Worksheet answers

Part 1: Simulated 100 m race

1. Describe the runner's motion (acceleration, deceleration, or constant speed) during each phase of the race.

drive (0–3 s)	*acceleration*
maintenance (4–7 s)	*constant speed*
slowing down (8–10 s)	*deceleration*

2. Which of Newton's laws of motion best explains each of the following?

a. The runner pushes against the ground at the beginning of the race.	*Newton's 3rd law*
b. He accelerates rapidly during the first few seconds.	*Newton's 2nd law*
c. His speed reaches a maximum value.	*Newton's 1st law*
d. His speed reduces towards the end of the race.	*Newton's* 2nd law

3. Use the velocity-time graph to estimate how far the runner travels in the first four seconds of the race. Describe the process you used to determine this distance.

   Distance travelled is indicated by the area under the curve.

   drop perpendiculars from the curve to 1.8 s and 4 s

   area of triangle = ½ x 1.8 x 10.6 = 9.54 m

   area of rectangle = 2.2 x 11 = 24.2 m

   total distance = 9.54 + 24.2 = 33.7 m

4. Determine the runner's average acceleration during the first two seconds of the race. Describe the process you used to determine this acceleration.

   u = 0, v = 10.6 m s^{-1}, t = 2 s

   a = (v - u)/t = (10.6 - 0)/2 = 5.3 m s^{-2}

5. Use your answer to question 4 to calculate average force exerted by the runner during the first two seconds of the race.

   F = m.a = 72 x 5.3 = 382 N

6. During which phase of the race is the runner exerting maximum force? Explain your answer.

   The runner exerts maximum force when his acceleration is at a maximum, which is during the drive phase of the race.

7. Comment on the runner's performance in the simulated 100 m race and identify any areas where his coach might want to intervene to bring about improvement.

   The runner accelerates rapidly for 1.8 s then at a slower rate to 3.5 s. He decelerates until 5 s, then maintains a fairly constant speed until 8.5 s. During the final section, his speed drops slightly. His coach may concentrate on maintaining the runner's speed from its maximum at the 3.5 s point until as late in the race as he can.

8. Explain the origin of forces acting on the runner's foot at the start of a race, and how they enable him to accelerate from rest.

   The runner pushes backwards (action force) on the ground. The ground exerts an equal and opposite reaction force on the runner's foot to propel him forwards according to Newton's third law of motion. The force on the runner enables him to accelerate from rest.

   Note: The forces do not cancel each other out because they act on different objects.

Part 2: Usain Bolt's World and Olympic record 100 m run

1. Estimate Bolt's maximum velocity in m s^{-1} and km h^{-1} (show your working).

   His maximum speed at 7.0 s is 12.4 m s^{-1}.

   Converting this to km h^{-1} gives 12.4 x 3600/1000 = 44.6 km h^{-1}.

2. Estimate the distance he travelled in reaching his maximum velocity? Describe the process you used to estimate this distance.

   Distance travelled is indicated by the area under the curve.

   Drop perpendiculars from the curve to 3.6 s and 7 s.

   area of triangle = ½ x 3.6 x 11.2 = 20.16 m

   area of rectangle = 3.4 x 11.6 = 39.4 m

   total distance = 20.16 + 39.4 = 59.6 m

3. Elite athletes win races because of their *speed endurance*, that is, their ability to maintain the same top speed for more of a race. Using the velocity-time graph, comment on Bolt's speed endurance.

   He reached his top speed shortly after 4 s and maintained it until 8 s before slowing (very slightly) in the final stage of the race. The graph shows that he maintained close to his top speed for most of the race. Usain Bolt has outstanding speed endurance.

4. What was Bolt's average speed over the final 10 m of the race? How does this compare with his speeds during the first 40 m of the race?

   average speed for final 10 m = distance / time = 10.0 / 0.86 = 11.63 m s^{-1}

   His average speeds over the first 40 m were:

   0 - 10 m = 5.88 m s^{-1}
   10 - 20 m = 10.0 m s^{-1}
   20 - 30 m = 11.1 m s^{-1}
   30 - 40 m = 11.49 m s^{-1}

   He finished the race faster than he started, even with his celebrations!

5. During the final 20 m of the race Bolt began celebrating his impending victory, which caused a slight reduction in his speed. Estimate the time he might have recorded in the absence of his celebrations. Describe the process you used to estimate this time.

   Had he maintained section times of 0.83 s from the 80 m mark, he might have saved 0.02 s and 0.03 s during the final 20 m, to give a final time of 9.685 - 0.05 = 9.635 s.