Scaffolded structure of concepts:

Overview: Below shows a progression of physics topics which have been set up as a spiral and scaffolded structure. These topics parallel the topics in the game, and also include other Physics concepts that partner well in the overall scaffolded structure. Also included are the A.I. questions from in the game, which shows how they fall in line with the overall structure.

Driving Range

1. Moving robot targets
    a. Vector introduction (magnitude/direction)–
        i. It will be beneficial to make a comment that when a vector is negative, the magnitude (or value) cannot ever be negative, and it is implying a particular direction based on the original frame of reference.
    b. Velocity introduction (robot targets have movement)–mention a force is initially applied to the ball
2. Scalar vs Vector
    a. A scalar is a numerical value. When comparing to velocity, it is the magnitude of the vector, also called speed.
    b. A vector has both a magnitude and a direction.
3. Velocity vs Speed
    a. Velocity is a vector. It is a speed with a direction. Velocity can change when either (or both) the speed changes or the direction changes.
    b. Speed is the magnitude of the velocity vector. It will always be positive.
4. Inertia—Newton's 1st law of motion
    a. A body in motion stays in motion unless a force acts upon it. Similarly a body a rest stays at rest unless a force is acted upon it.
    b. The golf balls will continue out into space unless acted upon. Similarly the non moving robot targets will stay at rest until acted upon by another object.
5. Scaffold Newton's 3rd law of motion
    a. For every action there is an equal and opposite reaction.
    b. This is observed when the ball strikes a robot target, and both the ball and the robot change their principal flight path.
6. Weightlessness
    a. Weight vs Mass scaffolded intro
    b. In a weightless environment mass is the primary dictating factor, since nothing actually has weight unless you have a 2nd body large enough to cause a pull (such as a planet) to gauge a measurement.
7. Frame of reference
    a. Frame of reference is best coupled with the concept of a negative vector or the negative value on the gravitational acceleration. If the original frame of references uses up as the positive direction, for example, with gravitational acceleration, then downwards would be a negative value.
    b. This is a great opportunity to associate positive and negative values for vectors to a particular direction, which is dictated by how you define the original frame of reference.

Planet 1—No atmosphere, earth gravity

8. What work is
    a. Things are moving
    b. Reference that "work" is being done when things move.
    c. *Optionally, leave this until after the concept energy transfer, or scaffold with a mention of work being done, then reinforce after energy transfer is defined*
9. **Energy transfer, forms of energy—A.I. question #1**
    a. **What provides the energy for the robot to hit the golf ball?**
        i. **<u>Correct answer:</u> *The chemical energy of the battery transfers to the robot as electrical potential energy.***
    b. Forms of energy
        i. Chemical Potential Energy (*battery)*
        ii. Electrical potential energy (inside the robot)
        iii. Kinetic Energy (*impact of ball being hit, movement energy from robot)*
        iv. Gravitational potential energy (*this might serve best as a possible scaffolding concept "mention" until getting to parabolic arc)*
    c. Energy transfer
        i. The sun recharges the battery.
        ii. The batter converts solar energy into chemical potential energy.
        iii. The energy from the battery flows into the robot allowing it to move in the form of electrical potential energy.
        iv. The robot transfers the electrical potential energy into kinetic energy.
        v. The kinetic energy from the robot and club is transferred into kinetic energy in the ball.
10. **Parabolic arc—A.I. question #2 (focusing on club type's effect on the flight path)**
    a. **Which club will hit the ball the farthest on a planet without atmosphere? (assume the same amount of energy is put into the ball for each club)**
        i. **<u>Correct answer:</u> *The wedge (50 degrees)***
    b. This might be a good opportunity to reinforce the concept of Gravity and Gravitational potential energy
    c. Different clubs shoot farther on a planet without an atmosphere.
        i. The wedge hits the farthest with a 50 degree loft angle, since gravity is the only acting force.
        ii. The driver hits the shortest distance (which is different when there is atmosphere, where the driver is ideal).
        iii. The reason behind this is that assuming the same energy input for the swing, and same club velocity, the angle the ball leaves the club determines how far it will go. The angle closest to 45 degrees will achieve the longest time in the air, which translates to traveling the farthest.
        iv. A driver only has a 10 degree loft angle.
11. Energy Transfer—Reinforcement from earlier on.
    a. Gravitation PE --> Kinetic energy
        i. The higher up an object is the more gravitational potential energy it gains. When it begins to descend back down the gravitational potential energy is converted into kinetic energy.
        ii. It is important to note that this is accurate to a certain threshold. The equation for the gravitation force is the following: $G_f = \frac{G_c M_1 M_2}{r^2}$. G_c is the gravitational constant (which won't change value), M_1 M_2 are the masses of the two objects,

and r is the radius between them. This equation implies the farther away something is, the smaller the pull of gravity is between the two objects. With a planet, one of the masses in the numerator is sufficiently large that you need a sufficiently large radius to yield any noticeable difference in gravitational pull. So the height a ball reaches during its flight negligible.

b. Heat— loss of energy when the club impacts the ball. This is the red color on the battery meter.

12. 2nd instance of what work is
    a. *If decided that it would be a better fit here, then "work" can be brought up at the end after energy transfer*
    b. Define work.
        i. If a force is applied to an object, then "work" has been done.
        ii. When work is done a displacement usually occurs, however the two terms are not mutually exclusive because of inertia. In the deep space driving range, once the ball is hit, no work is being done as it travels out into space, even though displacement is occurring.
            a) Displacement definition: The shortest distance from the initial position to the final position.
            b) Different from distance traveled, but in the deep space driving range they will be equal.
        iii. This will scaffold the next planet, since there are more acting forces.

13. Velocity/Acceleration relationship—A.I. question #3

a. What is true about the relationship between the vertical velocity component and acceleration after the golf ball is hit?

i. <u>Correct answer:</u> *When the velocity is changing linearly, the acceleration will be constant.*

b. Velocity: Change in position over time. This is a vector quantity.
    i. Units are distance/time.
c. Acceleration: Change in velocity over time. This is a vector quantity.
    i. Units are distance/(time^2).
d. The derivative of the position graph, a 2nd order equation, will give the velocity graph, and will now be a first order, linear equation.
e. The derivative of the first order equation will give a zero order equation, which will be a horizontal line. This is the acceleration graph.
f. This is an area where a lot of misconceptions arise, so it will be beneficial to spend some time here.
g. Reinforce the fact that both velocity and acceleration are vectors.
h. Reinforce that the velocity at any given moment of time is simply the slope of the tangent line at a particular point to the position graph.
i. Reinforce that the acceleration at any given moment of time is simply the slope of the tangent line at a particular point to the velocity graph.

Planet 2—Changing atmosphere, earth gravity

14. Newton's 3rd law of motion—deeper dive
    a. For every action there is an equal and opposite reaction.

b. Now that there are a number of forces acting on the ball, and the driving range has sufficiently scaffolded Newton's 3rd law by observation, addressing this law will be beneficial.
c. Everything from the air particles colliding with the ball, the bounce, the impact after the swing, to the spin, showcases some level of action/reaction.

15. Force (Newton's 2nd law)
    a. Force = mass x acceleration.
    b. It is important to address that forces only exist if an object that has mass is accelerating.
    c. As soon as the ball is hit by the club, there is an instantaneous force applied, at time zero. After that the ball will only ever be decelerating, since the net force acting on the ball is opposing its direction of travel.
16. Impact
    a. Opportunity to segue into elasticity. Upon impact, the ball noticeably flexes out of its normal shape, less noticeably the club does so too.
17. Elasticity
    a. Elasticity is the tendency for an object to return to its original shape upon a force being applied.
    b. The return to its original shape can add extra "bounce", which will add to the net force.
    c. A good analogy here is the fact that metal bats are used up to the college level for baseball, but in the major leagues wooden bats are used. This is due to the fact that metal has a higher elasticity than wood, and can make the ball go farther and faster. This can be dangerous for the pitchers, and can even seriously injure them.
18. Atmosphere
    a. Volume
        i. How much space something is taking up.
        ii. Segue into density.
    b. Mass
        i. An intrinsic property of matter.
        ii. The measure of how much matter an object has.
        iii. Segue into density.
    c. Density
        i. After defining mass and volume, put them together to make the definition for density. (mass/volume).
        ii. Density is always a tough subject, so a changing atmosphere is a good opportunity to deeper dive into what that actually means.
19. **Forces acting on the golf ball—A.I. question #4**
    a. Of the following, which does not determine the flight path of the ball?
        i. <u>Correct answer:</u> *Velocity*
        ii. It is important to note that velocity is a description of what is occurring, and not a dictating force. This is why it can be said that velocity does not determine the flight path of the ball, but is merely a description of the ball's speed and direction.
    b. Lift
        i. A reactive force that is perpendicular to the relative flow of particles around an object.
    c. Drag
        i. In air, the force acting opposite to the relative motion of an object.
    d. Gravity

i. The natural force that attracts two bodies of mass together.

e. Acceleration
   i. The change in velocity over time, having both a magnitude and a direction.

f. Component vectors
   i. In 2-dimensions, each vector can be broken into two component vectors (x/y plane), where the vector is the resultant of the two when they are added tip to tail.
   ii. In 3-dimensions, there is an extra component vector for the z-plane, for a total of 3.
   iii. It is much easier to approach the concept of component vectors from 2-dimensions first, then scale up to 3-dimensions.

20. Net Force—A.I. question #5

a. From the net force, what can be inferred about the flight of the ball?

i. <u>Correct answer:</u> *If the net force of the ball is not zero, the ball will change its speed and/or direction.*

b. Pick a vector, and then add the rest tip to tail. The resultant vector from the center of mass of the object is the net force.

c. Reinforce the effect that the net force has on the overall motion of the golf ball.

21. Spin—A.I. question #6

a. What does spin cause the ball to do on a planet with atmosphere?

i.* <u>Correct answer:</u> *Spin causes lift and can allow the ball to curve.

b. Dimples reduce drag comparatively to a laminar surface ball.

c. Reduction in drag results in longer time in flight and higher loft.

d. Spin also creates the Magnus effect, which can be analogized to a curve ball. The spin will pull the ball away from its principal flight path.

e. Be cautious referencing the Bernoulli Effect, which explains why lift and drag are caused (faster traveling particles above the ball compared to slower particles below the ball). The Bernoulli Effect and its equations are still under debate as to be the exact cause.

22. Clarifying points/misconceptions (optional)

a. Air friction

b. Energy transfer air/ground (loss)

c. Magnus effect

d. Velocity/Acceleration/position

Planet 3—Static atmosphere, changing gravity

23. Gravity focus

a. Revisit and define gravity, and if capable bring up the Gravitational force equation.

24. Potential energy reinforcement—A.I. question #7

a. When does the golf ball reach its maximum amount of potential energy?

i. <u>Correct answer:</u> *At the highest point of its flight path.*

b. The higher up the golf ball is during its flight, the higher the potential energy is. The equation for potential energy is $PE = mgh$. Where m is mass, g is gravitational force, and h is height.

25. Mass/weight—A.I. question #8

a. What effect does gravity have on the mass and weight of the robot and the ball?

        i. **<u>Correct answer:</u> *The mass remains the same while the weight of the robot and the ball changes.***
    b. Mass: measure of how much matter an object has.
    c. Weight: The force exerted on a body by gravity.
    d. Revisit and clarify any misconception students might have towards the two.
26. Revisit/reinforce elasticity on the course with the bouncy terrain.
27. **Conservation of energy—A.I. question #9**
    a. **What must be true about the energy on a planet with changing gravity?**
        i. **<u>Correct answer:</u> *The Potential energy in the system changes as gravity changes, and must be transferred from somewhere.***
    b. Frame of reference reinforcement
        i. Frame of reference is partners well with the physics definition of systems. Previously frame of reference was scaffolded when adding the vectors, and we chose one to leave where it is, and add the rest tip to tail.
    c. Systems (physics definition)
        i. A system is a set of interacting or interdependent components forming an integrated whole.
        ii. An open system exchanges matter and energy with its surroundings. Most systems are open systems; like a car, coffeemaker, or computer.
        iii. A closed system exchanges energy, but not matter, with its environment; like Earth.
        iv. An isolated system exchanges neither matter nor energy with its environment. A theoretical example of such system is the Universe
28. Remaining concepts not addressed, but can be observed in the game.
    a. Momentum
        i. The product of mass and velocity of an object. The tendency for an object in motion to stay in motion.
    b. Torque
        i. The tendency of a force to rotate an object about an axis, fulcrum or pivot. Spinning force.
    c. Double pendulum
        i. In physics and mathematics, in the area of dynamical systems, a **double pendulum** is a pendulum with another pendulum attached to its end, and is a simple physical system that exhibits rich dynamic behavior with a strong sensitivity to initial conditions.
        ii. In golf, one pendulum is represented by the shoulders and arms and the second forms right below at the wrists, extending through the club.
        iii. The cumulative motion of the two pendulums magnifies each other for maximum speed and force as the club head passes through the ball.
    d. Wrist cock angle
        i. When swinging a golf club, it is the angle that the club has in relation to your wrists. This enables the use of the double pendulum, and increases the distance of drives.
    e. Distance/displacement
        i. Distance: How much ground an object has covered during its motion. It is a scalar quantity.

ii. Displacement: The shortest distance from the initial position to the final position. It is a vector quantity. It can also be understood as an object's overall change in position, or how far out of place an object is.