Chapter 2
The different types of stem cells

This chapter investigates the two main types of stem cells, each with their own subcategories:

1. **Pluripotent stem cells** can become any cell type in the body. Types of pluripotent stem cells include embryonic stem cells, induced pluripotent stem cells and stem cells created by somatic cell nuclear transfer.

2. **Tissue stem cells** are found in human and animal tissue and are often referred to as adult stem cells. Tissue stem cells are multipotent meaning they are usually restricted to forming the cell types of the tissue or organ from which they are found. All tissues probably contain stem cells with the most well known coming from bone marrow and umbilical cord blood.

The activities in this chapter are designed to facilitate the development of a student’s understanding about these two main types of stem cells. The activities have varying levels of complexity. Teachers can use the basic level activities or just direct students to focus on the two main stem cell types if only a general knowledge of the types of stem cells is required. This chapter would be useful for non-science students who might be preparing for an issues based debate or issue analysis, such as an essay, multimedia presentation or a report on the issues surrounding stem cells.

If a more in-depth knowledge on the derivation, advantages and limitations of the specific types of pluripotent and tissue stem cells is required, then the more complex and detailed activities will provide teachers with that support.

**Background teacher information**

There are two main types of stem cells:

- **Pluripotent stem cells** can make every cell in the body except for placental cells. Examples of these cells include:
  - Embryonic stem cells have the capacity to renew themselves indefinitely and make almost every cell type in the body. They are obtained from embryos at a very early stage of development (pre implantation). This makes them extremely useful to scientists for research into how cells and tissues of the body grow and develop, and potentially useful for curing disease. However, an embryo must be destroyed to obtain the stem cells.
  - **iPS cells** – induced pluripotent stem cells – are stem cells made directly from a body cell (a somatic cell). Somatic cells are all the cell types of the human body apart from sperm or egg. The most common somatic cells used to make iPS cells are skin cells. The skin cells are induced to become pluripotent stem cells via various reprogramming techniques and have very similar features to embryonic stem cells. An advantage of the iPS cells is the ability to make patient specific cells for further research into the progression of that disease. Another possible advantage is that the cells will have the same ‘self’ markers as the donor nucleus. This potentially eliminates the issue of tissue rejection when transplanted back to the patient. However there are many other safety issues associated with this technology before this is an option.
  - **SCNT** – somatic cell nuclear transfer (therapeutic cloning) stem cells. These pluripotent cells are formed by inserting a somatic cell nucleus into an enucleated egg (an egg which has had the nucleus removed) which is then coaxed into dividing and becoming an embryo. The embryo then grows normally until the stem cells can be isolated. These stem cells resemble embryonic stem cells, but similar to the iPS cells, the SCNT pluripotent stem cells have the same ‘self’ markers as the donor nucleus and have the same potential advantages. SCNT stem cells have been made in mice and non-human primates (monkeys) but the technique has not yet worked using human cells.

- **Tissue stem cells** are termed multipotent as they can make many cells but only of a certain type. They can usually only make the main cell types from which they are derived. Most tissues contain only a very small number of stem cells and are usually difficult to obtain and grow in the laboratory. The most well known tissue stem cell resides in the bone marrow and umbilical cord of a newborn.
Purpose

This chapter contains activities designed to introduce the different types of stem cells and to help explain where they are derived. The activities can be used to build background knowledge on stem cell types for senior English, ethics or Philosophy students preparing an issue based task on stem cells. The activities can also be used for year 10–12 Science students as part of a unit of work to consolidate student's understanding of cells, cell types and the versatility of stem cells.

Activity 2.1 The two main categories of stem cells

Activities to introduce the different types of stem cells
2.1.1 Find the information and fill in the table (basic) (using online resources and print).
2.1.2 Cut and paste sheet – jumbled table task (basic).
2.1.3 Find the information and fill in the table (complex) (using online resources and print).
2.1.4 Cut and paste sheet – jumbled table task (complex).

Activity 2.2 Visualising thinking about stem cells

Activities to visualise thinking about stem cell types
2.2.1 Mind map of stem cell types. Students can use the mind map to investigate or summarise what they know about the different types of stem cells.
2.2.2 Stem cell picture sorting. View and categorise pictures on different kinds of unspecialised and specialised cells.

Activity 2.3 Consolidating knowledge about stem cells

Activities to consolidate knowledge on the types of stem cells
2.3.1 Role play stem cell types.
2.3.1 Poster of stem cell type.

Activity 2.4 Potent lingo

Activity to become familiar with the language of stem cells

Activity 2.5 So what’s so special about stem cells?

Activity to evaluate the usefulness of stem cell types
Stem cells have the incredible capacity to make all different cell types. This reading comprehension task encourages students to appreciate how versatile stem cells are. Plant cell differentiation is also highlighted in this task.

General chapter 2 teacher resources

- http://www.eurostemcell.org/films
- http://learn.genetics.utah.edu/content/tech/stemcells
- http://www.cirm.ca.gov/Stem_Cell_Education_Portal
- http://www.stemcellschool.org
Activity 2.1
The two main categories of stem cells

Educational rationale
The following tasks are designed to give a broad overview about the two main types of stem cells – pluripotent and tissue. These tasks also challenge students to understand the benefits and limitations of each stem cell type. Once students have this understanding they will be able to evaluate issues surrounding the use of stem cells in research and medical treatment of patients. Students will also appreciate how stem cells are obtained, which will benefit students when participating in ethical discussions on stem cells.

Class time
20–40 minutes

Resources required
See specific activities.

Student knowledge outcomes
- To understand that there are many different stem cell types, including embryonic stem cells, adult stem cells, umbilical cord blood stem cells and induced pluripotent stem cells.
- To be able to explain where each cell type comes from
- To describe the basic advantages and limitations of each of the stem cell types.
- To describe a stem cells as either pluripotent or multipotent.

Student skills outcome
Reading comprehension, analysing and evaluating information, problem solving, group work.

Prior knowledge
A stem cell is an unspecialised cell that can differentiate into specialised cell types.

Common misconceptions
- All stem cells come from embryos.
  Fact: This is untrue. There are many types of stem cells: embryonic, induced pluripotent and tissue stem cells derived from organs in the body.
- Embryonic stem cells come from babies.
  Fact: This is untrue. ESCs come from the inner cell mass of an IVF blastocyst. The remaining cells in the blastocyst are the cells that form the placenta. Pluripotent embryonic stem cells (ESC) can make all cells of the human body.
- Stem cells from the umbilical cord are always kept to be used later.
  Fact: Stem cells from the umbilical cord are routinely discarded. While the umbilical cord is a rich source of haematopoietic stem cells and are used to treat patients with leukaemia and other blood cancers, the majority of umbilical cords are thrown away in Australia.
- Somatic cell nuclear transfer cell research is mainly carried out to discover ways to clone humans.
  Fact: This is untrue. Most SCNT research is focussed on developing tissues for scientists to better understand the basis of diseases.
- Embryonic stem cells can make a baby.
  Fact: This is untrue. While embryonic stem cells have the ability to make all cells of the body, they are unable to make the placental cells (to make the placenta). Without a placenta a pregnancy cannot occur.
Further Resources
- Genetic Science Learning Centre – stem cells. Effective graphics: http://learn.genetics.utah.edu/content/tech/stemcells
- 'What are stem cells' video. Catalyst: http://www.abc.net.au/catalyst/stemcells
- Sciber brain stem cell resource for teachers and students: http://www.sciberbrain.org/Home/Stemcells.aspx

References
ASCC Fact sheet 2 – Types of stem cells http://www.stemcellcentre.edu.au/For_the_Public/FactSheets.aspx

This activity can be used as either a research task using the resources outlined, or as a cut and paste activity (using the pro-forma included). The tasks are duplicated. The first set of handouts requires the input of only basic information. They deal with pluripotent stem cells and adult stem cells in general terms. The second set of handouts are more complex. Use these handouts if a greater degree of reasoning, knowledge and understanding is required of the students. NB: the evaluation questions are the same for both basic (research and jumbled task) and both complex handouts (one extra question for both of these handouts).

Basic worksheet 2.1.1 and 2.1.2 Types of stem cells

2.1.1 As a research task
Teacher directions: Give students a hard copy or electronic copy of Handout 2.1.1. Students can use the internet or hard copies of the fact sheet material to fill in the table. Animations/videos can be shown via computer on a data projector/smart board as an introduction to this activity. Complete the associated questions.

Watch the video called 'Creation of Human Embryonic Stem Cell Lines' found at http://www.stemcellchannel.com.au under ‘What are stem cells?’ (4 minutes, 42 seconds).

Materials required: Copies of Handout 2.1.1, copies of Fact sheet 2 – Types of stem cells, computer access (optional), and access to TV or data projector with speakers.

2.1.2 As a cut and paste activity
Teacher directions: Give students a hard copy of Handout 2.1.2. Students are to cut out the whole top row and left column in its entirety. The cells of the table are in the incorrect places. Ask students to cut out the cells and place them under the appropriate column and in the correct row. Students can paste the completed table into their books. Complete the associated questions.

Complex worksheets 2.1.3 and 2.1.4 Types of stem cells

2.1.3 As a research task
Teacher directions: As above however use Handout 2.1.3.

Materials required: Copies of Handout 2.1.3, copies of Fact sheet 2, 3 and 4, computer access (optional), and access to TV or data projector with speakers.

2.1.4 As a cut and paste activity
Teacher directions: As above however use handout 2.1.4.

Materials required: Copies of Handout 2.1.4, copies of Fact sheet 2, 3 and 4 (optional).
There are three main categories of stem cells. Using the resources below, investigate each stem cell type and fill in the table.


<table>
<thead>
<tr>
<th>Type of stem cell</th>
<th>Where do they come from?</th>
<th>The cells they are able to make</th>
<th>Scientific advantages of these stem cells</th>
<th>Drawbacks of these stem cells</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pluripotent stem cells</strong></td>
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<td>e.g.</td>
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<tr>
<td><strong>Multipotent tissue stem cells</strong></td>
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<td>e.g.</td>
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</tbody>
</table>
Evaluation questions

1. Based on the information you found, which stem cells do you think are the most versatile? Explain why.

2. In your opinion, which stem cell type has the most drawbacks associated with its use in the scientific field? Explain why.

3. In regards to how stem cells are obtained, explain which stem cell type you would feel most comfortable using if you required the assistance of stem cells to cure a disease.
### Handout 2.1.1

**Types of stem cells**

- Research task (basic)
- Teacher copy

This answer sheet provides the answer for Handout 2.1.1 and 2.1.2 as well as answers to the evaluation questions for both tasks.

<table>
<thead>
<tr>
<th>Type of stem cell</th>
<th>Where do they come from?</th>
<th>The cells they are able to make</th>
<th>Advantages of these stem cells</th>
<th>Drawbacks of these stem cells</th>
</tr>
</thead>
</table>
| **Pluripotent stem cells**  
E.g. embryonic stem cells (ESC), induced pluripotent stem (iPS) cells, somatic cell nuclear transfer (SCNT) stem cells. | ESC – Derived from human blastocysts (early stage embryos) about 5–7 days old.  
iPS cells – derived from reprogrammed somatic cells, such as a skin cell.  
SCNT stem cells – derived from cloned blastocyst made from a reprogrammed somatic cell and enucleated egg. | Any cell in the body. | Can be grown in large quantities in the laboratory. Can be manipulated to grow into different cell types in the laboratory.  
IPs and SCNT – these cells are an identical match to the somatic cell donor and can be used to study disease and avoid immune rejection. | Due to the pluripotent nature they also carry a risk of cancer if not treated properly before transferred to a patient.  
As ESCs are not patient specific treatments using them may trigger rejection by the patient’s immune system. |
| **Multipotent tissue stem cells**  
E.g. cord blood cells, adult stem cells such as skin stem cells, muscle stem cells. | Undifferentiated cells found in tissues and organs. | Usually only the type of cells or tissue that it is derived from. | They are capable of limited self-renewal. Use in research is less controversial. No tissue rejection if cells derived from the patient. | Small numbers found in tissue, difficult to locate. Usually only generates the cell types of the tissue in which they are found.  
With the exception of cord blood and bone marrow only small numbers are found in tissue, difficult to locate. Only generate the cell types of the tissue in which they are found. Usually difficult to grow outside the body in large numbers. |
1. Based on the information you found, which stem cells do you think are the most versatile? Explain why.

May vary between students. The different student answer will give an indication as to how much they understand. Most commonly the most versatile stem cells are embryonic, because they can be differentiated into any cell type. However, embryos must be destroyed to obtain these cells, which is controversial. Adult stem cells can be generated by the patient and thus do not have tissue rejection issues but they are very difficult to acquire and culture and are more limited in their growth potential.

2. In your opinion, which stem cell type has the most drawbacks associated with its use in the scientific field? Explain why?

Again, the answers here will be various. An embryo is destroyed when ESC's are created. Tissue stem cells are often difficult to locate and to grow outside the body and usually only make a limited number of specific cell types. Treatments based on pluripotent stem cells also carry the risks of forming cancer if not appropriately screened prior to transferring into a patient.

3. In regards to how the stem cells are obtained, explain which stem cell type you would feel most comfortable using if you required the assistance of stem cells to cure a disease you had.

Various answers. Student understanding can be ascertained by the responses to this question. Answers will reflect a student position on the use of embryos for research and use. If students show poor appreciation for the issue of embryonic use, consider using the activities on techniques for obtaining stem cells in the later chapters.
### Handout 2.1.2
Types of stem cells – jumbled task (basic)

The following table outlines the types of different stem cells and provides information about each one. The only problem is that the information is all jumbled up. Cut out the row and column headings and paste them into your workbook. Next, cut out each cell and place it under the correct column and in the correct stem cell row. Arrange the cells in your book first and check your work before you paste them down.

<table>
<thead>
<tr>
<th>Type of stem cell</th>
<th>Where do they come from?</th>
<th>The cells they are able to make</th>
<th>Advantages of these stem cells</th>
<th>Drawbacks of these stem cells</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pluripotent stem cells</strong></td>
<td>E.g. embryonic stem cells, induced pluripotent stem (iPS) cells, somatic cell nuclear transfer (SCNT) cells.</td>
<td>Due to the pluripotent nature they also carry a risk of cancer if not treated properly before transferred to a patient. As ESCs are not patient specific treatments using them may trigger rejection by the patient's immune system.</td>
<td>Usually only the type of cells or tissue that it is derived from.</td>
<td>Small numbers found in tissue, difficult to locate. Usually only generates the cell types of the tissue in which they are found. With the exception of cord blood and bone marrow only small numbers are found in tissue, difficult to locate. Only generate the cell types of the tissue in which they are found. Usually difficult to grow outside the body in large numbers.</td>
</tr>
<tr>
<td><strong>Multipotent tissue stem cells</strong></td>
<td>Can be grown in large quantities in the laboratory. Can be manipulated to grow into different cell types in the laboratory. iPS and SCNT – these cells are an identical match to the somatic cell donor and can be used to study disease and avoid immune rejection.</td>
<td>They are capable of limited self-renewal. Use in research is less controversial. No tissue rejection if cells derived from the patient.</td>
<td>ESC – Derived from human blastocysts (early stage embryos) about 5–7 days old. iPS cells – derived from reprogrammed somatic cells, such as a skin cell. SCNT stem cells – derived from cloned blastocyst made from a reprogrammed somatic cell and enucleated egg.</td>
<td>Undifferentiated cells found in tissues and organs.</td>
</tr>
</tbody>
</table>
**Evaluation questions**

1. Based on the information you found, which stem cells do you think are the most versatile? Explain why.

2. In your opinion, which stem cell type has the most drawbacks associated with its use in the scientific field? Why?

3. In regards to how the stem cells are obtained, explain which stem cell type you would feel most comfortable using if you required the assistance of stem cells to cure a disease.
There are many different examples of pluripotent and tissue stem cells. Using the resources below, research the different stem cell types and fill in the table below.

**Resource 1:** The ASCC stem cell channel (http://www.stemcelchannel.com.au). Go to ‘What are stem cells’, watch the video ‘stem cell lines’. Go to ‘resources’ and look at the fact sheets 2, 3 and 4.

<table>
<thead>
<tr>
<th>Type of stem cell</th>
<th>Where they come from?</th>
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<tbody>
<tr>
<td><strong>Pluripotent stem cell</strong></td>
<td></td>
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<tr>
<td>Embryonic stem cells</td>
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<tr>
<td><strong>Pluripotent stem cell</strong></td>
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<tr>
<td>Induced pluripotent stem cells</td>
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<tr>
<td><strong>Pluripotent stem cell</strong></td>
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<tr>
<td>Somatic nuclear transfer stem cells</td>
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<tr>
<td><strong>Multipotent tissue stem cell</strong></td>
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<tr>
<td>Cord blood</td>
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<tr>
<td><strong>Multipotent tissue stem cell</strong></td>
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<tr>
<td>Adult stem cells (e.g. nerve)</td>
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</tbody>
</table>
The following table outlines the types of different stem cells and information about each one. The only problem is that the information is all jumbled up. Cut out the row and column headings and paste them into your workbook. Next, cut out each cell and place it under the correct column and in the correct stem cell row. Arrange the cells in your book first and check your work before you paste them down.

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</tr>
</thead>
<tbody>
<tr>
<td>Pluripotent stem cell</td>
<td>These cells are an identical match to the somatic cell donor and can be used to study disease and avoid immune rejection. Replicate and generate every cell type of the body. Can be grown in large numbers in the laboratory (self-renewing). Can be frozen and stored indefinitely whilst retaining viability. Can be grown in large quantities in the laboratory. Can be manipulated to grow into different cell types in the laboratory. Therefore scientists are able to study diseases in a cell model.</td>
<td>A somatic (adult) cell nucleus is placed into an enucleated egg. The egg is then stimulated to start dividing like a normal embryo and then the embryonic stem cells are derived from the blastocyst (early stage embryo about 5–7 days old).</td>
<td>These cells are an identical match to the somatic cell donor and can be used to study disease and avoid immune rejection. Replicate and generate every cell type of the body. Can be grown in large numbers in the laboratory (self-renewing). Can be frozen and stored indefinitely whilst retaining viability. Can be grown in large quantities in the laboratory. Can be manipulated to grow into different cell types in the laboratory. Therefore scientists are able to study diseases in a cell model.</td>
<td>Replicate and generate every cell type of the body. Can be grown in large numbers in the laboratory (self-renewing). Can be frozen and stored indefinitely whilst retaining viability. Can be grown in large quantities in the laboratory. Can be manipulated to grow into different cell types in the laboratory.</td>
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<tr>
<td>Embryonic stem cell</td>
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<tr>
<td>Pluripotent stem cell</td>
<td>Usually can only make the type of cells or tissue that it is derived from.</td>
<td>Any cell in the body. They can also make copies of themselves (self-renew)</td>
<td>Relatively easy to obtain. Maturing somatic (adult) cells are induced using various methods (e.g. using retro viruses) to become pluripotent stem cells which are similar to embryonic stem cells.</td>
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<tr>
<td>Induced pluripotent stem cell</td>
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<tr>
<td>Stem Cell Type</td>
<td>Description</td>
<td>Example</td>
<td>Notes</td>
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<tr>
<td><strong>Pluripotent stem cell</strong></td>
<td>They are capable of limited self-renewal. Use in research is less controversial. No tissue rejection if cells derived from the patient. Already being used and proven safe and effective in cell therapies for leukaemia and other blood cancers and autoimmune diseases.</td>
<td>Any cell in the body. They can also make copies of themselves (self-renew).</td>
<td>A somatic (adult) cell nucleus is placed into an enucleated egg. The egg is then stimulated to start dividing like a normal embryo and then the embryonic stem cells are derived from the blastocyst (early stage embryo about 5–7 days old). With the exception of and bone marrow only small numbers are found in tissue, difficult to locate. Only generate the cell types of the tissue in which they are found. Usually difficult to grow outside the body in large numbers.</td>
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<tr>
<td>Somatic nuclear transfer stem cells</td>
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<tr>
<td><strong>Multipotent tissue stem cell</strong></td>
<td>Haematopoietic (blood forming) stem cells derived from the umbilical cord can also be used to isolate mesenchymal stem cells (MSC) that can make muscle, cartilage and bone.</td>
<td>Any cell in the body. They can also make copies of themselves (self-renew).</td>
<td>Derived from blastocysts (early stage embryos) about 5–7 days old. In Australia researchers are only allowed to use human embryos that have been donated from IVF couples who have completed their infertility treatment.</td>
<td>Undifferentiated cells found in tissues and organs.</td>
</tr>
<tr>
<td>Cord blood</td>
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<tr>
<td><strong>Multipotent tissue stem cell</strong></td>
<td>Due to the pluripotent nature they carry a risk of cancer if not treated properly before transferred to a patient. The objective is to transfer a pure population of the cell type you are trying to achieve, if not done correctly, cancer risks arise. Additionally, as ESCs are not patient specific they can trigger rejection by the patient’s immune system is transferred.</td>
<td>Donor cord blood needs to be tissue matched to avoid rejection. Issues surrounding ‘saviour siblings’ and ‘designer embryos’. Still testing wider uses of cord blood for other diseases.</td>
<td>This process remains theoretical for humans. The process is heavily legislated as it has the capacity (in theory) to produce human clones. There are biological differences between naturally fertilised embryos and SCNT embryos. Due to the pluripotent nature they also carry a risk of cancer if not treated properly before transferred to a patient.</td>
<td>Currently, the process is still being developed as cells in previous animal research studies have developed cancer. The full extent of cellular pluripotency has also not been confirmed. Due to the pluripotent nature they also carry a risk of cancer if not treated properly before transferred to a patient.</td>
</tr>
<tr>
<td>Adult stem cells (e.g. blood)</td>
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</table>
2.1.3 Evaluation questions

1. Based on the information you found, which stem cells do you think are the most versatile? Explain why.

2. In your opinion, which pluripotent stem cell type has the most drawbacks associated with its use? Why?

3. In your opinion, which tissue stem cell type has the most drawbacks associated with its use? Why?

4. The main excitement surrounding iPS and SCNT cells is their potential use in researching the attributes of a disease and not necessarily direct use in humans. What do you think is meant by this statement?

5. In regards to how the stem cells are obtained, explain which stem cell type you would feel most comfortable using if you required the assistance of stem cells to cure a disease you had.
## Handout 2.1.3 and 2.1.4
### Types of stem cells
**– research task and jumbled table (complex)**
**– Teacher copy**

<table>
<thead>
<tr>
<th>Type of stem cell</th>
<th>Where they come from?</th>
<th>The cells they are able to make</th>
<th>Advantages of these stem cells</th>
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</thead>
<tbody>
<tr>
<td>Pluripotent stem cell</td>
<td>Derived from blastocysts (early stage embryos) about 5–7 days old. In Australia researchers are only allowed to use human embryos that have been donated from IVF couples who have completed their infertility treatment.</td>
<td>Any cell in the body. They can also make copies of themselves (self-renew)</td>
<td>Replicate and generate every cell type of the body. Can be grown in large numbers in the laboratory (self-renewing). Can be frozen and stored indefinitely whilst retaining viability. Can be grown in large quantities in the laboratory. Can be manipulated to grow into different cell types in the laboratory.</td>
<td>Due to the pluripotent nature they carry a risk of cancer if not treated properly before transferred to a patient. The objective is to transfer a pure population of the cell type you are trying to achieve, if not done correctly, cancer risks arise. Additionally, as ESCs are not patient specific they can trigger rejection by the patient’s immune system is transferred.</td>
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<tr>
<td>Embryonic stem cell</td>
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</tr>
<tr>
<td>Induced pluripotent stem cell</td>
<td>Mature somatic (adult) cells are induced using various methods (e.g. using retro viruses) to become pluripotent stem cells which are similar to embryonic stem cells.</td>
<td>Any cell in the body. They can also make copies of themselves (self-renew).</td>
<td>These cells are an identical match to the somatic cell donor and can be used to study disease and avoid immune rejection. Replicate and generate every cell type of the body. Can be grown in large numbers in the laboratory (self-renewing). Can be frozen and stored indefinitely whilst retaining viability. Can be grown in large quantities in the laboratory. Can be manipulated to grow into different cell types in the laboratory. Therefore scientists are able to study diseases in a cell model.</td>
<td>Currently, the process is still being developed as cells in previous animal research studies have developed cancer. The full extent of cellular pluripotency has also not been confirmed. Due to the pluripotent nature they also carry a risk of cancer if not treated properly before transferred to a patient.</td>
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<tr>
<td>Pluripotent stem cell</td>
<td>Somatic nuclear transfer stem cells</td>
<td>Any cell in the body. They can also make copies of themselves (self-renew).</td>
<td>These cells are an identical match to the somatic cell donor and can be used to study disease and avoid immune rejection. Replicate and generate every cell type of the body. Can be grown in large numbers in the laboratory (self-renewing). Can be frozen and stored indefinitely whilst retaining viability. Can be manipulated to grow into different cell types in the laboratory. Therefore scientists are able to study diseases in a cell model.</td>
<td>This process remains theoretical for humans. The process is heavily legislated as it has the capacity (in theory) to produce human clones. There are biological differences between naturally fertilised embryos and SCNT embryos. Due to the pluripotent nature they also carry a risk of cancer if not treated properly before transferred to a patient.</td>
</tr>
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<td>----------------------</td>
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</tr>
<tr>
<td>Multipotent tissue stem cell</td>
<td>Umbilical cord blood</td>
<td>From cells in the umbilical cord, this is attached to the placenta at birth.</td>
<td>Haematopoietic (blood forming) stem cells derived from the umbilical cord can also be used to isolate mesenchymal stem cells (MSC) that can make muscle, cartilage and bone.</td>
<td>Relatively easy to obtain. Can be induced to make a range of blood and circulatory system cells. Can be patient specific which reduces tissue rejection. Already being used and proven safe and effective in cell therapies for leukaemia and other blood cancers and auto immune diseases.</td>
</tr>
<tr>
<td>Multipotent tissue stem cell</td>
<td>Adult stem cells (e.g. nerve)</td>
<td>Undifferentiated cells found in tissues and organs.</td>
<td>Usually can only make the type of cells or tissue that it is derived from. They are capable of limited self-renewal. Use in research is less controversial. No tissue rejection if cells derived from the patient. Already being used and proven safe and effective in cell therapies for leukaemia and other blood cancers and auto immune diseases.</td>
<td>With the exception of and bone marrow only small numbers are found in tissue, difficult to locate. Usually difficult to grow outside the body in large numbers.</td>
</tr>
</tbody>
</table>
2.1.3 and 2.1.4 Evaluation questions – Teacher copy

1. Based on the information you found, which stem cells do you think are the most versatile? Explain why.
   May vary between students. The different answers will give an indication as to how much students understand. Most commonly, the most versatile stem cells are embryonic, because they can be differentiated into any cell type. However, embryos must be destroyed to obtain these cells, which is controversial. Adult stem cells are generated by the patient and thus do not have tissue rejection issues but they are very difficult to acquire and culture and are tissue.

2. In your opinion, which pluripotent stem cell type has the most drawbacks associated with its use? Why?
   Again, the answers here will be varied. Points to be considered:
   a. embryonic stem cell involve the destruction of a embryo which may be viewed as a life
   b. the process of obtaining iPS cells is still being developed
   c. embryonic and iPS cells both have the potential to become any cell in the human body
   d. therapies based on pluripotent stem cells are not yet proven safe and carry the risk of forming cancer if not appropriately treated prior to transfer to a patient
   e. SCNT cells bring up issues relating to human cloning

3. In your opinion, which tissue stem cell type has the most drawbacks associated with its use? Why?
   Again, the answers here will be varied. Tissue stem cells can usually only make cells of the same type as the tissue they were derived from. Stem cells from bone marrow and cord blood can make a number of different blood and immune systems cells and are already being used in cell therapies. Where the cord blood and bone marrow are taken from a donor there is a requirement for the tissue to be matched to avoid rejection. Tissue adult stem cells derived from the patient do not have tissue rejection issues. Using a patient’s own adult stem cells also eliminates the issue of ‘designer’ or ‘saviour’ babies. Drawbacks of adult stem cells include the difficulty in locating the cells and they have limited growth potential in culture and obtaining appropriate ‘match’ to avoid rejection.

4. The main excitement surrounding iPS and SCNT cells is their potential use in researching the attributes of a disease and not necessarily direct clinical applications. What do you think is meant by this statement?
   From this statement, students should decipher that iPS cells and SCNT cells have more potential in research than in clinical/therapeutic use. Scientists see enormous research potential using these cells. When these types of cells are highlighted in the media, many people become passionate about their hypothetical uses, such as cloning humans (i.e. Making clones of dead relatives or cloning past political leaders etc). Misinformation can sway public opinion. Although, in theory, a human ‘could’ be cloned (and it should be noted that some agricultural animals are being cloned, such as Dolly the sheep), human stem cell scientists are more interested in using these cells to learn more about diseases and how they function in the body. This information is what will help scientists find cures.

5. In regards to how the stem cells are obtained, explain which stem cell type you would feel most comfortable using if you required the assistance of stem cells to cure a disease.
   Various answers. Student understanding can be ascertained by the responses to this question. Answers will reflect a student position on the use of embryos for research and use. If students show poor participation or appreciation for the issues surrounding the use of embryos, consider using the activities on techniques for obtaining stem cells in the later chapters.
Activity 2.2
Visualising thinking on stem cells

The next two activities cater for all students, but will appeal to visual learners in particular. These activities ask students to summarise information and visualise their thinking. Use these tasks to summarise knowledge gained in activities in 2.1. The two main categories of stem cells, or else use the activities as standalone research or problem solving tasks.

Activity 2.2.1 Mind map of stem cell types

Purpose
This activity is a mind mapping exercise to help students visualise their thinking about the different stem cell types. It can be used as a research activity or as a summary task (after completing activities from chapter 2.1).

Class time
20–40 minutes

Resources required
2.2.1 Mind map of stem cell types (A3 or A4), completed activity sheets from chapter 2.1 (optional), printed fact sheets (2, 3, and 4) from http://www.stemcellcentre.edu.au/For_the_Public/FactSheets.aspx or access to computers.

Student knowledge outcomes
- To summarise understanding of the different stem cell types, including: pluripotent stem cells and tissue stem cells.
- To be able to explain where each stem cell type comes from
- To summarise the basic advantages and limitations of each of the stem cell types.
- To be able to use the words multipotent and pluripotent to describe stem cell types

Student skills outcome
Summarising, to visualise thinking via mind mapping, analysing and evaluating information, problem solving, group work.

Prior knowledge
- A stem cell is an unspecialised cell that can differentiate into many cell types.
- Pluripotent stem cells include embryonic stem cells, induced pluripotent stem cells and somatic cell nuclear transfer stem cells.
- Tissue stem cells (multipotent) include stem cells from all tissues of the body including the blood forming (haematopoietic) stem cells from bone marrow and cord blood. Often referred to as adult stem cells.

Common misconceptions
- All stem cells come from embryos.
  
  Fact: This is untrue. There are many types of stem cells: embryonic, induced pluripotent and tissue stem cells derived from organs in the body.
- Embryonic stem cells come from babies.
  
  Fact: This is untrue. ESCs come from the inner cell mass of an IVF blastocyst. The remaining cells in the blastocyst are the cells that form the placenta. Pluripotent ESCs can make all cells of the human body.
Stem cells from the umbilical cord are always kept to be used later.

**Fact:** Stem cells from the umbilical cord are routinely discarded. While the umbilical cord is a rich source of haematopoietic stem cells and are used to treat patients with leukaemia and other blood cancers, the majority of umbilical cords are thrown away in Australia.

Somatic cell nuclear transfer cell research is mainly carried out to discover ways to clone humans.

**Fact:** This is untrue. Most SCNT research is focussed on developing tissues for scientists to better understand the basis of diseases.

Embryonic stem cells can make a baby.

**Fact:** This is untrue. While embryonic stem cells have the ability to make all cells of the body, they are unable to make the placental cells (to make the placenta). Without a placenta a pregnancy cannot occur.

**Further Resources**

- Great animation on types of stem cells with very effective graphics: http://learn.genetics.utah.edu/content/tech/stemcells/
- ‘What are stem cells’ video. Catalyst: http://www.abc.net.au/catalyst/stemcells
- Sciber brain stem cell resource for teachers and students: http://www.sciberbrain.org/Home/Stemcells.aspx

**References**


**Teacher directions**

**As a learning task:** Print out Handout 2.2.1 Mind map of stem cell types onto A3 or A4 paper. Distribute to individual students or pairs of students. Using printed fact sheets or the internet resources, ask students to annotate the mind map with further information on each of the headings. They may like to include diagrams or printed pictures if it assists with their visualisation of the concepts.

**As a summary task:** Print out Handout 2.2.1 Mind map of stem cell types onto A3 or A4 paper. Distribute to individual students or pairs of students. Ask students to write down all they know about the different headings. If they have trouble remembering, direct them to previous worksheets or facts sheets (printed or on the internet). They may like to include diagrams or printed pictures if it assists with their visualisation of the concepts.
Handout 2.2.1
Mind map of stem cell types

Task: This mind map shows an outline of the different types of stem cells. Summarise what you know about these different cell types and write this information next to the headings. NB The ‘Stem cells’ summary has been done for you.

Stem cells

Tissue stem cells (multipotent)
- Eg. Skin
- Eg. Blood (Haematopoietic)
- Eg. Bone (Mesenchymal stem cells)

Cord blood
Bone marrow

Pluripotent stem cells
- Embryonic stem cells
- Induced pluripotent stem cells

Somatic cell nuclear transfer stem cells

Stem cells are unspecialised, can become specialised and are self renewing.
**Activity 2.2.2 Stem cell picture sorting**

**Purpose**
Many students learn well through exposure to visually appealing activities. In this task there are a number of amazing photographs from the Australian Stem Cell Centre. Students can arrange the photographs based on the complexity of the cells that they see. Although students will not be able to distinguish the exact morphology of the images, it should give them an understanding that specific cell types produce specific proteins that make them a specialised cell.

**Class time**
15–30 minutes

**Resources required**
Printed images from a PowerPoint file available for download from http://www.stemcellcentre.edu.au/For_the_Public/StemCellsinSchool/TeachersKit.aspx

**Student knowledge outcomes**
- For students to understand that from an embryonic stem cell can arise practically any cell in the body. The number of different cells and tissues that can be generated from these generic cells is amazing!
- From a multipotent tissues specific stem cell, only a few cells types can be generated.
- Specialised cells make certain types of proteins which is what makes the cell specialised.
- Specialised cells often have distinctive morphology.
- Scientists use different stains to highlight the presence of certain molecules, such as proteins.

**Student skills outcome**
Problem solving, application of prior knowledge, analysing and evaluating information, group work.

**Prior knowledge**
- A stem cell is an unspecialised cell that can differentiate into many cell types.
- Pluripotent stem cells include embryonic stem cells, induced pluripotent stem cells and somatic cell nuclear transfer stem cells.
- Tissue stem cells (multipotent) include cord blood stem cells, skin stem cells, blood, muscle stem cells etc.

**Common misconceptions**
- Scientific stem cell photographs are always coloured.
  - Fact: Not always true. Some scientific photographs are artificially coloured to highlight key organelles or structures. Electron micrographs are initially black and white. Colours are added for effect. Some photographs are also overlays of a number of different exposures at different wavelengths of light (e.g. FISH – fluorescent in-situ hybridisation photos. The probes used in these diagrams fluoresce at different wavelengths so a number of photographs need to be taken).
- It's difficult to tell what the diagram is.
  - Fact: This is true! To the untrained eye, it is difficult to tell what the photograph is specifically. However, the complexity of the cells morphology and the proteins produced by the cell help the scientist identify specific types of cells.

**Further Resources**
- The following site contains a number of images of human embryonic material.
  http://www.advancedfertility.com/embryos.htm

**References**
Embryo images courtesy of Monash IVF.
Stem cell images courtesy of ASCC.
Teacher directions

1. Project the images onto a screen or print off and supply to students.

2. Present students with the picture of the embryo and blastocyst (5–7 day old embryo) (simple, low colour diagram with easily distinguishable cells). Then show students the brilliant and colourful images of the different embryonic or tissue (adult stem cell).

3. Ask students to categorise the pictures into:
   a. The original, simple, primordial (or precursor) cells (i.e. the embryo cells). NB these images tend to be taken when the embryo is alive and so there is no stain present.
   b. The stem cells or specialised cells that are derived from the stem cells.
      - Highlight to students that images depicting stem cells or specialised cells will be complex in nature. There may be numerous cells and the images may be difficult to decipher. These cell images may be stained (coloured). Specialised tissue has specialised proteins and therefore may have special colours. Stains can be protein specific and are usually colourful (can be fluorescent). Stress to the students that they don’t have to know or guess what the images are of (this is very difficult to do). Their task is to categorise the pictures into simple unspecialised cells and specialised cells.
   c. Show diagram 2.2.2 What am I looking at? Deciphering scientific photographs, found below as an example.
   d. Once students have categorised their cells and discussed the diagrams, ask them to write a reflection in their workbooks about what they have learned about the different kinds of stem cells and also about scientific photography.
Diagram 2.2.2 What am I looking at? Deciphering scientific photographs

- **8 cell embryo (approx 3 days old)**

- **Blastocyst embryo (approx 5–7 days old)**

Light microscopy, live specimen, not stained, no fluorescence, grey scale or monochromatic, rounded cell shapes.

Fluorescence microscopy, colourful, complex structures stained, nuclei stained and mostly visible, lots of cells, diverse cell shapes.

- **Embryonic stem cells (pluripotent)**

- **Tissue stem cells (multipotent)**
Activity 2.3
Consolidating knowledge about stem cells

Create a role play or a poster about the types of stem cells

For introductory information, resources, links and key knowledge see the information at the start of activity 2.1.

Class time
30–90 minutes

Role play activity

Teacher directions: Split students up into four groups. Assign a stem cell type to each group (embryonic stem cells, tissue stem cells, umbilical cord blood cells, induced pluripotent stem cells, somatic cell nuclear transfer cells). Students are to create a role play about the creation, advantages and disadvantages of their type of stem cell. Act out their role play to the other members of the class. The audience members are then questioned about their understanding of that cell type. Ask students to write a summary in their books about each of the stem cell types.

Materials required
- Hard copies of Fact sheet 2 – Types of stem cells.
- Access to computers for online research (optional).
- Student workbooks for writing a summary/evaluation at the end of the task.

Create a poster on their type of stem cell

Teacher directions: Provides students with Fact sheet 2 (and 3, 4 for added complexity) – Types of stem cells and/or links to the internet resources above and ask students to produce a poster on a type, or many types of stem cells. Teachers might like to have students work in groups. Each group can make a small presentation to the rest of the class at the completion of the lesson. Posters can be displayed on the classroom walls and can be referred to when discussing the issues surrounding stem cells later in the unit. Encourage students to view other groups work and write a reflection on what they have learned about the types of stem cells.

Materials required
- Butcher’s paper/ poster paper/ A3 paper.
- Felt tip pens, colouring pencils, colours paper.
- Student access to computers and a printer.
Activity 2.4
Potent lingo

As examined in activity 2.1 there are a few different stem cell types. When scientists refer to different stem cell types, they often refer to the potency of the cell, that is, its potential to give rise to any cell type or whether it can only give rise to a specific cell line and also how many specialised cells they can produce. The following activity can be used to help students differentiate between the different words used to explain the ability of stem cells to produce other cells.

Class time
10–15 minutes

Resources required
Handout 2.2 Potent lingo

Student knowledge outcomes
- To become familiar with the language used to describe the different potency of cells, i.e. pluripotent, multipotent, and totipotent.

Student skills outcome
- To realise that in biology many words are made up of one or more descriptive Latin or Greek origin words and that the meaning of difficult words can often be deciphered.

Prior knowledge
- Stem cells are undifferentiated cells that give rise to other cell types.
- There are different stem cell types, such as embryonic stem cells, tissue stem cells and iPS cells (induced pluripotent stem cells).

Common misconceptions
**Note for teachers:** The use of the word totipotent refers to the cells within a 1–4 day embryo. Each cell of an embryo at this stage can theoretically make a whole new individual. It is a word that is used infrequently by stem cell scientists, but is still prevalent in secondary school text books. The pluripotent stem cells that are most commonly referred to in the media are derived from blastocyst embryos, which are 5–7 days old.

Further Resources
Information on the use of ‘potential’ words. This site explains the level of potency as a tissue type develops:
http://www.csa.com/discoveryguides/stemcell/overview.php
In science many of the words used to describe something are one or more Latin or Greek words used together. For example the word dinosaur comes from the Greek words deïnos meaning ‘terrible’ + sauros meaning ‘lizard’.

### Table 1: Common Latin and Greek prefixes and suffixes used to make scientific words.

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Description</th>
<th>Suffix</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-</td>
<td>Many, much, multiple</td>
<td>-cellular</td>
<td>Made of cells</td>
</tr>
<tr>
<td>Pluri-</td>
<td>More or most</td>
<td>-parous</td>
<td>Giving birth to</td>
</tr>
<tr>
<td>Tatus- (toti)</td>
<td>Meaning whole or total</td>
<td>-potis</td>
<td>Potential</td>
</tr>
<tr>
<td>Uni-</td>
<td>One, singular</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Using the table below, decipher the meanings of the following scientific words:
   a. Multipotent
   b. Uniparous
   c. Pluripotent
   d. Multicellular

2. Using the information in the table, explain what you think the difference might be between a cell that is multipotent and cell that is classified as pluripotent.

3. A totipotent cell is found in a very young embryo (about 1–4 days old). What do you think totipotent means when it is used to describe a cell?

4. Identical twins arise when a totipotent embryo splits. This is really cloning, as both new embryos are genetically identical. The diagrams below show the different stages of embryo development. To make twins, there has to be a way of dividing the cells evenly to ensure both new embryos receive the genetic information. Draw a line through the embryo with totipotent cells that will divide evenly to make identical twins.
In science many of the words used to describe something are one or more Latin or Greek words used together. For example, the word dinosaur comes from the Greek words *deinos* meaning ‘terrible’ + *sauros* meaning ‘lizard’.

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<tr>
<td>Uni-</td>
<td>One, singular</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Using the table below, decipher the meanings of the following scientific words:
   a. Multipotent: many – potential. Stem cells that make many different cell types.
   b. Uniparous: one – giving birth to. Giving birth to one offspring.
   c. Pluripotent: most – potential. Stem cells that give rise to more/most cell types.

2. Using the information in the table, explain what you think the different might be between a cell that is multipotent and cell that is classified as pluripotent.
   Multipotent would give rise to many cell types. Pluripotent would give rise to more or the most cell types.

3. A totipotent cell is found in a very young embryo (about 1–4 days old). What do you think totipotent means when it is used to describe a cell?
   Totipotent means ‘total-power’. These cells would be able to give rise to all cell types.

4. Identical twins arise when a totipotent embryo splits. Both new embryos are genetically identical. The diagrams below show the different stages of embryo development. To make twins, there has to be a way of dividing the cells evenly to ensure both new embryos receive the genetic information. Draw a line through the embryo with totipotent cells that will divide evenly to make identical twins.

The above are **correct**. It is imperative students indicate that each half of the sectioned blastocyst includes a component of inner cell mass cells.

The above are **incorrect** as they fail to include sufficient allocation of embryonic cells.
Activity 2.5
So what’s so special about stem cells?

Having completed some of the other activities on stem cells, use this activity as a thinking task about how important stem cells are and why they have such unique potential.

This task is not all about stem cells. It can be used in any biology class to reinforce how cells are different, yet inherently have very similar internal organelles.

Class time
Approx 5–15 minutes reading time
5 minutes constructing glossary
10–15 minutes answering questions

Resources required
- Handout 2.5 ‘So what’s so special about stem cells?’
- Workbooks or loose leaf paper.

Student knowledge outcomes
- Differentiate between the different ground tissue types in developing embryos and plant seedlings.
- Understand the plant cells can transdifferentiate (form different cell types after specialisation has occurred) where as human cells, once specialised, cannot change cell type.

Student skills outcome
- Reading comprehension, interpreting new information, applying previous knowledge and understanding to new situations, visualising thinking and higher order thinking.

Prior knowledge
- Cells are the basic building blocks of living things.
- A basic understanding of the major organs/tissues of the human body.
- A basic understanding of the different tissue types in a plant, i.e. stem, root, leaves.

Common misconceptions
- In humans, specialised cells can repair any damaged or diseased tissue.
  Fact: Not true. Stem cells that reside in tissue are responsible for normal maintenance of tissue and organ function but usually do not have the capacity to completely repair or replace diseased or damaged cells.
- Human cells have the same regenerative properties as plant cells.
  Fact: Not true. Plants can be propagated via cuttings but humans cannot.

Further Resources
- BioCoach Activities – online student activities on plant structure:
- BioCoach Activities – references for teachers:
- Biology reference – glossary of terms:
  http://www.biologyreference.com/Co-Dn/Differentiation-in-Plants.html
References


Teachers can also provide students with the glossary found at the end of this kit.
Handout 2.5
So what’s so special about stem cells?

Text box 1 The first cell types in animals and plants

Human pluripotent stem cells have the extraordinary capacity to form every cell in the body. Pluripotent stem cells differentiate into three germ layers within a developing embryo. These three layers are: the ectoderm, the mesoderm and the endoderm. The ectoderm layer gives rise to the skin (and related structures), sensory and autonomic nerve cells as well as skin pigment cells and sensory organs. The second layer, the mesoderm, eventually gives rise to bone cells, muscle cells, red blood cells, kidneys and connective tissues. The endoderm layer is the innermost layer in the developing embryo. It gives rise to the gut and other internal organs, such as the pancreas and lung alveoli cells.

By contrast to animals, plants only have about a dozen different cell types. These different cell types are derived from the apical meristems (the region found at the very tip of the shoot or root). Undifferentiated plant cells rely on signals from neighbouring cells to induce cells to develop into one of the three precursor tissue types: the protoderm (dermal tissue), ground meristem and the procambium (vascular tissue). These precursor tissues are found in a predictable fashion in the plant. The protoderm makes the outer plant cell layers, which are made up of the epidermal cells and guard cells. Inward from this layer is the dermal layer. This consists of the larger, more supportive and undifferentiated cells called parenchyma. Mesophyll cells are a type parenchymal cell found in the leaves and shoots. These cells carry out photosynthesis. The procambium is the innermost layer and forms the vascular tissue, namely the xylem and phloem.

Questions for text box 1

1. Using the text above, complete the following mind map showing how a pluripotent stem cell differentiates into the three germ layers and then into the many different cell types in a human.

   ![Mind Map](image)

2. Draw a similar mind map (or a circular mind map) showing how plant cell types are derived.
Text box 2 Specialised cell types in animals and plants

In plants, as cells grow further away from the apical meristems, they can become increasingly more specialised. In roots, the epidermal cells might start to make root hair cells. In leaves, guard cells of the stomata will form. If a tissue is damaged, surrounding plant cells will divide and repair the wound.

Once tissues and organs in the human body are formed, tissue (adult) stem cells aid in growth and repair. Unlike in plants, only the stem cells in a particular organ or tissue can aid in the repair of that specific organ or tissue. For example, haematopoietic stem cells in the bone marrow usually only give rise to new blood cells and immune system cells. But these are the only specialised cell types these stem cells can normally produce. It is interesting to note, that when these adult stem cells divide, they make more copies of the stem cells as well as copies of the other required blood cells. That way, there is always a readily available supply of stem cells in the bone marrow.

Questions for text box 2

3. Would a human bone cell within the body be able to aid in the repair of the liver? Explain why/why not.

4. If an epidermal cell on a plant leaf was damaged by an herbivorous insect, which cells would repair the wound?
1. Using the text above, complete the following mind map showing how a pluripotent stem cell differentiates into the three germ layers and then into the many different cell types in a human.

```
Pluripotent stem cell
  ↓
Ectoderm
  ↓
Skin
  ↓
Sensory organs
  ↓
Sensory and autonomic nerve cells
  ↓
Skin pigment cells
  ↓
Mesoderm
  ↓
Bone cells
  ↓
Muscle cells
  ↓
Connective tissue
  ↓
Red blood cells
  ↓
Endoderm
  ↓
Kidney cells
  ↓
Lung alveoli cells
  ↓
Gut
  ↓
Skin
  ↓
Sensory organs
  ↓
Sensory and autonomic nerve cells
  ↓
Skin pigment cells
  ↓
Mesoderm
  ↓
Bone cells
  ↓
Muscle cells
  ↓
Connective tissue
  ↓
Red blood cells
  ↓
Endoderm
  ↓
Kidney cells
  ↓
Lung alveoli cells
  ↓
Gut
```

2. Draw a similar mind map showing how plant cell types are derived.

```
Protoderm
  ↓
Ground meristem
  ↓
Procambium
Vascular tissue: xylem and phloem
  ↓
Epidermal cells
  ↓
Guard cells
  ↓
Parenchyma cells
  ↓
Apical meristem
  ↓
Protoderm
  ↓
Ground meristem
  ↓
Procambium
Vascular tissue: xylem and phloem
  ↓
Epidermal cells
  ↓
Guard cells
  ↓
Parenchyma cells
```

3. Would a human bone cell within the body be able to aid in the repair of the liver? Explain why/why not.
   No. A bone cell in the body is already differentiated into a specialised cell type and cannot be changed into liver tissue. (NB if the bone cell was removed from the body; its nucleus could be removed and made into an induced pluripotent stem cell. See chapter 3 for more information on these special cells.)

4. If an epidermal cell on a plant leaf was damaged by an herbivorous insect, which cells would repair the wound?
   Other epidermal cells surrounding the wound.