Unit 2: 2D Kinematics
UNIT PLAN

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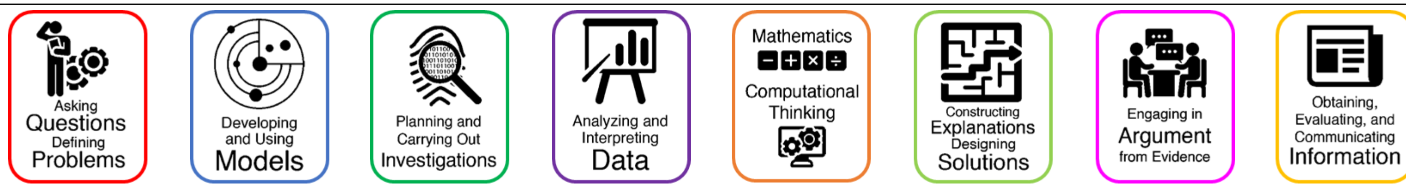
UNIT NARRATIVE
This unit is a natural scaffold from Unit 1 because it requires all of the same concepts and equations that must be applied to scenarios where there are two simultaneous 1D motions happening, which is how we make 2D motion mathematically simple enough to be predicted with simple algebra for introductory physics. Students the part of the unit by drawing the horizontal and perpendicular components of angled vectors on graph paper so that they can observe how two 1D vectors can be equivalent to a 2D angled vector. Then students will apply this to the familiar scenario of comparing distance and displacement but this time for 2D motion which gives them more practice with the concepts and math around 2D vectors before moving on to more complicated scenarios with 2D velocity. In this course **students will not be required to resolve vectors into components mathematically** (all angled vectors the components will be given or able to be determined graphically) but it is important that students develop a conceptual understanding about how the angle of a vector changes the relative magnitudes of its components. Next students will be introduced to 2D velocity with a virtual simulation of a riverboat crossing a river. This is introduced before projectile motion because this 2D motion scenario is constant velocity in both the vertical and horizontal directions and in the simulation the two velocities are fully controllable and easy to observe , making this scenario a scaffold toward more complex projectile motion. Students will conduct an investigation to experimentally determine the variable relationships that define the time to cross the river and the downstream displacement while crossing and then explore how these relationships can be derived from the average velocity equation for the horizontal and vertical directions. Students will be exposed to a new variable relationship and variables that are indirectly related, which helps prepare them for projectile motion because of similar relationships. Students will also spend a couple of days working in small groups to make qualitative and quantitative predictions based on these variable relationships and the two components of the riverboat's velocity. Students will build conceptual understanding by making claims, supporting them with evidence from the scenarios and reasoning from physics principles and peer discussion. The riverboat simulation also allows students to check their predictions which gives them instant feedback about their predictions to allow their learning to be more self-guided. Next students will explore horizontal projectile motion starting by analyzing slow motion video data of horizontal projectiles to determine the type of motion for both the horizontal and vertical directions. Next students will use a PhET simulation to experimentally determine the variable relationships that define the time of flight and range of horizontal projectile. Students will then make claims supported by evidence and physics reasoning about horizontal projectile motion. Both the progression of lessons and the content is very similar to the riverboat scenario and simulation progression to help students tackle increasing more complex scenarios. This part of the unit culminates with a Horizontal Projectile Challenge which challenges students working in small groups to predict the range of a marble rolling off a classroom table as a horizontal projectile. This is appropriately called a Challenge because it will be difficult for students to make all the measures with

precision and make the correct calculations to make an accurate prediction. These types of challenges can be fun for students and provide a lot of opportunity for discussion about the physics required to make the correct prediction.

In the final part of this unit students will explore angled projectile motion using the same PhET simulation and a very similar arc of learning so that the routine stays mostly the same while the content becomes more difficult. The first lesson students will use the simulation to conduct lab investigation in the relationships and characteristics of angled projectile motion. Then students will work in small groups to make and discuss qualitative predictions with justification and finally to make and discuss quantitative claims with justification. By the end of this unit we expect that students have a thorough understanding about how to analyze and make predictions about angled projectile motion which requires all of the physics equations and concepts from Units 1 & 2.

Focus on Disciplinary Literacy

In science, disciplinary literacy is synonymous with the science and engineering practices. The SEPs are the context through which all science concepts should be taught. In the lessons, you will find the Science and Engineering practices icons when the SEPs are being explicitly used by students.



Physics Teams Join Link: This Teams is essential for teachers and contains both district resources and Physics Course Leaders and Team contributions. All webinars and training will be hosted in meetings in the channels of this Team and teachers will need to join to appreciate the full support and hard work the Course Leaders put in to help support the Physics teacher family.

CONTENT STANDARDS

TEKS Standards

Standard ID	Standard Description
C.5	The student knows and applies the laws governing motion in a variety of situations. The student is expected to:
C.5.A	analyze different types of motion by generating and interpreting position versus time, velocity versus time, and acceleration versus time using hand graphing and real-time technology such as motion detectors, photogates, or digital applications;
C.5.B	define scalar and vector quantities related to one- and two-dimensional motion and combine vectors using both graphical vector addition and the Pythagorean theorem;
C.5.C	describe and analyze motion in one dimension using equations with the concepts of distance, displacement, speed, velocity, frames of reference, and acceleration;
C.5.D	describe and analyze acceleration ~~in uniform circular~~ and horizontal projectile motion in two dimensions using equations;

College Board AP Physics Standards

only the green standards are tested in this unit but others are supporting standards

Learning Objective				Essential Knowledge	
Topic #	**Topic**	**LO #**	**Learning Objective**	**EK #**	**Essential Knowledge**
1.1	**Scalars and Vectors in One Dimension**	1.1.A	Describe a scalar or vector quantity using magnitude and direction, as appropriate.	1.1.A.1	Scalars are quantities described by magnitude only; vectors are quantities described by both magnitude and direction.
				1.1.A.2	Vectors can be visually modeled as arrows with appropriate direction and lengths proportional to their magnitude.
				1.1.A.3	Distance and speed are examples of scalar quantities, while position, displacement, velocity, and acceleration are examples of vector quantities. i. Vectors are notated with an arrow above the symbol for that quantity. **Relevant Equation -->** $\boldsymbol{v = v_0 + at}$ ii. Vector notation is not required for vector components along an axis. In one dimension, the sign of the component completely describes the direction of that component. **Derived Equation -->** $\boldsymbol{v_x = v_{x0} + a_x t}$
		1.1.b	Describe a vector sum in one dimension.	1.1.B.1	When determining a vector sum in a given one-dimensional coordinate system, opposite directions are denoted by opposite signs.
1.2	**Displacement, Velocity, and Acceleration**	1.2.A	Describe a change in an object's position.	1.2.A.1	When using the object model, the size, shape, and internal configuration are ignored. The object may be treated as a single point with extensive properties such as mass and charge.

				1.2.A.2	Displacement is the change in an object's position. **Relevant Equation -->** $\Delta x = x - x_0$
		1.2.B	Describe the average velocity and acceleration of an object.	1.2.B.1	Averages of velocity and acceleration are calculated considering the initial and final states of an object over an interval of time.
				1.2.B.2	Average velocity is the displacement of an object divided by the interval of time in which that displacement occurs. **Relevant Equation -->** $v_{avg} = \frac{\Delta x}{\Delta t}$
				1.2.B.3	Average acceleration is the change in velocity divided by the interval of time in which that change in velocity occurs. **Relevant Equation -->**$a_{avg} = \frac{\Delta v}{\Delta t}$
				1.2.B.4	An object is accelerating if the magnitude and/or direction of the object's velocity are changing.
				1.2.B.5	Calculating average velocity or average acceleration over a very small time-interval yields a value that is very close to the instantaneous velocity or instantaneous acceleration.
1.3	**Representing Motion**	1.3.A	Describe the position, velocity, and acceleration of an object using representations of that object's motion.	1.3.A.1	Motion can be represented by motion diagrams, figures, graphs, equations, and narrative descriptions.
				1.3.A.2	For constant acceleration, three kinematic equations can be used to describe instantaneous linear motion in one dimension. **THREE KINEMATIC EQUATIONS -->** $v_x = v_{x0}a_xt$ $x = x_0 + v_{x0}t + \frac{1}{2}at^2$ $v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$
				1.3.A.3	Near the surface of Earth, the vertical acceleration caused by the force of gravity is downward, constant, and has a measured value approximately equal to **g = 10 m/s^2**
				1.3.A.4	Graphs of position, velocity, and acceleration as functions of time can be used to find the relationships between those quantities. i. An object's instantaneous velocity is the rate of change of the object's position, which is equal to the slope of a line tangent to a point on a graph of the object's position as a function of time. ii. An object's instantaneous acceleration is the rate of change of the object's velocity, which is equal to the slope of a line tangent to a point on a graph of the object's velocity as a function of time. iii. The displacement of an object during a time interval is equal to the area under the curve of a graph of the object's velocity as a function of time (i.e., the area bounded by the function and the horizontal axis for the appropriate interval). iv. The change in velocity of an object during a time interval is equal to the area under the curve of a graph of the acceleration of the object as a function of time.

		BOUNDARY STATEMENT: AP Physics 1 does not expect students to quantitatively analyze nonuniform acceleration. However, students will be expected to be able to qualitatively analyze, sketch appropriate graphs of, and discuss situations in which acceleration is nonuniform. **BOUNDARY STATEMENT:** For all situations in which a numerical quantity is required for g, the value g = 10 m/s^2 will be used. However, students will not be penalized for correctly using the more precise commonly accepted values of **g = 9.8 or 9.81 m/s^2**			
1.4	**Reference Frames and Relative Motion**	1.4.A	Describe the reference frame of a given observer.	1.4.A.1	The choice of reference frame will determine the direction and magnitude of quantities measured by an observer in that reference frame.
		1.4.B	Describe the motion of objects as measured by observers in different inertial reference frames.	~~1.4.B.1~~	~~Measurements from a given reference frame may be converted to measurements from another reference frame.~~
				1.4.B.2	The observed velocity of an object results from the combination of the object's velocity and the velocity of the observer's reference frame. i. Combining the motion of an object and the motion of an observer in a given reference frame involves the addition or subtraction of vectors. ii. The acceleration of any object is the same as measured from all inertial reference frames.
		BOUNDARY STATEMENT: *Unless otherwise stated, the frame of reference of any problem may be assumed to be inertial.* *Adding or subtracting vectors to find relative velocities is restricted to motion along one dimension for AP Physics 1.*			
1.5	**Vectors and Motion in Two Dimensions**	1.5.A	Describe the perpendicular components of a vector.	1.5.A.1	Vectors can be mathematically modeled as the resultant of two perpendicular components.
				1.5.A.2	Vectors can be resolved into components using a chosen coordinate system.
				~~1.5.A.3~~	~~Vectors can be resolved into perpendicular components using trigonometric functions and relationships.~~
		1.5.B	Describe the motion of an object moving in two dimensions.	1.5.B1	Motion in two dimensions can be analyzed using one-dimensional kinematic relationships if the motion is separated into components.
				1.5.B.2	Projectile motion is a special case of two-dimensional motion that has zero acceleration in one dimension and constant, nonzero acceleration in the second dimension.

UNDERSTANDINGS AND QUESTIONS

Important big ideas and processes for the unit.

Key Understandings

- ❑ Vectors are quantities that require both a magnitude and direction to be fully described.
- ❑ For 2-dimensional motion the direction is indicated as positive (+) or negative (-) in either the vertical or horizontal plane.
- ❑ For convenience we will typically consider motion to the right/up as positive and motion to the left/down as negative.
- ❑ The sum of the square of the horizontal vector and the square of the vertical vectors is equal to the square of the angled vector (resultant)
- ❑ When the three vectors are connected head to tail this is vector addition and the answer for vector addition is called a resultant vector.
- ❑ Vectors MUST be added head-to-tail ⍰ compared to following a treasure map, each vector MUST start where the previous vector ends.
- ❑ For 2-dimensional motion the direction is indicated as positive (+) or negative (-) for the horizontal and vertical plane.
- ❑ For convenience we will typically consider motion to the right/up as positive and motion to the left/down as negative.
- ❑ 2D vectors at a 45-degree angle have equal magnitude components. As the angle of a 2D vector increases, y-component increases and the x-component decreases in magnitude, and vice versa.
- ❑ Distance is a scalar measurement (does not need/include direction) of total amount traveled.
- ❑ Displacement is a vector measurement of distance that is equal to the final position minus the initial position.
- ❑ The total velocity and displacement of the boat crossing the river are 2D vectors and can be calculated from the horizontal and vertical vector components using Pythagorean Theorem
- ❑ River current speed has no effect on the crossing time because perpendicular factors have no direct effect on each other
- ❑ Boat speed does indirectly change the downstream displacement (even though they are perpendicular because it changes the crossing time and crossing time effects both directions
- ❑ River current is proportional to downstream displacement
- ❑ Boat speed is inversely proportional to crossing time and crossing time is proportional to downstream displacement
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- ❑ Horizontal projectiles have an initial y-velocity of zero
- ❑ x-velocity is constant for horizontal projectiles
- ❑ y-velocity is constant acceleration for horizontal projectiles (acceleration of gravity, little *g*)
- ❑ Time of flight is related to initial height only
- ❑ Time of flight has a square root relation with height (or height has a square relation with time of flight)
- ❑ Range has proportional relationship with initial velocity and time of flight
- ❑ Angled projectile motion has nonzero initial x-velocity **and y-velocity**

- ❑ x-velocity is constant for angled projectile motion (zero acceleration)
- ❑ y-velocity is constant acceleration for angled projectile motion (acceleration of gravity, little *g*)
- ❑ x-velocity is constant for angled projectile motion (zero acceleration)
- ❑ y-velocity is constant acceleration for angled projectile motion (acceleration of gravity, little *g*)
- ❑ Angled projectile motion horizontal and vertical velocities have no effect on each other.
- ❑ Time of flight depends on initial y-velocity only (for angled projectile over level surface)
- ❑ For angled projectile an angle of 45 degrees creates the largest range
- ❑ For an angled projectile an angle of 90 degrees creates the largest time of flight

Key Questions

- ❑ How can we work with 2D vectors without complicated math?
- ❑ How can we determine the type of horizontal motion for a 2D motion scenario?
- ❑ How can we determine the type of vertical motion for a 2D motion scenario?
- ❑ How can we predict the crossing time for a riverboat?
- ❑ How can we predict the downstream displacement during a riverboat crossing?
- ❑ Describe the magnitude and direction of the riverboat velocity components that will allow the riverboat to make a perfectly horizontal crossing.
- ❑ Compare the motion of a horizontal projectile to an object dropped from rest.
- ❑ How can we predict the time of flight for a horizontal projectile?
- ❑ How does the angle of launch for an angled projectile affect the initial velocity components?
- ❑ How can we predict the range for a horizontal projectile?
- ❑ How can we predict the time of flight for a angled projectile?
- ❑ How can we predict the range for a angled projectile?
- ❑ How can we predict the maximum height of an angled projectile?

VERTICAL STANDARDS

This section details the **progression** of key student expectations/standards** in the courses **before** and **after** this course. This will help you understand what **prior knowledge skills to build upon** and guide you in knowing what **skills you are preparing your students** for in the subsequent course.

5th Grade Science	6/7 Grade Hybrid Science	8th Grade Science
5.7A investigate and explain how equal and unequal forces acting on an object cause patterns of motion and transfer of energy; and	7.7A calculate average speed using distance and time measurements from investigations; 7.7B distinguish between speed and velocity in linear motion in terms of distance, displacement, and direction; 7.7C measure, record, and interpret an object's motion using distance-time graphs; and	8.7A calculate and analyze how the acceleration of an object is dependent upon the net force acting on the object and the mass of the object using Newton's Second Law of Motion; and

VOCABULARY GLOSSARY

Domain-specific words and definitions for this unit.

Key Content Vocabulary

Projectile Motion – free fall motion that is released with an initial horizontal component of velocity that is non-zero
Vector Components – the two perpendicular vectors (usually horizontal and vertical) that when added together equal the original angled vector
Resultant Vector – the resulting vector from the addition of two or more vectors
X-component – the horizontal component of an angled vector
Y-component – the vertical component of an angled vector
Vector Resolution – the process of calculating the perpendicular component vectors for an angled vector
Trajectory – the flight path of a projectile

Scalar – a quantity that can be measured/described with a magnitude only (without a direction)
Vector – a quantity that requires both a magnitude and direction to be properly measured/described
Distance – a scalar measure of the distance an object travels (meters)
Displacement – a vector measure of the distance and object travels (the vector distance between the starting position and the end position of an object, meters)
Speed – a scalar measure of how far an object travels per unit of time (meters/second)
Velocity – a vector measure of how far an object travels per unit of time (meters/second)
Acceleration – a vector measure of how the velocity of an object changes per unit of time (meters/second/second)
Motion diagram – any diagram that represents the relative motion of objects using arrows or other visual symbols
Dot diagram – a motion diagram that shows a dot that represents the position of an object at specific, consistent intervals of time, often 1 sec
Position-Time graph – graph describing the motion of an object with time on the horizontal axis and position on the vertical axis
Velocity-Time graph – graph describing the motion of an object with time on the horizontal axis and velocity on the vertical axis
Free Fall – Constant acceleration motion that is the result of the force of gravity only (one dimensional)

Related Vocabulary

Constant velocity Constant acceleration Slowing down Speeding up	Parabolic motion Horizontal component Vertical component	Projectile				