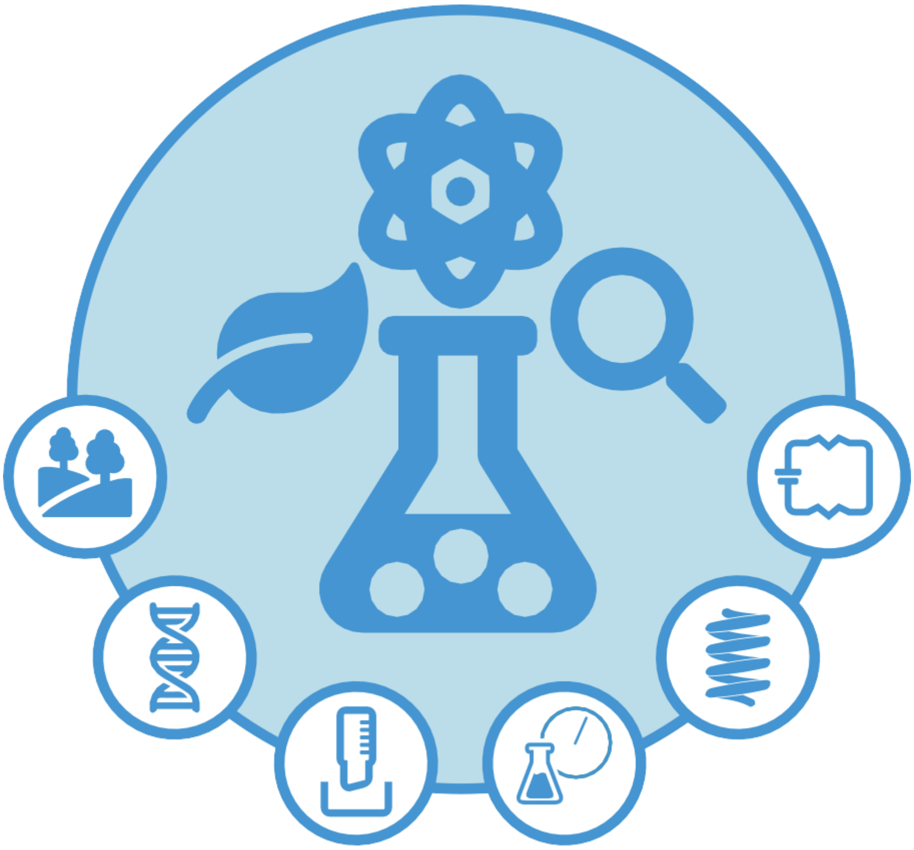
EXEMPLAR LESSON

OpenSTEM Africa

THE HUMAN HEART



Acknowledgements

Ministry of Education

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Ghana Education Service, and the expert SHS science teachers, for their expertise in producing materials that are rooted in the Ghanaian school context, accessible and useful to learners and teachers.

For information on OpenSTEM Africa see:
www.open.edu/openlearncreate/OpenSTEM_Africa

OPITO for their generous support, which has made OpenSTEM Africa and the development of the Virtual Laboratory and these materials possible.

Contents

Exemplar lessons for the OpenSTEM Africa Virtual Laboratory applications

All the exemplar lessons are examples of lessons which could be used both individually and by whole classes of Senior High School (SHS) students in the elective sciences of Biology, Chemistry and Physics. Each of the lessons is linked specifically to one of the applications in the OpenSTEM Africa Virtual Laboratory. The exemplar lesson is created to give, both to SHS students and to SHS teachers, a clear example of the ways in which the applications can be used in the learning and teaching of practical science. There is a focus throughout the lesson on the student's development of the practical and experimental skills which, along with knowledge and understanding, are integral to the profile of learning, teaching and assessment in SHS sciences.

The 'you' in this lesson is 'you', the Senior High School student. Remember that you can repeat the experiments and activities in this lesson as often as you have time for in class. This freedom to repeat experiments and activities is also important if you are accessing the lesson outside the classroom, for example for homework. Every application in the OpenSTEM Africa Virtual Laboratory contains real data – the experiments are real experiments. This means you might make mistakes the first or second or third time you try an experiment or an activity – and that is exactly what often happens in the real world in the sciences. So, it is helpful for you as a student to share in some of the real-world trial and error of science as you develop your skills as a scientist.

The exemplar lesson also contains a set of teaching notes at the end of this document for 'you' the SHS science teacher, to suggest how you might want to set up this particular lesson with one of your classes. Hopefully it will also generate ideas for other lessons on the same topic, or other lessons which use the same OpenSTEM Africa Virtual Laboratory application.

The human heart

This exemplar lesson is very different to the others as the application is not an experiment or instrument. Instead, it is a tool that allows students to explore an anatomically correct human heart and investigate many of its functions and properties.

Lesson objectives

By the end of the lesson, you will be able to:

- Describe the structure of the mammalian heart (Biology 4.3.2 and Integrated Science 3.3.1).
- Draw and Label key structural features on diagrams of the heart (Biology 4.3.2 and Integrated Science 3.3.1).
- Explain the function of the heart and how blood flows through the heart (Biology 4.3.2 and Integrated Science 3.3.1).
- Explain the mechanism of heart excitation and contraction (Biology 4.3.3 and Integrated Science 3.1.3).
- Interpret activity traces of the cardiac cycle (Biology 4.3.3 and Integrated Science 3.1.3).
- Calculate the heart rate of a person (Practical and Experimental Skills).
- Plan, design and carry out an experiment testing the effects of exercise on a person's heart rate (Practical and Experimental Skills).

The following practical and experimental skills will also be developed:

- Observation
- Manipulation
- Drawing
- Interpretation
- Planning and designing of experiments
- Measuring
- Recording
- Reporting
- Conduct in laboratory.

Please note that any terms shown in **bold**, are defined in the Glossary, at the end of this Lesson Plan.

Background

The standard anatomical position is shown in Figure 1– the person is standing up with the palms of their hands facing outwards. Note the terms ‘right’ and ‘left’ refer to the person being viewed rather than the viewer, so the right lung is on the viewer’s left. As shown in Figure 1, the heart is located in the centre of the chest, in between the two lungs. The bottom of the heart points slightly to the left.

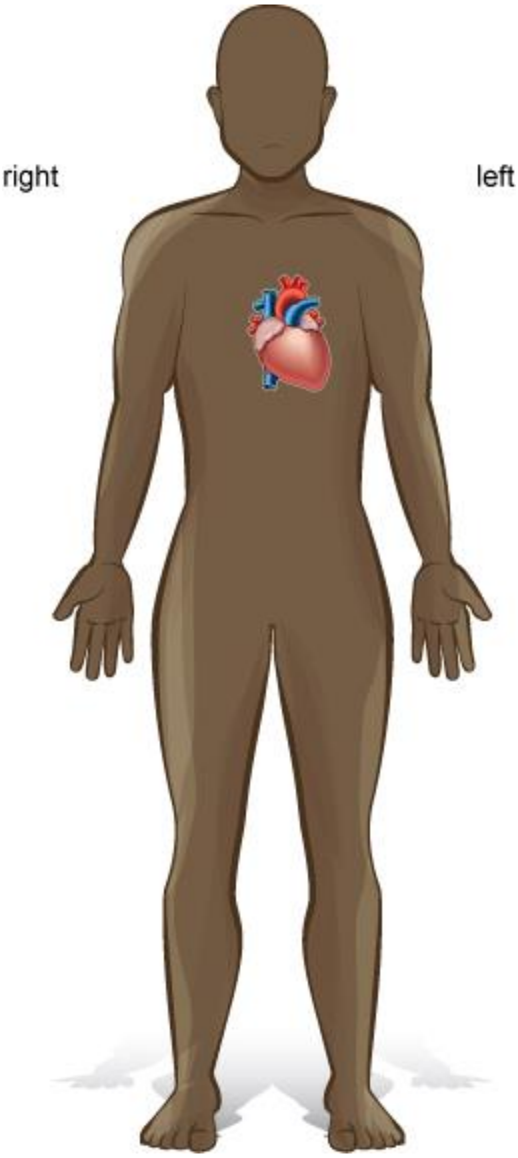


Figure 1. Standard anatomical position with the location of the heart shown.

Make a clenched fist with your hand this is approximately the same size as your heart.

The function of the heart is to pump blood to all the cells of the body. This is important for life as the blood contains oxygen and nutrients, such as glucose, which are needed by cells for **cellular respiration**. The blood also removes the waste gas carbon dioxide and other waste products.

The Human heart application

This lesson uses the Human heart application to allow you to explore the anatomy (structure) and physiology (function) of a human heart. If the application has already been installed on your machine, click on the Human heart icon which should be located on your desktop (Figure 2).

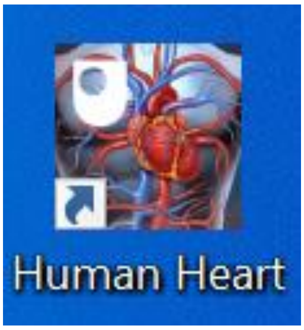


Figure 2. Human heart application icon

If the application has yet to be installed on your machine, instructions on how to install it are provided at the end of this lesson.

To launch the application, click on the icon. The application runs as a full screen programme and to return to this lesson you will have to exit the application and then relaunch it when you need to return to it (alternatively, you can read the lesson fully, noting down the activities in your laboratory notebook and then launch the application to complete the activities).

The opening screen offers you two modes 'Standard' and 'Accessibility', if you can use a mouse select the 'Standard' mode (the 'Accessibility' mode uses keystrokes to control the application).

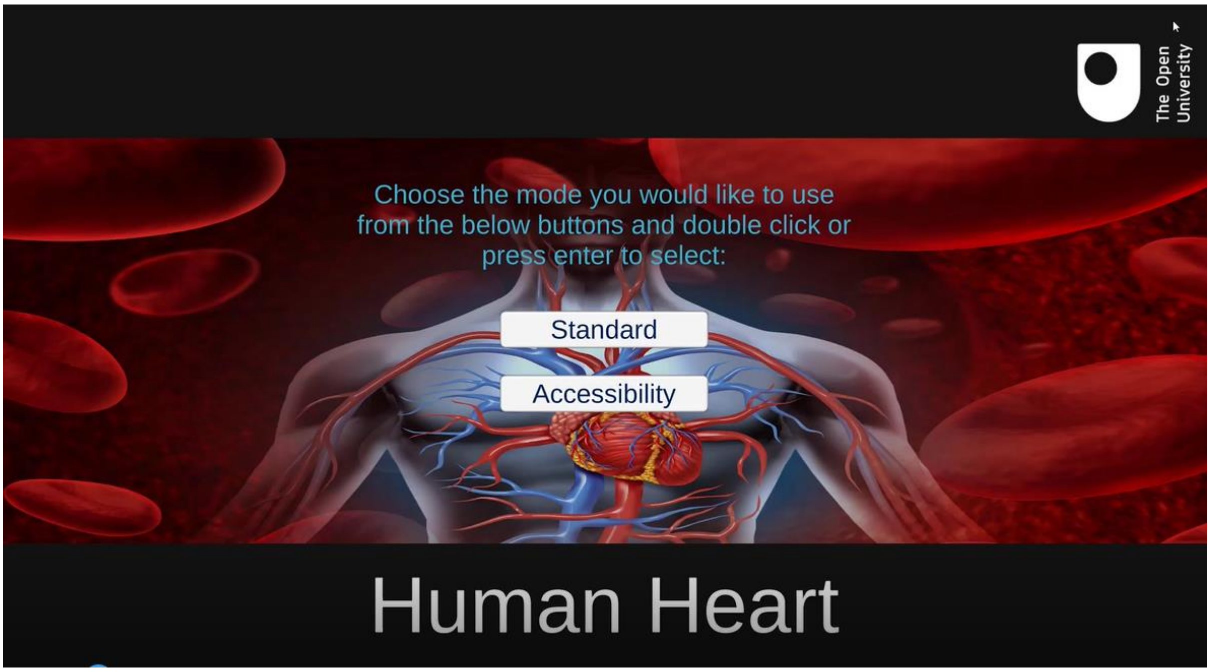


Figure 3. The opening screen of the Human heart application.

Once you have selected your user mode, the application opens to the main screen which has both the heart and a menu of options (Figure 4).

Figure 4. The main screen of the Human heart application.

Spend a few minutes exploring the options. You can rotate the heart by holding down the left-click button of your mouse and moving the cursor. You can zoom in and out by clicking on the plus and minus icons on the right-hand side of the screen or by using the plus and minus keys on your keyboard.

The structure of the heart

Atria, Ventricles and Septum

First, we are going to explore the inside structure of the heart. Click on the 'Open Heart' button to see inside the heart. Click on the 'Show pins' button. Pins should appear, as in Figure 5. There are 18 pins in total – you will need to click and hold on the heart to rotate it and reveal all the pins.

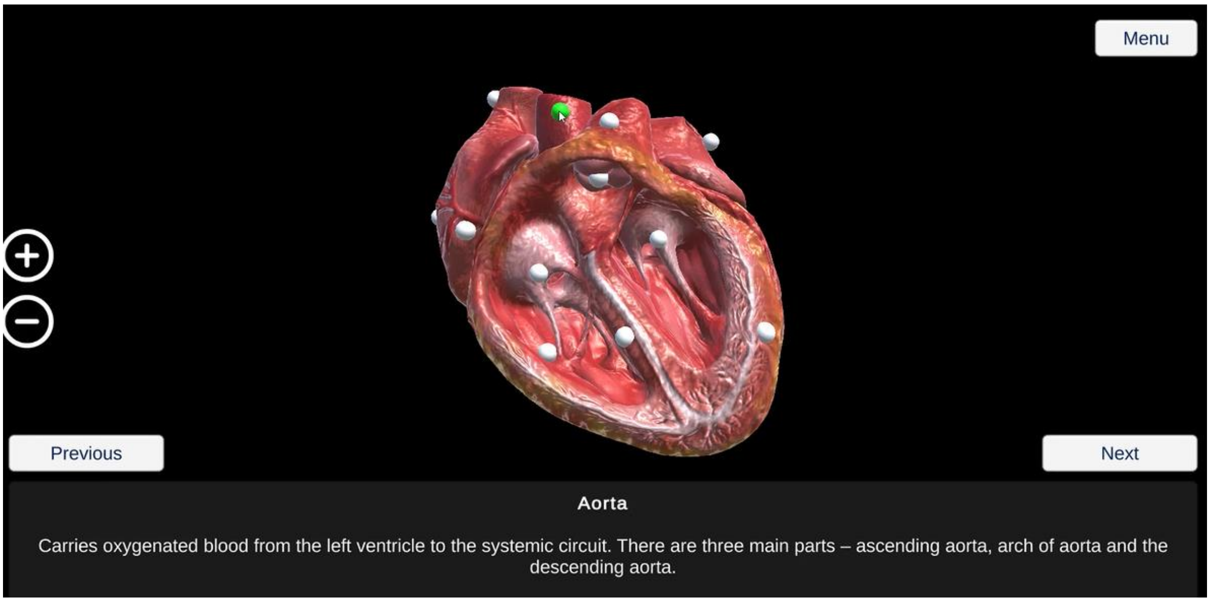


Figure 5. The opened heart and pins – the pin for the aorta has been selected is now green.

When you click on a pin, it changes colour from white to green and a description of the selected pin appears at the bottom of the screen. You can also use the 'next' and 'previous' buttons to move around the pin in a zoom in mode.

See if you can locate the **intraventricular septum**. This is a thick wall down the vertical axis of the heart**.** It divides the heart into two sides – the right-hand side and the left-hand side. The heart is made up of four chambers – two smaller, upper chambers called **atria** (singular: **atrium**) and two larger, lower chambers called **ventricles**. See if you can locate the **right atrium**, **right ventricle**, **left atrium** and **left ventricle**. The atria and ventricles are surrounded by muscular walls.

Which chambers of the heart have thicker muscular walls – the atria or ventricles?
Go to Appendix 3 for the answer.

Which ventricle has a thicker wall?
Go to Appendix 3 for the answer.

Make a note of these observations in your laboratory notebook- we will re-visit the importance of these observations later in the lesson, when we consider the function of the heart.

Blood vessels

Rotate the heart to see the blood vessels – **arteries** (singular: **artery**) and **veins** – at the top of the heart, as shown in Figure 6. Arteries take blood away from the heart, while veins return blood back to the heart.

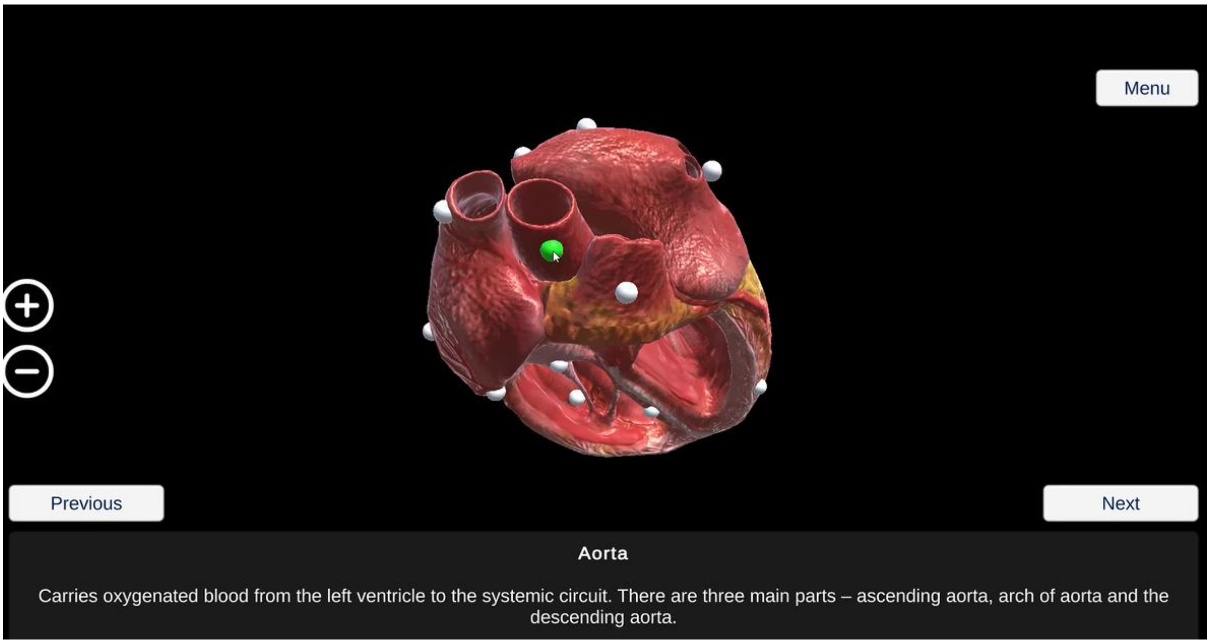


Figure 6. The blood vessels at the top of the heart. The aorta is indicated by the green pin.

See if you can locate the **pulmonary artery**, which takes blood from the right ventricle of the heart to the lungs. The **aorta** is the largest artery in the body and takes blood from the left ventricle of the heart to all organs of the body (except the lungs). You will see that the aorta branches into three main parts – ascending aorta, arch of aorta and the descending aorta.

The **pulmonary veins** carry blood from the lungs to the left atrium of the heart. The **right pulmonary vein** and the **left pulmonary vein** carry blood from the right and left lungs respectively. The **vena cavae** are the largest veins in the body and carry blood from the body to the right atrium of the heart. The **superior vena cava** carries blood from the upper half of the body, while the **inferior vena cava** carries blood from the lower half of the body. Remember, you will need to rotate the heart to locate some of these structures.

Heart valves

You can also see the atrio-ventricular valves located between the atria and ventricles. The atrio-ventricular valve between the right atrium and right ventricle is called the **tricuspid valve** as it has three flaps. The atrio-ventricular valve between the left atrium and left ventricle is called the **bicuspid valve** as it has two flaps (it is also known as the **mitral valve**). You can also see the **papillary muscles** and **chordae tendineae**, which connect the atrio-ventricular valves to the ventricular walls. The papillary muscles secure the chordae tendineae, connective tissue underneath the valves to maintain the valves in a closed position.

The semilunar valves have three flaps and are named because of their half-moon shape. See if you can locate the **pulmonary semilunar valve** at the base of the pulmonary artery and the **aortic semilunar valve** at the base of the aorta.

Outside surface of the heart

Next, we are going to look at the outside surface of the heart. Click on the 'Menu' button. Click on the 'Close Heart' button. Click on the heart to rotate it.

What structural features can you see on the outside surface of the heart?
Go to Appendix 3 for the answer.

You may have noticed the blood vessels on the outside surface of the heart. These **coronary blood vessels** form the heart's own blood circulation. Click on 'Show pins' button and find the 'Coronary blood vessels' pin.

This circulation is important. Just like the other organs of the body, the heart needs to receive blood containing oxygen and nutrients – via the coronary arteries. Similarly, blood containing carbon dioxide and other waste products needs to be removed from the heart – via the coronary veins.

We have now found all 18 structure pins – in the next part of the lesson, we are going to discuss the functions of these structures.

Activity

In your laboratory notebook, draw a schematic diagram of the heart, including labels for the 18 structures we have looked at. See how many you can remember without looking at the application.

You can then re-visit the application to add any labels you may have missed.

The function of the heart

The heartbeat in action

The heart can be thought of as a powerful muscle, which continuously contracts then relaxes then contracts again throughout a person's lifetime.

We are now going to see the heart in action. Click on the 'Hide pins' button. Click on the 'Play Heartbeat' button. Click on the 'Show Heartbeat Control' button. At the bottom of the screen, you will find a controller for increasing or decreasing the heart rate – the default setting for the application is 72 beats per minute (bpm) (Figure 7).

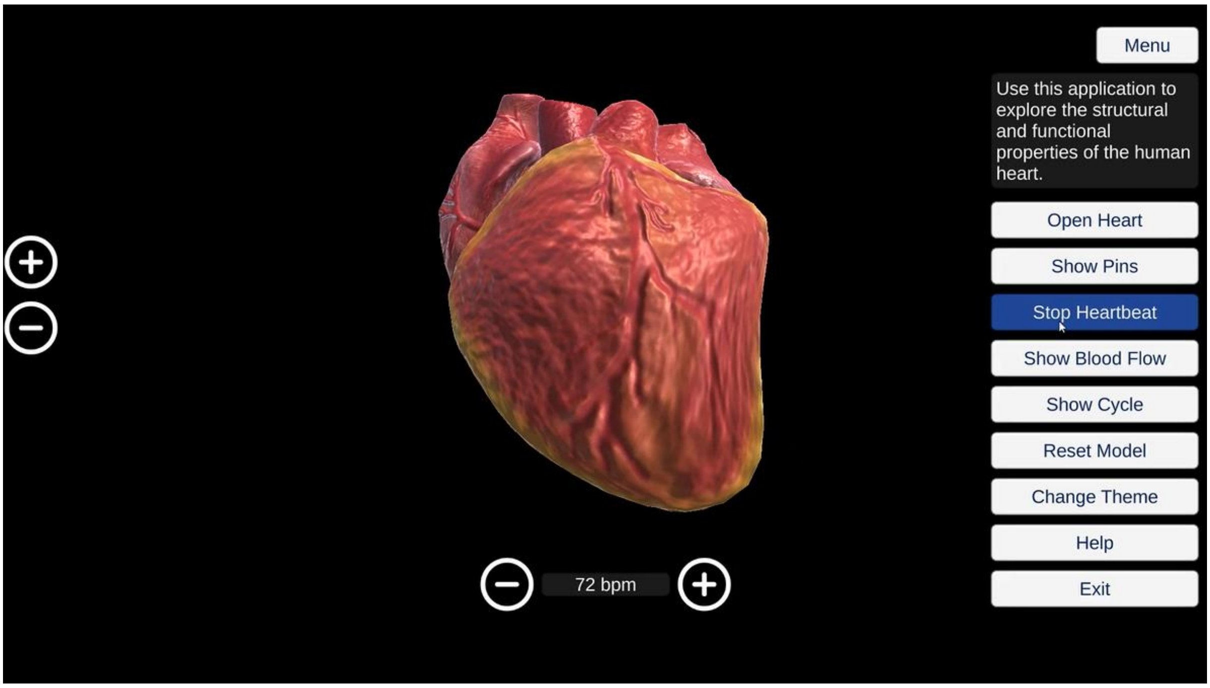


Figure 7. The beating human heart.

Let’s do a calculation to see how hard your heart works. You may wish to use the calculator function on your phone or computer device.

What would be the heart rate of the heart shown in Figure 7 in beats per hour?
Go to Appendix 3 for the answer.

What would be the heart rate of this heart in beats per day?
Go to Appendix 3 for the answer.

What would be the heart rate of this heart in beats per year?
Go to Appendix 3 for the answer.

According to figures in 2016 from The World Health Organisation, the average life expectancy for a person in Ghana is 64 years old.

How many times would a heart beat during the lifetime of a 64-year-old individual?
Go to Appendix 3 for the answer.

Of course, this is an underestimate – a person will not have a steady heart rate of 72 bpm throughout their life – their heart rate will change rapidly depending on their environment and activity. For example, a person’s heart rate will be lower during sleep as the heart does not need to pump as much blood to the organs of the body.

Practical activity

Designing your experiment

Let's carry out an experimental investigation to see if a subject's heart rate changes in response to different exercise activities. The subject participant may be you or your classmate.

What hypothesis is your experiment going to test?
Go to Appendix 3 for the answer.

What is the independent variable (the variable you are going to change) for your experiment?
Go to Appendix 3 for the answer.

What is the dependent variable (the variable you are going to measure) for your experiment?
Go to Appendix 3 for the answer.

Any type of experiment using a human as its subject must be ethical. The participant needs to be fully informed about what will happen during the experiment, the purpose of the experiment and how the experimental data will be used. The experiment should only take place after the participant has given their consent. The participant has the right to decline participating in the experiment and to withdraw from the experiment, without providing a reason.

Measuring the pulse of a subject

You can measure your own (or your classmate's) heart rate indirectly by measuring their pulse rate. You should be able to feel the subject's pulse, by placing your two fingers on the subject's wrist (radial pulse) or neck (carotid pulse), as shown in Figure 8. (Note: the experimenter should not use their thumb to measure the subject's pulse as their thumb also contains a pulse.) Record in your notebook which pulse you are going to measure.

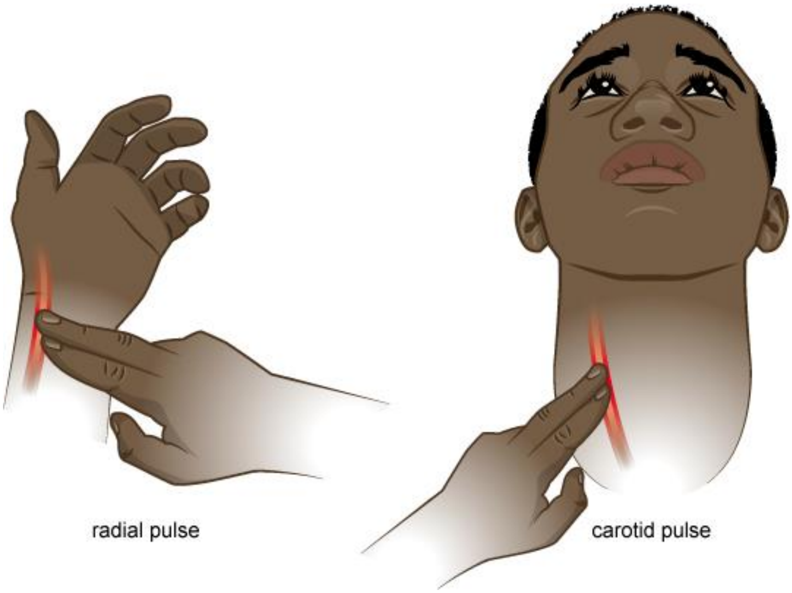


Figure 8. Measuring a subject's (a) radial pulse or (b) carotid pulse

Once you have decided how you are going to measure heart rate it is important for the experimenter to use the same method throughout the experimental trials.

Apart from the independent variable in the experiment, it is important to try and control other variables during the experiment. Otherwise, the experimenter may not be able to determine if any changes observed in the dependent variable are due to changes in the independent variable or changes in another uncontrolled variable during the experiment. There may be variations in a subject's radial pulse rate and their carotid pulse rate.

Using a stopwatch, timer or stopwatch function on your phone, the experimenter should measure the subject's pulse rate as the subject is sitting down for 1 minute. This is the subject's resting heart rate.

Next, ask the subject to stand up and again, measure their pulse rate for 1 minute.

For the next trial, ask the subject to walk on the spot for 1 minute and then measure their pulse rate for 1 minute.

For the final trial, ask the subject to jog on the spot for 1 minute and then measure their pulse rate for 1 minute.

Complete your results table as shown below.

Results Table: Heart rate of a subject following different exercise activities

Exercise activity trial	Exercise level	Heart Rate (bpm)
Sitting down (at rest)	LOW (1)	
Standing up	LOW (2)	
Walking on the spot for 1 min	MEDIUM (3)	
Jogging on the spot for 1 min	HIGH (4)	

Interpreting your results and evaluating your experimental design

Have your results confirmed your research hypothesis?
Go to Appendix 3 for the answer.

How do your findings compare with another group in your class?
Go to Appendix 3 for the answer.

How could you improve the reliability of your experimental results?
Go to Appendix 3 for the answer.

You could pool results from the different experiments taking place using different subjects in your class and then calculate mean average heart rates for this class data. It would be really useful to see if the heart rates of your classmates respond in the same way to exercise.

You could also plot your results using a graph and use statistical tests to see if any difference in heart rates for different exercise activities is statistically significant or not.

Discuss with your classmates how you might improve your experimental design before reading the suggestions below.

- If you have time, you could maybe measure the carotid pulse rate of the subject if you measured the radial pulse rate of the subject, or vice-versa to see if you obtain similar results.
- You could maybe measure the heart rate of the subject using a heart rate monitor app on a smart phone or smart watch.
- You could test further exercise activities such as walking up some stairs or sprinting for a minute to see if the results obtained agree with your experimental hypothesis.
- You could carry out further experiments with Senior High School Year 1 students and with students from other High Schools in Ghana, to increase the sample size for your experiment.

Now that you have completed your experimental work, the following sections of this lesson will explore further some of the physiological properties of the heart related to exercise.

The effects of exercise on a subject's heart rate

When you exercise, your leg and arm muscles require more oxygen for respiration. Also, waste products such as lactic acid start to build up in these muscles. For both these reasons, the muscles need more blood to transport the oxygen and to remove the lactic acid. To increase the blood flow to these muscles, your heart needs to pump blood faster – your heart rate increases.

- Let's look at the heart beating faster. Use the plus button at the bottom of the screen to increase the heart rate to 200 bpm.

We have seen why it is important for the heart rate to increase in response to exercise. Some people have a resting heart rate above 100 bpm – this condition is called **tachycardia**.

- Let's look at the heart beating more slowely. Use the minus button at the bottom of the screen to decrease the heart rate to 60 bpm.

Some people have a resting heart rate below 60 bpm – this condition is called **bradycardia**.

Blood flow through the heart

We are now going to consider the journey that blood takes through the heart (Figure 9). Click on the 'Show Blood Flow' button. You will see some blue and red arrows appear. Again, you may wish to rotate the heart to getter a better view of the atria, ventricles and blood vessels.

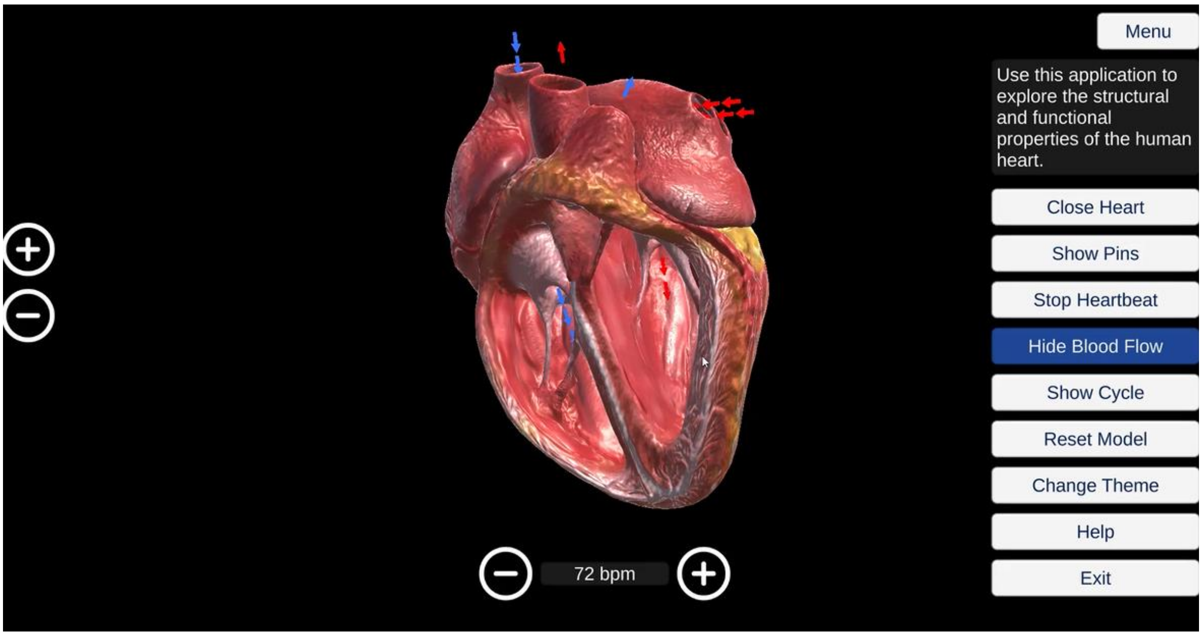


Figure 9. The circulation of blood through the chambers and blood vessels of the heart.

The blue arrows represent blood containing low oxygen levels while the red arrows represent blood containing high oxygen levels. The direction of the arrows indicates the direction in which the blood is flowing.

Which side of the heart contains the blood which is low in oxygen levels?
Go to Appendix 3 for the answer.

Let's consider the blue arrows first. We can see that the blood low in oxygen levels enters the right atrium of the heart through the superior and inferior vena cavae. When the right atrium contracts, the blood then moves from the right atrium into the right ventricle. When the right ventricle contracts, the blood moves into the pulmonary artery and is taken to the lungs, where it will become more oxygenated.

You will recall that the atria have thinner walls than the ventricles. This is because the atria only need to contract to move blood into the ventricles below them using gravity so do not need thick muscular walls and therefore have thin walls. However, the ventricles need to force blood against gravity from the ventricles up into the arteries located above the heart and therefore require thick muscular walls.

We can see this blood with higher oxygen levels, as represented by the red arrows, returning through the right and left pulmonary veins and into the left atrium of the heart. When the left atrium contracts, the blood then moves from the left atrium into the left ventricle. When the left ventricle contracts, the blood moves into the aorta and is taken to all the other organs of the body (except the lungs) where it will release oxygen. This blood with lower oxygen levels will then return to the heart through the vena cavae, to start the cycle again.

Earlier, we saw that the left ventricle has a much thicker wall than the right ventricle. The left ventricle needs to pump blood through the aorta, which takes blood to all organs of the body (except the lungs) whereas the right ventricle pumps blood into the pulmonary artery, which takes blood to the lungs. The lungs are located much closer to the heart than other organs of the body.

The cardiac cycle

However, as we can see from the animation, the heartbeat is co-ordinated so that blood enters both the right and left atria at the same time from the veins (vena cavae and pulmonary veins, respectively). This is known as **diastole**.

Then, both atria contract at the same time so that blood enters the right and left ventricles at the same time. This is known as **atrial systole**.

Then, both ventricles contract at the same time so that blood is pumped through the arteries (pulmonary arteries and aorta) at the same time. This is known as **ventricular systole**. This series of three events make up the cardiac cycle.

For a heart beating at a rate of 72 bpm, how long does one heartbeat (or cardiac cycle) take?
Go to Appendix 3 for the answer.

The heart valves ensure that blood flows in one direction during the cardiac cycle. During atrial systole, the atrio-ventricular valves open and blood flows from the atria into the ventricles. The semilunar valves remain closed.

During ventricular systole, the atrio-ventricular valves close (this creates the ‘lub’ sound of the heartbeat), preventing backflow of blood from the ventricles to atria and the semilunar valves open, ensuring that blood is forced into the arteries.

During diastole, the semilunar valves close (this creates the ‘dub’ sound of the heartbeat). The atrio-ventricular valves remain closed.

The double circulation

Humans have a double circulatory system – a pulmonary circuit of blood vessels carrying blood between the heart and lungs and a systemic circuit of blood vessels carrying blood between the heart and the other organs of the body (except the lungs). This is illustrated in Figure 10.

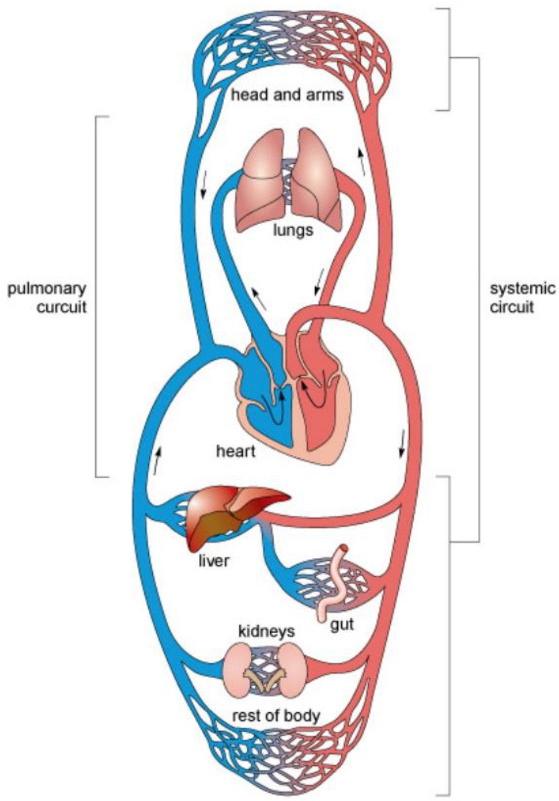


Figure 10. The double circulation. Blood high in oxygen is coloured red and blood low in oxygen is coloured blue.

The cardiac cycle in focus

We are now going to explore the events happening during the cardiac cycle in more detail. Click on the 'Show Cycle' button. To help us follow the events, decrease the heart rate to 1 bpm. You will see six traces, represented by different colours, during two cardiac cycles. Follow the traces with the beating heart as shown in Figure 11.

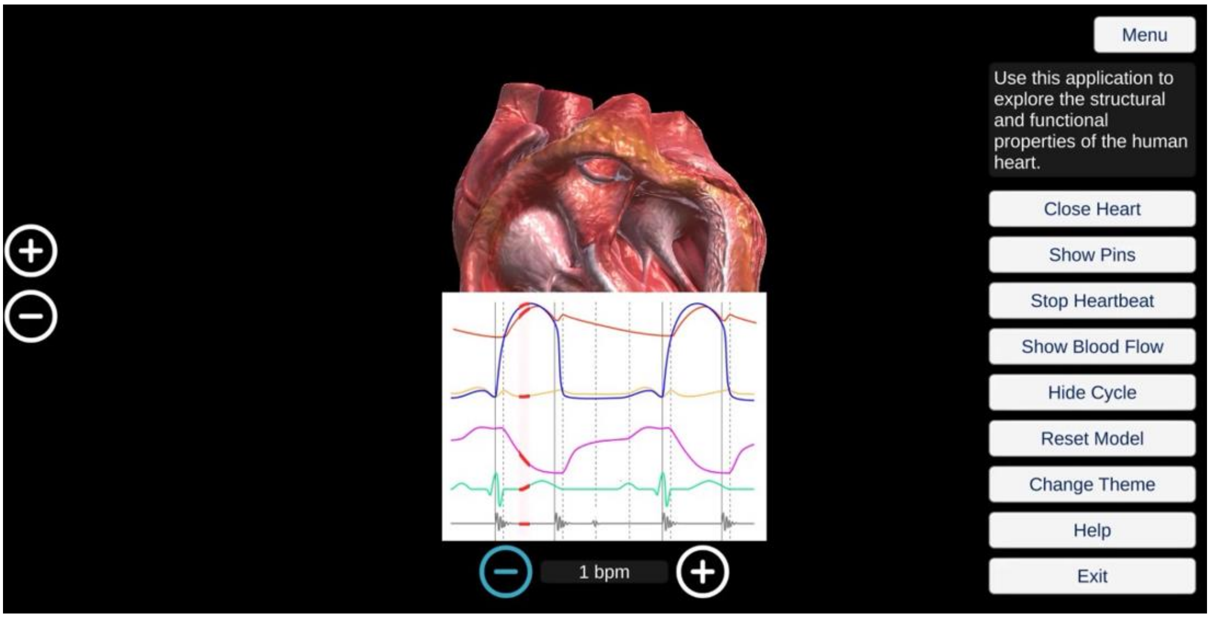


Figure 11. The cardiac cycle

The top three traces measure the pressure within the aorta, ventricles and atria, respectively. The orange line represents pressure within the atria. You can see that there is a small peak in this trace, during atrial systole, when the atria contract in the animation. The trace then levels out, as the atria relax, during diastole. The blue line represents pressure within the ventricles. There is a peak in this trace when the ventricles contract during ventricular systole. This trace then levels out as the ventricles relax, during diastole.

Why are there differences between ventricular pressure and atrial pressure during the cardiac cycle?
Go to Appendix 3 for the answer.

The red line represents pressure within the aorta. Notice how the pressure in the aorta increases as blood is forced from the left ventricle into the aorta during ventricular systole.

The pink trace is measuring the volume within the ventricles during the cardiac cycle.

The green trace is an electrocardiogram, or ECG, showing the electrical activity changes taking place during the cardiac cycle. Finally, the grey line represents the ‘lub’ and ‘dub’ sounds of the atrio-ventricular valves and the semilunar valves closing respectively, during the cardiac cycle.

Summary

We hope you have enjoyed using the Human heart application in your Lesson, to study the structure and function of the heart. You may wish to further test your knowledge of the structure and function of the heart by re-visiting the application. You could explore further the internal structures of the heart. You could increase the heart rate to match those you recorded in the Practical activity and examine how this changes the cardiac cycle. Finally, you have also developed your numeracy, practical and experimental skills during this lesson.

Human heart application installation

Go to the OpenSTEM Africa Virtual Laboratory.

Click on the icon to access the Human heart application homepage and then click on the download link.

Once the installer file has downloaded, double click on it to install the application. If Windows Defender SmartScreen pauses the installation, click on 'More info' and then click 'Run anyway' to continue the installation.

During the installation process you will be asked if you want to create a desktop shortcut, click this option.

Quiz

Answer the questions, then search for the correct answers in Appendix 4.

Question 1

How many chambers does the human heart have?

a) 1
b) 2
c) 3
d) 4

Question 2

Which side of the human heart receives blood that is low in oxygen?

a) Left side
b) Right side
c) Both sides

Question 3

Which part of the heart is the most muscular?

a) Left atrium
b) Left ventricle
c) Right atrium
d) Right ventricle

Question 4

Which one of the following statements is true?

a) The hearts sounds are produced by the closing of the heart valves
b) The aorta delivers blood high in oxygen to the lungs via the pulmonary system
c) A slowly beating heart is a sign of tachycardia

Glossary

Aorta – Largest artery taking blood from the left ventricle to all organs of the body (except the lungs).

Aortic semilunar valve – valve at the base of the pulmonary artery

Artery – blood vessel taking blood away from the heart

Atrial systole – stage in the cardiac cycle where the atria contract and blood moves from the atria into the ventricles

Atrium (plural **atria**) – an upper, smaller chamber of the heart. There are two atria – the **right atrium** and the **left atrium**

Bicuspid valve or **mitral valve** – left atrio-ventricular valve between the left atrium and left ventricle

Bradycardia – a slow heart rate

Cellular respiration – the process by which cells generate energy. Not to be confused with lung respiration (breathing)

Chordae tendineae – connective tissue between the atrio-ventricular valves and ventricular walls

Coronary blood vessels – blood vessels supplying blood to and carrying blood away from the heart

Diastole – stage in the cardiac cycle where the atria and ventricles relax and blood flows into the heart

Intraventricular septum – wall between the right- and left-hand sides of the heart

Papillary muscles – secure the chordae tendineae and maintain the valves in a closed position

Pulmonary artery – artery taking blood from the right ventricle to the lungs

Pulmonary veins – veins taking blood from the lungs to the left atrium. The **right pulmonary vein** carries blood from the right lung and the **left pulmonary vein** carries blood from the left lung

Pulmonary semilunar valve – valve at the base of the pulmonary artery

Tachycardia – a fast heart rate

Tricuspid valve – right atrio-ventricular valve between the right atrium and right ventricle

Vein – blood vessel taking blood back to the heart

Vena cavae – largest veins taking blood from the organs of the body (except the lungs) to the right atrium. The **superior vena cava** carries blood from the upper half of the body and the **inferior vena cava** carries blood from the lower half of the body

Ventricle – a lower, larger chamber of the heart. There are two ventricles – the **right ventricle** and the **left ventricle**

Ventricular systole – stage in the cardiac cycle where the ventricles contract and blood is forced into the arteries

Appendix 1: Teacher notes – organisation of the lesson

This lesson on the human heart links directly to SHS and the teaching and learning activities associated with it.

Biology SHS Year 2 Section 4 Unit 3

Integrated Science: SHS Year 2 Section 3 Unit 3 and SHS Year 3 Section 1 Unit 3

Ideas for organising this exemplar lesson link directly to activities and teaching examples in the OpenSTEM Africa CPD units on *Using ICT to support learning*, and *Approaches to active notetaking*.

A full list of the OpenSTEM Africa CPD units can be found at: https://www.open.edu/openlearncreate/CPD_units

Overview

If possible, this lesson should take place in the ICT Lab in your school if this can be arranged through your Head of Science and the Head of ICT. If the lesson takes place in the ICT Lab, it may be possible for each student to work individually at a computer; otherwise divide the class so that students are in small groups at a computer.

If it is not possible to use the ICT Lab for this lesson, then try to set up this lesson in your classroom. You may be lucky enough in your school to have a set of 'empty' tablets or mobile phones which students can use. Or you may be able to bring into the classroom a laptop connected to the internet or to your school intranet – and perhaps connected to a projector to make it possible for the whole class to view at once. If access to ICT is a real challenge in your school but you want your students to view an experiment, you might be able demonstrate it to small groups of your students at a time, using your own mobile phone

Whatever way(s) you set up the class, it would still be helpful to the students to be able to work in pairs or small groups for at least some of the lessons associated with using the human heart application. Do remember as well that students need desk space to be able to write in their notebooks and to draw tables and diagrams.

Steps in organising the lesson

Step 1: This could take place in the classroom in the lesson or lessons **preceding** the one where you and your class access the OpenSTEM Africa Virtual Laboratory Human heart application. As you will see there are a number of questions and activities in the lesson that students can carry out in the classroom, and which will help them prepare for the activities where they use the human heart application.

Have students work in pairs to pre-read the short Background section of the exemplar lesson. Ask them also to read all the instructions for accessing and using the human heart application as this process involves several steps. You may want to ask them to draw the schematic diagram of the heart before they move to looking at the heart application in the OpenSTEM Africa Virtual Laboratory. While they are doing so, you may want to walk round the class and check their laboratory notebooks, as accurate drawing of the diagram is important for this exemplar lesson.

Step 2: This could also take place in the classroom in the lesson **preceding** the one where you and your class access the OpenSTEM Africa Virtual Laboratory Human heart application. Check students' understanding by asking them to carry out the activity of checking for radial and carotid pulse. Have each student make a note of the observations they are going to carry out and the calculations they are going to make when they are interacting with the human heart application. Make sure that they have set out appropriate headings for the tables in their own laboratory notebook in preparation for their data collection.

Step 3: Once the students have access to the OpenSTEM Africa Virtual Laboratory, give them time to go through the steps in setting up/opening the applications, time to try out all of the activities in the menu, and time to complete all the practical activity tasks.

Step 4: Make sure that each pair has access to/can see the computer screen to begin the actual observations. Ensure that each pair knows how to carry out the observations – or, if you are using a laptop/projector, that you draw on the expertise of the class as you go through each step of the human heart activities – e.g., ask them what the next step is.

Step 5: Have the class follow the instructions for each of the human heart activities. Make sure, if working in a pair on a PC, that each student in the pair gets to follow all the steps; if working in a group on a PC, have the group leader ensure that everyone in the group is involved.

Step 6: What they write in their notebooks should be agreed between the pair or within the group but allow enough time for everyone in the class to fill in their own set of tables. Have them check each other's writing.

Step 7: Ten minutes before the end of the lesson, tell the students to complete the quiz.

Appendix 2 Teacher notes – outputs of the lesson

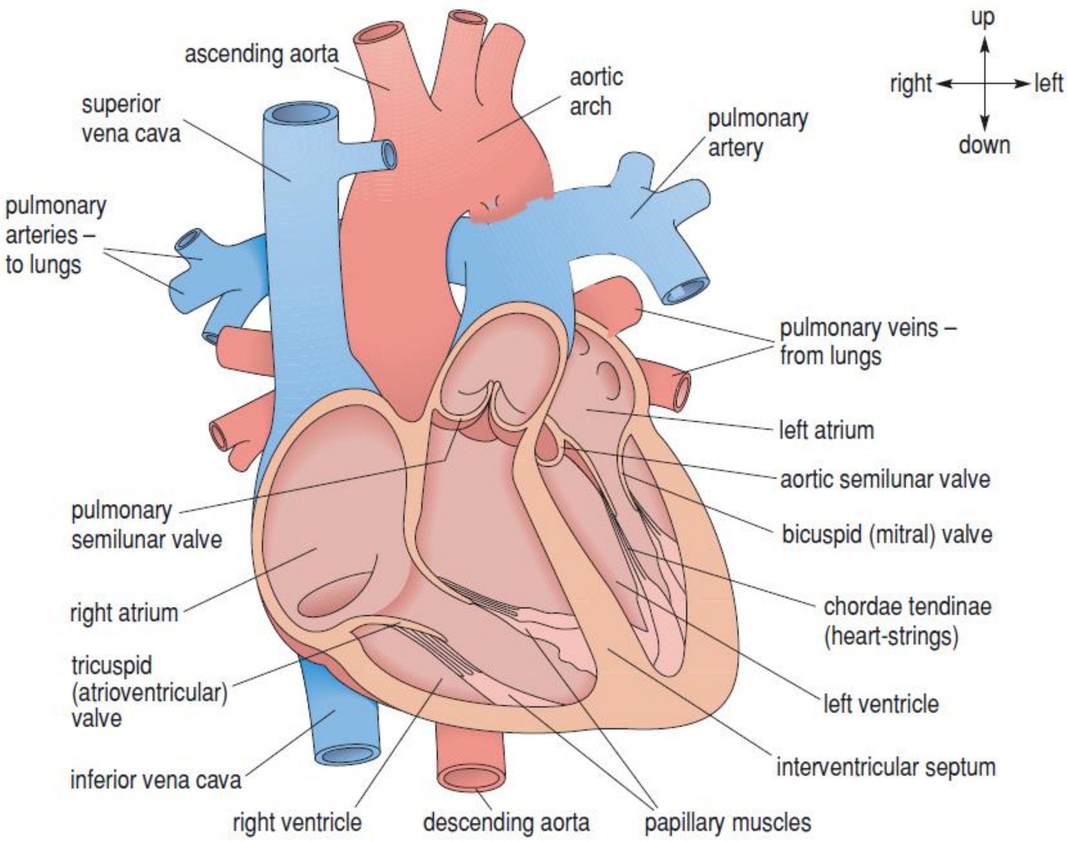
This lesson relates to the following areas of the SHS curriculum:

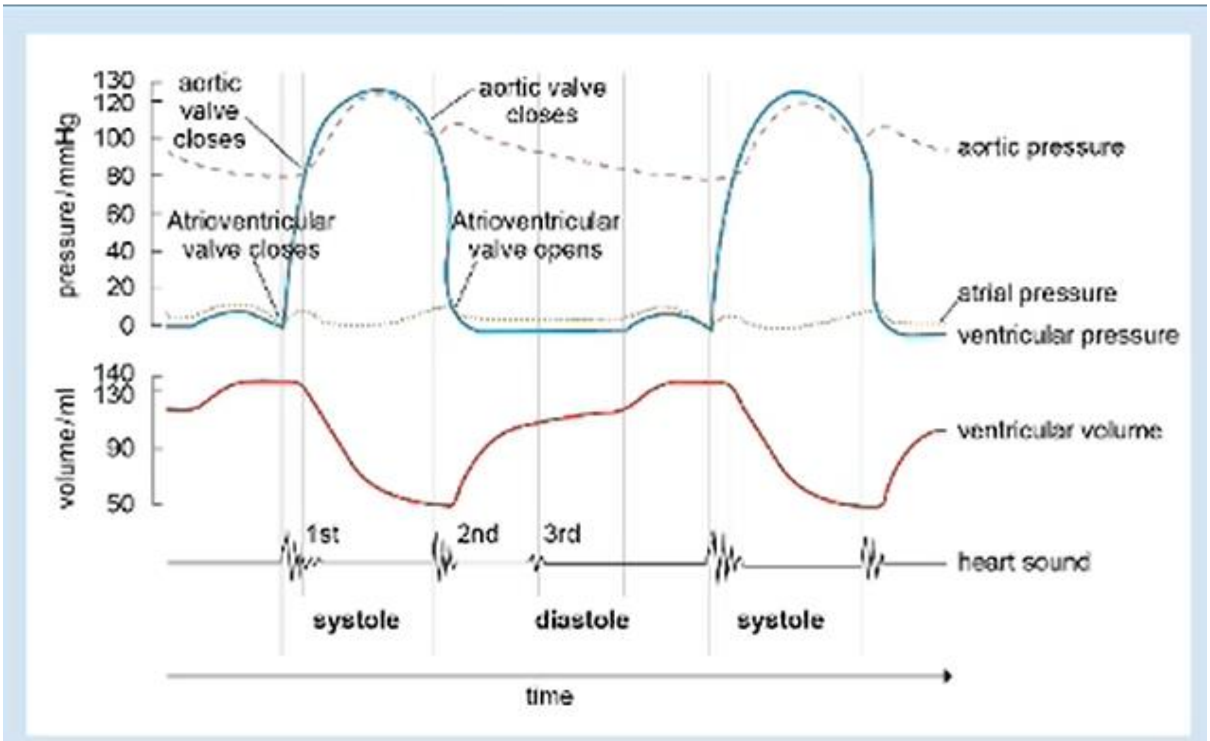
Biology: SHS Year 2 Section 4 Unit 3

Integrated Science: SHS Year 2 Section 3 Unit 3 and SHS Year 3 Section 1 Unit 3

This lesson is different to the others which are focused on the use of a virtual laboratory and virtual instruments. Instead, the Human heart application provides students with an opportunity to explore an anatomically correct human heart in 3D.

Below are two figures that you might find useful. The first is a labelled drawing of the heart and the second is the cardiac cycle with additional detail.





Finally, if your students carry out the physical exercise activity – ask them to explain why physical exercise causes an increase in both heart rate and respiration rate.

Appendix 3: In-text question answers

Which chambers of the heart have thicker muscular walls – the atria or ventricles?
Answer: The ventricles have thicker muscular walls than the atria.

Which ventricle has a thicker wall?
Answer: The left ventricle has a thicker wall. Its wall is actually 3 times thicker than the right ventricle wall.

What structural features can you see on the outside surface of the heart?
Answer: As well as the muscular walls of the atria and ventricles, you can see some fat (yellow) and some blood vessels on the surface of the heart.

What would be the heart rate of the heart shown in Figure 7 in beats per hour?
Answer: There are 60 minutes in an hour so 72 x 60 = 4320 beats per hour

What would be the heart rate of this heart in beats per day?
Answer: There are 24 hours in a day so 4320 x 24 = 103,680 beats per day

What would be the heart rate of this heart in beats per year?
Answer: There are 365.25 days in a year so 103,680 x 365.25 = 37,869,120 beats per year (nearly 38 million beats per year!)

How many times would a heart beat during the lifetime of a 64-year-old individual?
Answer: 37,869,120 x 64 = 2,423,623,680 beats per lifetime

What hypothesis is your experiment going to test?
Answer: Your experimental hypothesis may be for example, ‘A person’s heart rate will increase in response to increasing exercise’

What is the independent variable (the variable you are going to change) for your experiment?
Answer: The level/activity of exercise

What is the dependent variable (the variable you are going to measure) for your experiment?
Answer: The heart rate of you (or your classmate)

Have your results confirmed your research hypothesis?
Answer: Results will vary for different experiments, but you would expect that, in general, the heart rate of the subject would increase with increasing exercise activity. If this is the case, then you could state that the results agree with your research hypothesis.

How do your findings compare with another group in your class?
Answer: You are likely to find that different subjects will have very different heart rates at rest and during exercise. Factors such as gender, age and fitness levels can cause variations in the heart rate of participants.

How could you improve the reliability of your experimental results?
Answer: You could repeat the experiment three times with the same subject participant and then calculate their mean average heart rates for each exercise level.

Which side of the heart contains the blood which is low in oxygen levels?

Answer:
The right-hand side of the heart.

For a heart beating at a rate of 72 bpm, how long does one heartbeat (or cardiac cycle) take?

Answer:
The heart is beating 72 beats per minute. A minute is 60 seconds so this is 72 beats per 60 seconds. To calculate the time it takes for one heartbeat, we divide 60 by 72 which equals 0.83 seconds (to 2 decimal places).

Why are there differences between ventricular pressure and atrial pressure during the cardiac cycle?

Answer:
1. There is a much larger peak in ventricular pressure, compared to the peak in atrial pressure, as ventricular systole is more forceful than atrial systole (remember, the ventricles are more muscular than the atria).
2. The peak in ventricular pressure occurs after the peak in atrial pressure. This is important as ventricular systole should only occur after atrial systole is complete.
3. The ventricular pressure peak is also more sustained and lasts longer than the atrial pressure peak. This is because ventricular systole takes much longer than atrial systole.

Appendix 4: Quiz answers

Correct answers are **highlighted in green**.

Question 1

How many chambers does the human heart have?

a) 1
b) 2
c) 3
d) 4

Question 2

Which side of the human heart receives blood that is low in oxygen?

a) Left side
b) Right side
c) Both sides

Feedback

The right atrium receives the blood returning to the heart from the systemic system, which is low in oxygen, this blood is then pumped into the right ventricle which in turn pumps the blood to the lungs where it can take on more oxygen.

Question 3

Which part of the heart is the most muscular?

a) Left atrium
b) Left ventricle
c) Right atrium
d) Right ventricle

Feedback

The left ventricle has the thickest muscle walls. These are needed to pump blood into the systemic system via the aorta, which has a high arterial blood pressure.

Question 4

Which one of the following statements is true?

a) The hearts sounds are produced by the closing of the heart valves.
b) The aorta delivers blood high in oxygen to the lungs via the pulmonary system.
c) A slowly beating heart is a sign of tachycardia.

ACKNOWLEDGEMENTS

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