse of another.**
 - c. (+) **Read values of an inverse function from a graph or a table, given that the function has an inverse.**
 - d. (+) **Produce an invertible function from a non-invertible function by restricting the domain.**
5. (+) **Understand the inverse relationship between exponents and logarithms and use this relationship to solve problems involving logarithms and exponents.**

Linear, Quadratic, and Exponential Models**F.LE****Construct and compare linear, quadratic, and exponential models and solve problems. ★**

4. 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. ★

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.
3. (+) **Use special triangles to determine geometrically the values of sine, cosine, tangent for $\pi/3$, $\pi/4$ and $\pi/6$, and use the unit circle to express the values of sine, cosine, and tangent for $\pi-x$, $\pi+x$, and $2\pi-x$ in terms of their values for x , where x is any real number.**

4. (+) *Use the unit circle to explain symmetry (odd and even) and periodicity of trigonometric functions.*

Model periodic phenomena with trigonometric functions.

5. Choose trigonometric functions to model periodic phenomena with specified amplitude, frequency, and midline. ★
6. (+) *Understand that restricting a trigonometric function to a domain on which it is always increasing or always decreasing allows its inverse to be constructed.*
7. (+) *Use inverse functions to solve trigonometric equations that arise in modeling contexts; evaluate the solutions using technology, and interpret them in terms of the context.* ★

Prove and apply trigonometric identities.

8. Prove the Pythagorean identity $\sin^2(\theta) + \cos^2(\theta) = 1$ and use it find $\sin(\theta)$, $\cos(\theta)$, or $\tan(\theta)$ given $\sin(\theta)$, $\cos(\theta)$, or $\tan(\theta)$ and the quadrant.
9. (+) *Prove the addition and subtraction formulas for sine, cosine, and tangent and use them to solve problems.*

Statistics and Probability

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. ★