D3.1 Reproduction

Continuity and change—Organisms

Standard level and higher level: 5 hours

Additional higher level: 3 hours

Guiding questions

• How does asexual or sexual reproduction exemplify themes of change or continuity?

• What changes within organisms are required for reproduction?

Recommended prior learning:

SL and HL

D3.1.1—Differences between sexual and asexual reproduction

Include these relative advantages: asexual reproduction to produce genetically identical offspring by individuals that are adapted to an existing environment, sexual reproduction to produce offspring with new gene combinations and thus variation needed for adaptation to a changed environment.

Sexual reproduction	Asexual reproduction
2 parents of opposite gender needed	1 parent
Genetically different offspring	Genetically identical offspring
Genetic change (variation)	Genetic continuity (no variation)
Sexual life cycle (mitosis + meiosis)	Asexual life cycle (only mitosis)

D3.1.2—Role of meiosis and fusion of gametes in the sexual life cycle

Students should appreciate that meiosis breaks up parental combinations of alleles, and fusion of gametes produces new combinations. Fusion of gametes is also known as fertilization.

Meiosis *halves* the number of chromosomes in order to break up parental combinations of alleles and create more variation. **Fertilization** is the fusion of gametes in order to *double* the number of chromosomes again back to diploid.

D3.1.3—Differences between male and female sexes in sexual reproduction

Include the prime difference that the male gamete travels to the female gamete, so it is smaller, with less food reserves than the egg. From this follow differences in the numbers of gametes and the reproductive strategies of males and females.

	Male gamete	Female gamete
Size	Smaller	Larger
Motility	Motile + mobile, travel to female	Sessile
Quantity	Many	Fewer
Nutritional reserves	Less - enough for one gamete	More – enough for embryo development

D3.1.4—Anatomy of the human male and female reproductive systems

Students should be able to **draw diagrams of the male-typical and female-typical systems and annotate them** with names of structures and functions.

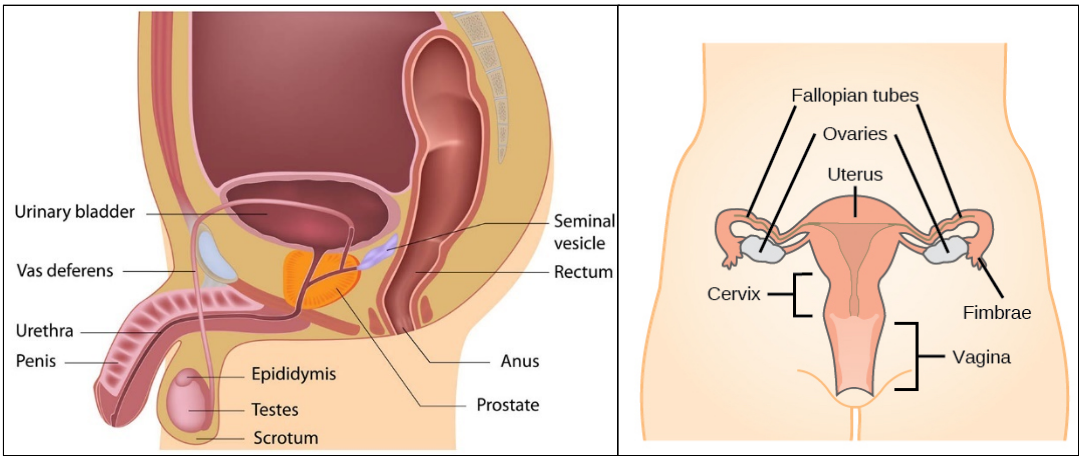

Figure 1: male and female reproductive systems (Healthdirect, Khan Academy).

Male Structure	Function
Testis	Site of spermatogenesis and testosterone production
Scrotum	Loose skin to protect the testis
Epididymis	Site of sperm maturation
Seminal vesicle	Produce seminal fluid
Prostate gland	Nourishes and supports sperm through fluid secretions
Vas deferens	Carries sperm to prostate gland and urethra
Penis	Used for urination and intercourse
Urethra	Tube carrying urine and semen

Female Structure	Function
Ovaries	Site of oogenesis / development of oocytes (eggs)
Fallopian tubes (oviducts)	Transportation of secondary oocyte to uterus and site of fertilization
Uterus	Support in embryo development
Cervix	Connects the uterus and vagina
Vagina	Birth canal, passage of menstrual flow, entry way for semen
Fimbriae	Assists in transporting the secondary oocyte from ovaries to tubes

D3.1.5—Changes during the ovarian and uterine cycles and their hormonal regulation

Include the roles of oestradiol, progesterone, luteinizing hormone (LH), follicle-stimulating hormone (FSH) and both positive and negative feedback. The ovarian and uterine cycles together constitute the menstrual cycle.

The primary hormones produced by the ovaries are **estrogens**, which include **estradiol**, estrone, and estriol. Estrogens play a significant role in the development of primary and secondary sexual characteristics in females. The ovaries also produce **progesterone**, which regulates the menstrual cycle and prepares for pregnancy as well as maintains it.

The ovarian and uterine cycles *together* constitute the **menstrual cycle**. The **ovarian cycle** describes the changes occurring in the follicles of the ovary and is correlated with but is *not* the same as the menstrual cycle.

Ovarian cycle stage 1 | Follicular phase (pre-ovulatory)

- FSH is secreted by the pituitary gland to stimulate the growth of follicle**s**
- LH is released by the pituitary gland to stimulate the production of estradiol in the follicle**s**
- The high estrogen concentrations inhibit the production of FSH and LH (negative feedback). Since the developing follicles need FSH to develop, many will die as a result
- Only the **dominant follicle** will survive and will begin producing even greater amounts of estrogen to the extent that the *normal* negative feedback loop no longer applies
- The extremely high estrogen concentrations trigger the release of large amounts of LH and FSH into the bloodstream, leading to the ovulation of the dominant follicle in which it turns into a **secondary oocyte** and is arrested at metaphase II (this positive feedback between estradiol and LH/FSH *only* occurs at this part of the follicular phase)
- LH triggers the degradation of the ovary wall leading to the expulsion of the oocyte
- LH also stimulates the development of a new endocrine structure, the **corpus luteum**, which produces large amounts of progesterone
- Progesterone keeps GnRH, LH, and FSH secretions low to prevent new dominant follicles from developing at this time

Ovarian cycle stage 2 | Luteal phase (post-ovulatory)

- The secondary oocyte, now in either the left or right uterine tube, is sessile and thus cannot move on its own
- High estrogen concentrations induce smooth muscle contraction along the uterine tube resulting in a coordinated movement that sweeps the secondary oocyte into the uterus slowly but surely with the help of the cilia
- If the secondary oocyte is successfully fertilized (the sperm typically meets the oocyte when it is still in the uterine tube), a zygote forms
- If the oocyte is not fertilized it will simply degrade along with the corpus luteum (now called **corpus albicans**) – the oocyte will be shed in the next menstrual period and the corpus albicans will disintegrate in the ovary over several months

The **uterine cycle** describes the changes that occur to the endometrium in the uterus.

Uterine cycle stage 1 | Menses phase

- The first day of menses is the first day of a period
- The menses phase occurs during the early days of the follicular phase when LH, FSH, and progesterone levels are low and the endometrial lining is shedding

Uterine cycle stage 2 | Proliferative phase

- This phase begins when menstrual flow ceases and high estrogen levels stimulate the endometrial lining to rebuild. Ovulation marks the end of the proliferative phase

Uterine cycle stage 3 | Secretory phase

- The endometrium prepares for implantation and secretes a fluid that nourishes the developing zygote if fertilization occurs
- If no fertilization occurs the endometrium will grow thin and its tissue will die, marking the first day of the next cycle and the beginning of menses

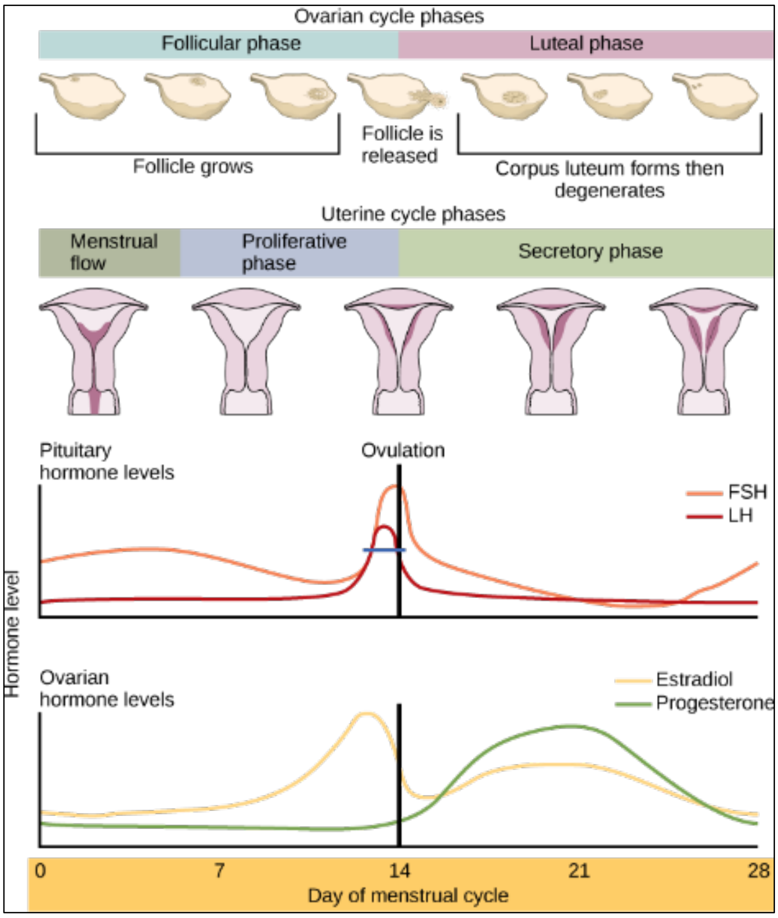

Figure 2: a diagram of the menstrual cycle (Gordon Betts).

D3.1.6—Fertilization in humans

Include the fusion of a sperm's cell membrane with an egg cell membrane, entry to the egg of the sperm nucleus but destruction of the tail and mitochondria. Also include dissolution of nuclear membranes of sperm and egg nuclei and participation of all the condensed chromosomes in a joint mitosis to produce two diploid nuclei.

Fertilization occurs when the sperm and oocyte fuse their plasma membranes and combine their nuclei to form one diploid nucleus. Now called a **zygote**, the cell completes its second meiotic division and then divides via mitosis through the participation of all the condensed chromosomes to produce two diploid nuclei. Since the rest of the sperm's body does not enter the oocyte's cytoplasm, the remainder of the organelles are destroyed. While the offspring inherits chromosomes from both parents, mitochondrial DNA is only inherited from the mother.

D3.1.7—Use of hormones in in vitro fertilization (IVF) treatment

The normal secretion of hormones is suspended, and artificial doses of hormones induce superovulation.

- **Step 1 | suspending normal secretion of hormones**: the patient is given birth control pills or estrogen in order to allow the healthcare provider to control the timing of the menstrual cycle.
- **Step 2 | ovarian stimulation**: hormonal medications (FSH and LH) are used to induce the development of multiple oocytes.
- **Step 3 | egg retrieval**: via a minor surgery, the oocytes are removed from the patient's body.
- **Step 4 | insemination and fertilization**: concentrated sperm are mixed together with the eggs (insemination) and then stored in a controlled chamber until fertilization.
- **Step 5 | embryo culture and transfer**: the zygote is left to grow for a few days until it becomes a blastocyst and then is transferred to the patient's body and implanted into the uterus.

D3.1.9—Features of an insect-pollinated flower
Students should draw diagrams annotated with names of structures and their functions.

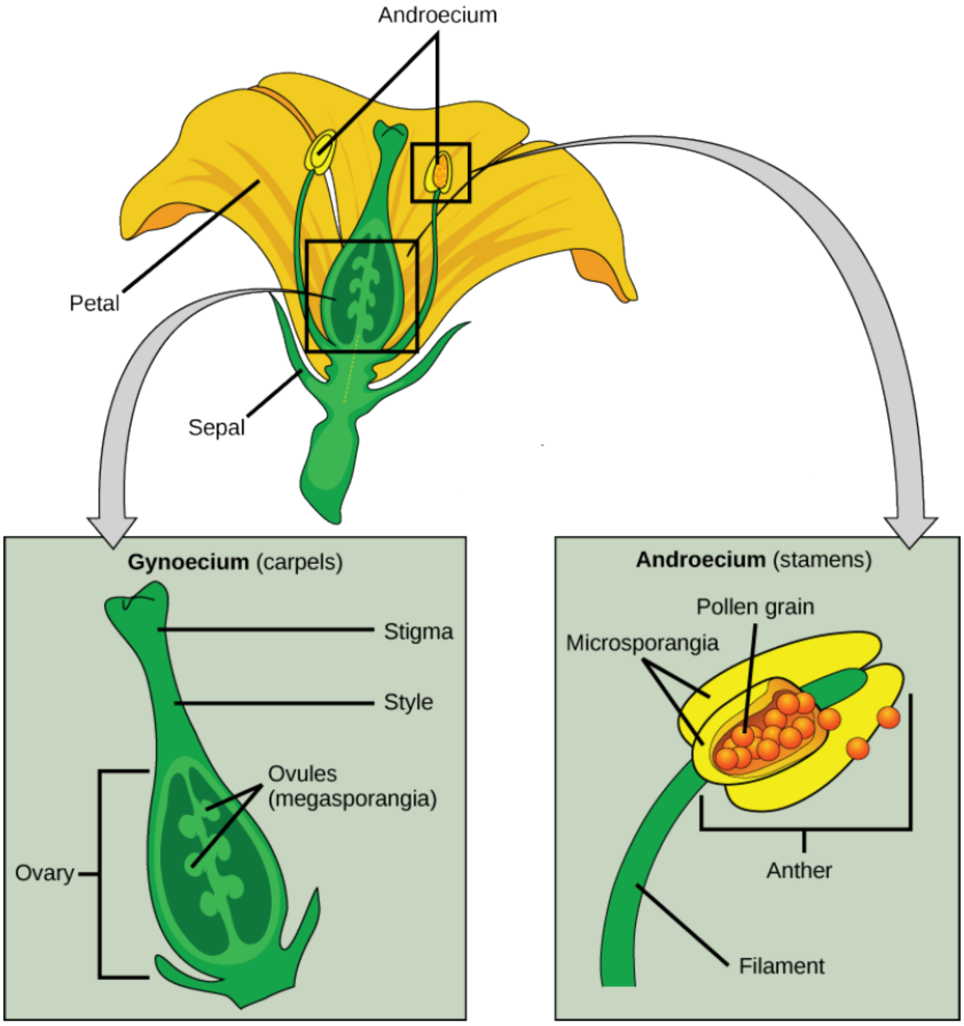

Figure 3: diagram of flower structure (Ann Clark).

Structure	Function
Petals	Attractive color and scent to attract pollinators
Ovary	Houses the ovules until fertilization then develop into fruit
Ovules	House the female gametes until fertilization and then develop into seed
Style	Guides pollen tube and keeps the position of the stigma open to pollinators
Stigma	Captures pollen from pollinators
Anther	Produce male gametes
Filament	Keeps the position of the anther exposed for pollinators
Sepal	Protect the organs of the flower during development

D3.1.8—Sexual reproduction in flowering plants

Include production of gametes inside ovules and pollen grains, pollination, pollen development and fertilization to produce an embryo. Students should understand that reproduction in flowering plants is sexual, even if a plant species is hermaphroditic.

Flowering plants (**angiosperms**) reproduce sexually as they can undergo meiosis, even if they are **hermaphroditic** (possessing both male and female gametes).

Production of male gametes:

- Within the anther's microsporangia (pollen sacs), microspore mother cells each divide by meiosis to produce four microspores, all four of which form a pollen grain
- Each pollen grain will develop into two cells, a **pollen tube cell** and a **generative cell** (which is contained within the larger pollen tube cell)
- The pollen tube cell develops the pollen tube upon germination which the generative cell travels through to enter the ovary
- During transit in the pollen tube, the generative cell divides to form two male gametes (sperm cells)
- Pollen grains are released from the anther upon maturity when the pollen sacs burst

Production of female gametes:

- A single diploid cell in an area of tissue in the ovules divides by meiosis to form 4 haploid cells, of which only 1 survives
- The surviving cell then undergoes mitosis to produce 8 **nucleate cells**, now forming the embryo sac
- Only one cell develops into the egg; the rest assist in fertilization and embryo development then degenerate

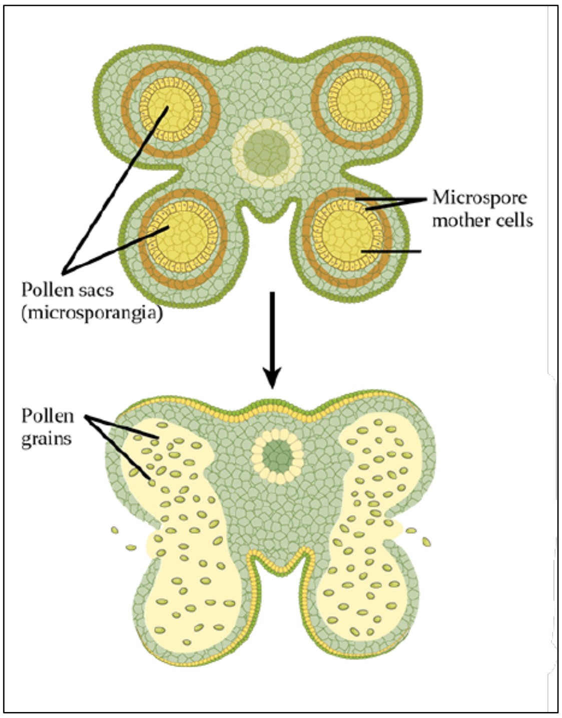

Figure 4: cross-section of anther at two stages (Ann Clark).

D3.1.10—Methods of promoting cross-pollination
Include different maturation times for pollen and stigma, separate male and female flowers or male and female plants. Also include the role of animals or wind in transferring pollen between plants.
Cross-pollination is the transfer of pollen from the anther of one flower to the stigma of another flower on a different plant- thus promoting genetic diversity, adaptability, and hybrid vigor. This is achieved through: • Transferring pollen by wind, insects, and animals • Different maturation times for pollen and stigma • Separate male and female parts within the same plant or on a different plant

D3.1.11—Self-incompatibility mechanisms to increase genetic variation within a species
Students should understand that self-pollination leads to inbreeding, which decreases genetic diversity and vigour. They should also understand that genetic mechanisms in many plant species ensure male and female gametes fusing during fertilization are from different plants.
To prevent self-pollination, plants have evolved self-incompatibility mechanisms to increase genetic variation within a species and prevent inbreeding. This is genetically controlled by the **S (sterility) locus**, which encodes for enzymes that detect and degrades self-pollen to prevent fertilization.

D3.1.12—Dispersal and germination of seeds
Distinguish seed dispersal from pollination. Include the growth and development of the embryo and the mobilization of food reserves.
Pollination is the transfer of pollen from the anther to the stigma, whereas **seed dispersal** is scattering the plant seeds far away from the parent plant to reduce competition between them. After fertilization, the embryo begins to develop inside the seed, and only when there is no more enough room for growth is the seed ready for dispersal. Embryonic growth is suspended until seed germination, and the developing seedling will rely on the food reserves in its **cotyledons** until leaves grow for photosynthesis.

Additional higher level

D3.1.13—Control of the developmental changes of puberty by gonadotropin-releasing hormone and steroid sex hormones
Limit to the increased release of gonadotropin-releasing hormone (GnRH) by the hypothalamus in childhood triggering the onset of increased luteinizing hormone (LH) and follicle-stimulating hormone (FSH) release. Ultimately the increased sex hormone production leads to the changes associated with puberty.
The hypothalamus produces **GnRH**, a peptide hormone that signals to the anterior pituitary gland to produce the gonadotropins FSH and LH in *both* males and females. GnRH is secreted during early childbirth but stops, and resumes during teenage years to mark the beginning of **puberty** (the process of transitioning to sexual maturity). At around ages 8 or 9, the hypothalamus becomes **less** sensitive to estrogen and testosterone concentrations. Since these hormones are in negative feedback with LH and FSH, this causes the gradual rise of LH and FSH levels. The gonads, however, become **more** sensitive to FSH and LH, leading to their slow but imminent development throughout teenage years (along with secondary sexual traits).

D3.1.14—Spermatogenesis and oogenesis in humans

Include mitosis, cell growth, two divisions of meiosis and differentiation. Students should understand how gametogenesis, in typical male and female bodies, results in different numbers of sperm and eggs, and different amounts of cytoplasm.

	Spermatogenesis	Oogenesis
Gametes produced	4 functional spermatozoa	1 ovum
Meiotic progression	Continuous, no pauses	Several long pauses
Cytoplasm amounts in gametes	4 spermatozoa of equal-sized cytoplasm	1 ovum with a big-sized cytoplasm + 3 small polar bodies
Duration of growth phase	Short	Long
Onset	Begins at puberty	Begins before birth
Nature of gamete production	Continuous after puberty	Cyclical pattern
Involvement of germline cells	Yes	No

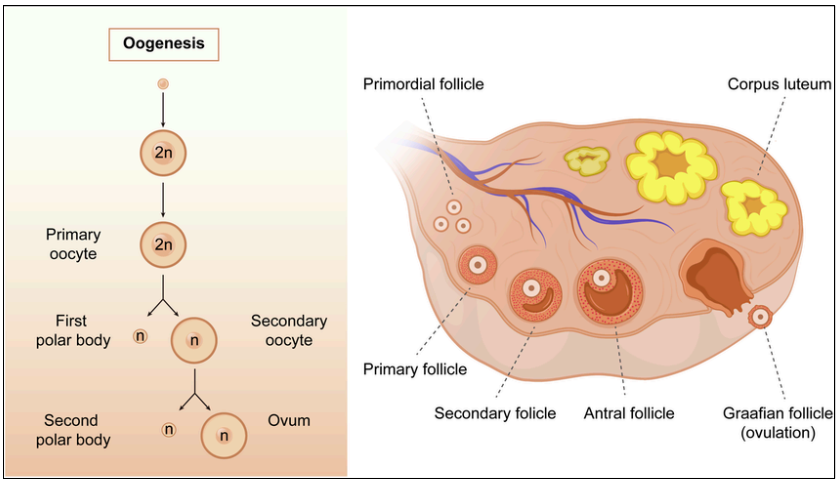

Figure 5: oogenesis diagram (Yao).

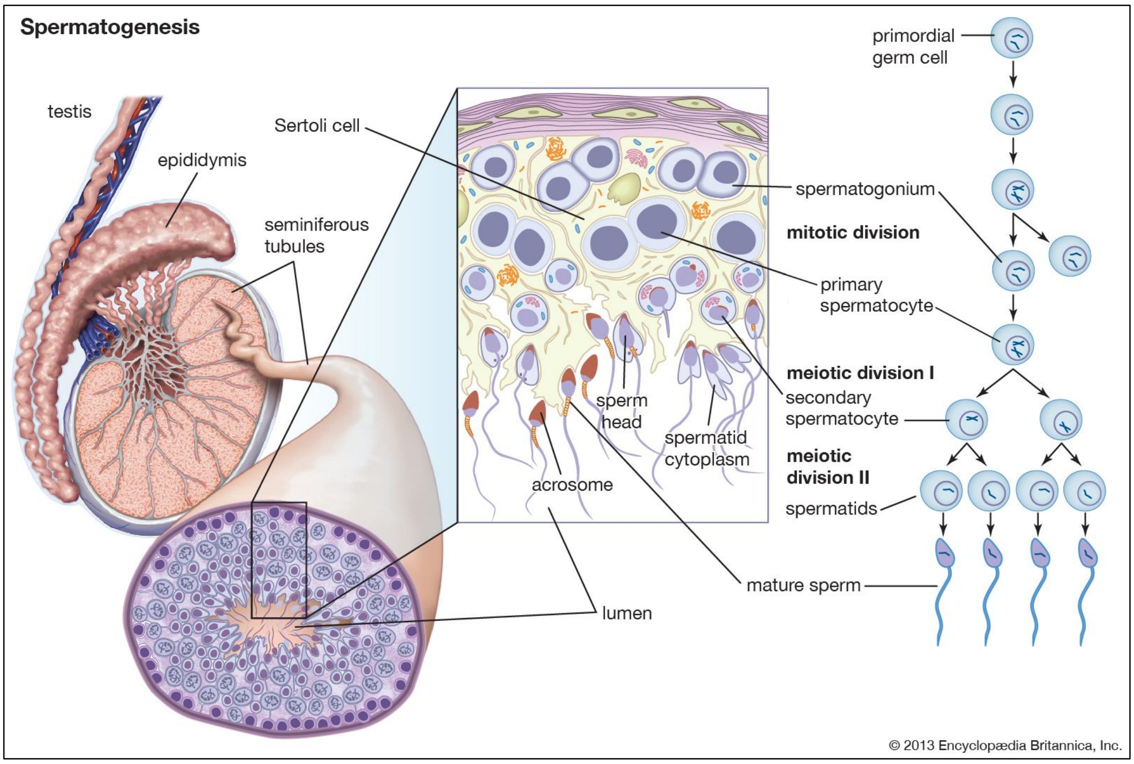

Figure 6: spermatogenesis diagram (Britannica).

Spermatogenesis:

- **Spermatogonia** (germ cells lining the basement membrane) divide by mitosis to produce **primary spermatocytes**
- Primary spermatocytes undergo meiosis I to produce **secondary spermatocytes**
- Secondary spermatocytes undergo meiosis II to produce **spermatids**
- **Sertoli** and **Leydig cells** both help control this process
- Spermatozoa are then transported to the epididymis for the next step of sperm maturation

Oogenesis:

- **Oogonia** (ovarian stem cells) form during fetal development and divide by mitosis to form primary oocytes before birth
- **Primary oocytes** begin meiosis I but are arrested at prophase I before birth and until puberty
- LH stimulates a few primary oocytes to complete meiosis I and they are again arrested at metaphase II, forming **secondary oocytes** (a **polar body** is produced upon completion of meiosis I, which is a byproduct cell smaller than the main oocyte and eventually disintegrates)
- If fertilization occurs, the fusion of the two nuclei is followed by the completion of meiosis II and the formation of the zygote

D3.1.15—Mechanisms to prevent polyspermy

The acrosome reaction allows a sperm to penetrate the zona pellucida and the cortical reaction prevents other sperm from passing through.

- **Acrosome reaction**: after burrowing through the corona radiata and binding to receptors on the zona pellucida, the acrosome releases its stored digestive enzymes in order to clear away the zona pellucida. This enables the sperm to contact the plasma membrane of the oocyte, fusing with it and releasing its nucleus into its cytoplasm.
- **Cortical reaction**: cortical granules situated below the oocyte's plasma membrane fuse with the membrane and release proteins that destroy sperm receptors and cause the release of any other attached sperm. They also secrete polysaccharides that form an impenetrable barrier around the zygote, called the **fertilization membrane.**

D3.1.16—Development of a blastocyst and implantation in the endometrium

Students are not required to know the names of other stages in embryo development.

The **blastocyst** is developed in the uterus where its cells begin to secrete and organize themselves around the **blastocoel**, a fluid-filled cavity. The **trophoblasts** are the cells forming the outer shell of the blastocyst, and when they come in contact with the uterine wall they adhere to and embed themselves in it, beginning **implantation**. If the endometrium is not yet fully developed, the blastocyst will detach and find a better place. Successful implantation could be accompanied by minor bleeding, but if the blastocyst fails to implant it is shed during menses with the endometrium.

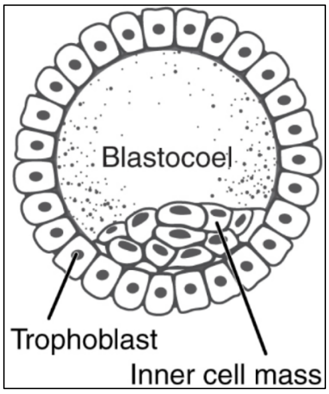

Figure 7: blastocyst anatomy (Gordon Betts).

D3.1.17—Pregnancy testing by detection of human chorionic gonadotropin secretion
Include the production of human chorionic gonadotropin (hCG) in the embryo or developing placenta and the use of monoclonal antibodies that bind to hCG.

hCG functions:

- **hCG** is a peptide hormone released by the embryo during early weeks of pregnancy (first 4-18 weeks)
- hCG maintains the corpus luteum until the placenta is developed and able to function
- Once developed, the placenta is able to produce the required amount of progesterone and estrogen, so the embryo eventually reduces hCG production
- Reduction in levels of hCG/halting production causes corpus luteum degeneration
- If hCG levels are insufficient during early pregnancy, the endometrial lining may be too weak for blastocyst implantation or sustainment of developing embryo, possibly resulting in a miscarriage

Pregnancy tests:

- **Monoclonal antibodies** are antibodies produced by **hybridoma** cells (a B cell and a cancer cell fused together)
- A monoclonal antibody that can bind to hCG is used in pregnancy tests, changing color if hCG attaches to it
- Present in the test is a control band with hCG previously attached to the antibody
- The remaining antibodies do not have hCG bound to them
- hCG is excreted in urine and so if a woman is pregnant, the empty antibodies will bind to hCG and change color, thus displaying two colored bands and indicating a positive result

D3.1.18—Role of the placenta in foetal development inside the uterus
Students are not required to know details of placental structure apart from the large surface area of the placental villi. Students should understand which exchange processes occur in the placenta and that it allows the foetus to be retained in the uterus to a later stage of development than in mammals that do not develop a placenta.

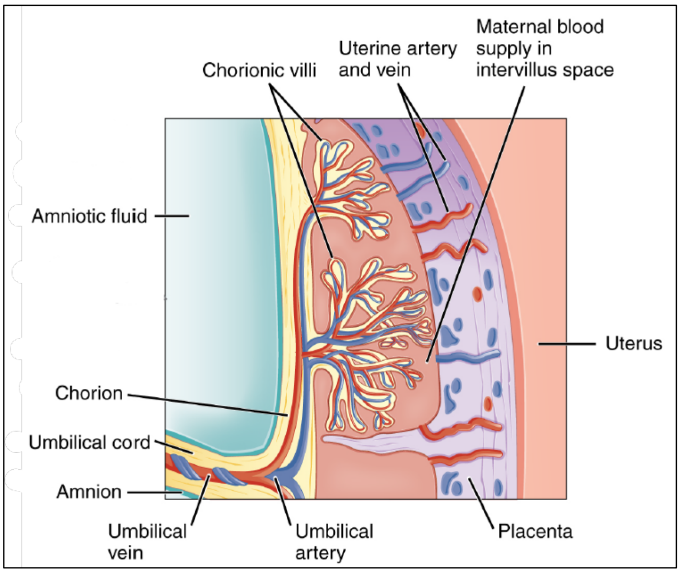

Figure 8: placental structure (Gordon Betts).

The **placenta** completes development by 14-16 weeks and carries out the following functions:

- Provides nutrition through the umbilical vein
- Removes excreted material from the fetus through the umbilical artery
- Carries out respiration for the fetus by allowing exchange of gases through chorionic villi
- Secretes several hormones to stimulate fetal development
- Prevents mixing of maternal and fetal blood to avoid inducing an immune response

D3.1.19—Hormonal control of pregnancy and childbirth
Emphasize that the continuity of pregnancy is maintained by progesterone secretion initially from the corpus luteum and then from the placenta, whereas the changes during childbirth are triggered by a decrease in progesterone levels, allowing increases in oxytocin secretion due to positive feedback.

During the first 8-12 weeks of pregnancy, the corpus luteum is responsible for the majority of progesterone secretion, and then the placenta takes charge of this function.

Towards the end of pregnancy, progesterone levels begin to drop but estrogen continues increasing, causing the endometrium to become more sensitive to contractions. Uterine contractions stimulate the release of **oxytocin** from the pituitary, which in turn triggers more powerful contractions (positive feedback loop), ultimately resulting in **parturition** (childbirth).

NOS: In early epidemiological studies, it was argued that women undergoing hormone replacement therapy (HRT) had reduced incidence of coronary heart disease (CHD) and this was deemed to be a cause-and-effect relationship. Later randomized controlled trials showed that use of HRT led to a small increase in the risk of CHD. The correlation between HRT and decreased incidence of CHD is not actually a cause-and-effect relationship. HRT patients have a higher socioeconomic status, and this status has a causal relationship with lower risk of CHD.
Correlation does not equal causation.

Linking questions

• How can interspecific relationships assist in the reproductive strategies of living organisms?

• What are the roles of barriers in living systems?

Review questions

SL and HL

- Suggest a reason for why human eggs have a lower quantity of food reserves than plant eggs. [1]
- Suggest why DNA replication provides evidence for why meiosis evolved after mitosis. [1]
- Outline the mechanism for self-incompatibility in flowering plants. [2]
- Outline the process of fertilization in humans. [3]
- Using an example, explain why correlation is not the same as causation. [3]
- Distinguish between male and female gametes. [3]
- Outline seed dispersal and germination of flowering plants. [3]
- Explain why sexual reproduction is useful despite being complex. [3]
- Outline how cross-pollination is promoted in flowering plants. [3]
- Distinguish between sexual and asexual reproduction. [4]
- Explain the mechanism of IVF. [5]
- Explain how the female reproductive system in humans is adapted to its function. [5]
- Explain how the male reproductive system in humans is adapted to its function. [5]
- Describe the production of gametes in flowering plants. [6]
- Compare and contrast gamete productions in humans and flowering plants. [6]
- Describe the sexual reproduction of flowering plants. [8]
- Explain how hormones simultaneously regulate the ovarian and uterine cycles. [8]
- Natural selection is driven by variation. Discuss the role of physiological processes in living organisms that have evolved to increase variation within a species. [8]

Additional Higher Level

- Explain the role of hCG during pregnancy. [3]
- Explain how pregnancy tests work. [3]
- Outline the process of parturition (childbirth). [3]
- Describe the development and implantation of a blastocyst. [4]
- Describe the mechanisms that prevent polyspermy. [4]
- Explain the hormonal regulation of puberty. [4]
- Explain the hormonal regulation of pregnancy and childbirth in humans. [4]
- Explain the role of the placenta during pregnancy. [5]
- Describe the journey of a sperm cell from development until ejaculation. [7]
- Compart and contrast spermatogenesis and oogenesis. [8]

References

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