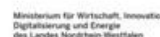




FunForLab

Serious games to learn (about) the profession of medical laboratory technologist (MLT)

Lector instruction manual of VR game + Pedagogical sequence for MLT Students





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With the investment of EU funds in Interreg projects, the European Union directly invests in the economic development, innovation, territorial development and social inclusion and education of this region, stretching out from Leuven (Belgium) in the west, Cologne (Germany) in the east, and from Eindhoven (the Netherlands) in the north, to the borders of Luxemburg.

The FUNFORLAB consortium is a collaboration between 3 countries and 6 organizations:

CRIG HELMo, le Centre de Recherches des Instituts Groupés de la Haute École Libre de Mosane, Belgium

CECOTEPE, Le Centre de Coopération Technique et Pédagogique associé à la Haute École de la Province de Liège (HEPL), Belgium

FORS, le centre des Formations Continues, Recherches et Services de la Haute École de Namur-Liège-Luxembourg (Hennalux), Belgium

UCLL, Hogeschool UC Limburg vzw, Belgium

ZUYD Hogeschool, the Netherlands

UNIKLINIK RWTH AACHEN, Universitätsklinikum Rheinisch-Westfälische Technische Hochschule Aachen, Germany

Website: <https://funforlab.eu>

E-mail: info@funforlab.eu

Disclaimer: the contents of this publication are the sole responsibility of the FUNFORLAB project partners, and can in no way be taken to reflect the views of the European Commission.

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Summary

The FUNFORLAB project is a 2.5-year project, that took place in the period between March 2021 and August 2023, with consortium partners from Belgium, Germany and the Netherlands in the Euregio Meuse-Rhine (EMR).

The mission of the FUNFORLAB project is to promote the profession of medical laboratory technologist (MLT), to improve and homogenize the training and education of MLT students in university colleges and related educational programs across the EMR, and to improve cross-border mobility in the EMR. The project targets specifically secondary school pupils and their teachers, people who are not in education, employment or training (NEET's), and students and lecturers in MLT education.

Current MLT educational programs in the EMR are characterized by a solid theoretical component, complemented by sufficient amount of practical training at school and during internships on the job. In fact, in Belgium and Germany, minimum hours of practical training to obtain the degree of MLT are stipulated by law. However, practical training at school is mainly manual, contrasting to the highly automated character of analyses in professional medical laboratories. Resources in education are insufficient to overcome this discrepancy, therefore, the FUNFORLAB project has developed a virtual reality (VR) serious game. Input for game development, and a summary of the challenges MLT students are facing, was obtained by a SWOT analysis across regions (For more information on these results, please check the SWOT report on the FUNFORLAB project website¹). By engaging students from the beginning of their studies, the FUNFORLAB game will create early awareness of the day-to-day realities in a professional medical lab and the challenges that MLT professionals encounter, improve students' career expectations, as well as improve their skills to independently perform automatic laboratory analyses, and this in a controlled, safe and fun digital environment.

This training guide provides an introduction to the use of serious games in teaching, as well as a hands-on training guide for MLT lecturers to set-up and use the FUNFORLAB game in their classes, to provide students with a realistic but game-based view of the daily routine in a professional medical laboratory and a way to practice their skills in automated medical analysis. Not only MLT lecturers can benefit from this training guide, but also MLT program directors from the FUNFORLAB consortium partners can use this as an example of good practice from their own institution, to disseminate the game also outside the EMR.

¹ <https://funforlab.eu/>

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Introduction

Purpose: the FunForLab project

Through the development and sharing of two Serious Games, the Interreg FunForLab project will address several target audiences:

- Secondary school pupils: Promote scientific professions, including MLT among secondary school students.
- MLT students: Increasing specific skills on automated analyses, reach equivalent training in EMR, increase cross border mobility, thus increasing employability.
- MLT professionals: Opportunity to use FUNFORLAB as a ICTE tools for continuing education
- Jobseekers via scientific training courses

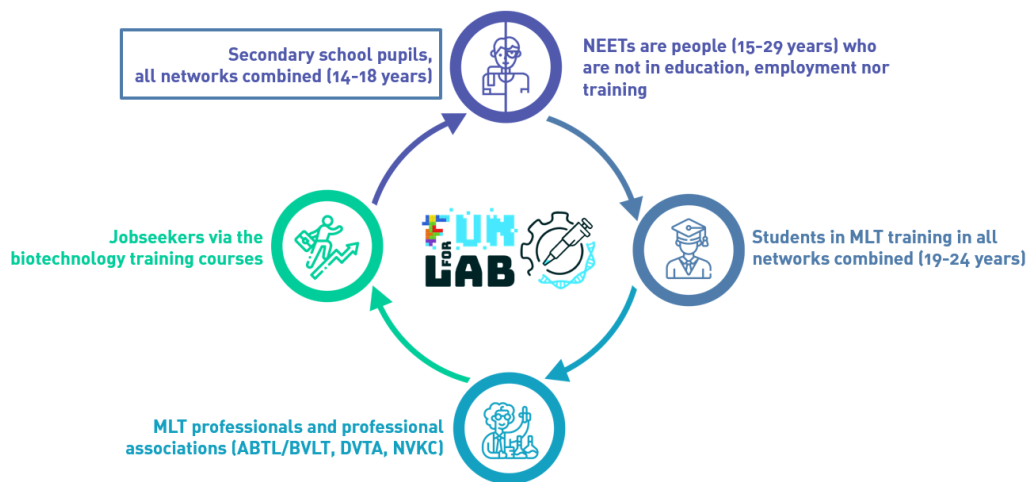


Figure 1. FunForLab target audiences

Target group + FunForLab MLT education objectives

MLT students and MLT lectors are one of the major target groups for the FunForLab project. The SWOT analysis conducted at the beginning of the project highlighted that there is a gap between the MLT training and the highly automated workplace where MLT's conduct laboratory analyses. Whilst every curriculum in the EMR region provides an adequate training and hand-on approach, working in an automated setting is only learned during internships and initial training in the field at the start of the MLT's career. With the help of the FunForLab virtual reality (VR) serious game, we aim to fill this gap and start getting acquainted earlier with the automatons during MLT training.

The FunForLab context

An MLT is a paramedical health professional who carries out in vitro laboratory tests on human samples (such as blood, urine or cerebrospinal fluid) and who supervises these analyses and guarantees the accuracy of the medical data + results. The MLT helps establish an accurate diagnosis for doctors.

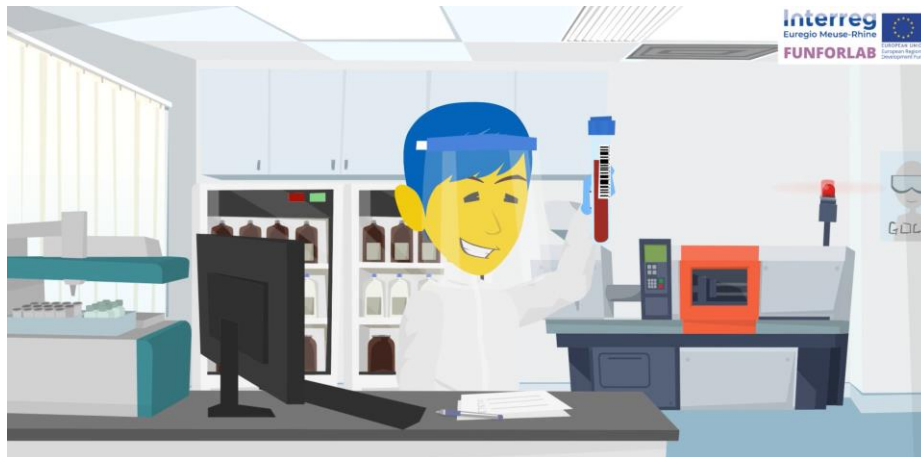


Figure 2. Medical laboratory technologist

The Euregio Meuse-Rhine members are the following five regions: The Province of Liège, German-speaking Community and province of Limburg in Belgium, the Southern part of the province of Limburg in the Netherlands and the Province of Aachen in Germany.

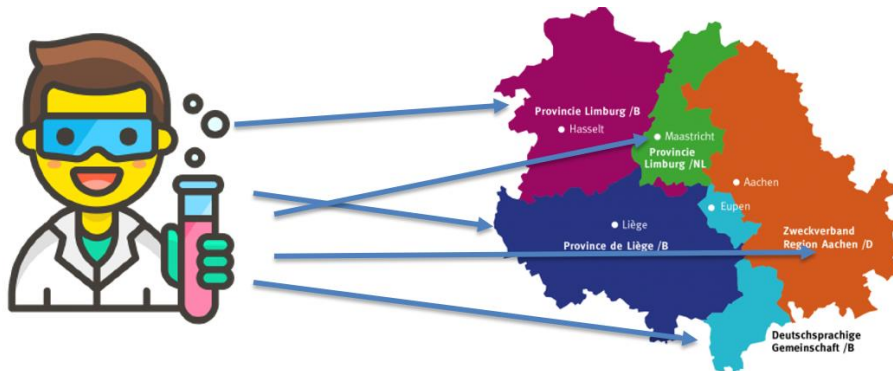


Figure 3. MLT Cross border Mobility in EMR

The partners

Six partners for on joined efforts and shared knowledges:



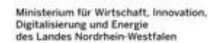
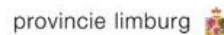
Figure 4. FunForLab partners in EMR

To meet these challenges, the Funforlab project brought together a consortium including:

- The CRIG Research Center (HELMo, Liège, BE), as leadpartner;
- With support of MLT graduate school UCLL (Hasselt, BE), ZUYD (Heerlen, NL), UKAachen (Aachen, DE) as financial partners bringing in pedagogical and technical skills in the field of sciences and biomedical sciences;
- CECOTEPE Training Center (HEPL, Liège, BE), and FoRS Research Center (Henallux, Namur, BE), as financial partners experienced in developing of IT tools and Virtual Reality.

Financial support

The FunForLab project is financed by:



The FUNFORLAB project is funded by the European subsidies INTERREG EMR for CALL 6 in the field of social inclusion.

The project is also co-financed by the Walloon Region and the Wallonia Brussels Federations and German Region, in Belgium; the Province of Limburg in The Netherlands and the Ministry for Economic Affairs, Innovation, Digitalisation and Energy of the State of North Rhine-Westphalia in Germany.

The instruction manual

This instruction manual is intended to help MLT lecturers of the Euregio Meuse-Rhine to become VR game facilitators and provides inspiration for implementing the FunForLab VR game in MLT training.

It contains:

- Project objectives
- The game's pedagogical tools
- Instructions for using the game
- Implementation + inspiration for VR training inside the MLT curriculum

The aim is to have a common pedagogical framework for all regions in EMR when using the FunForLab serious game during MLT training.

The instruction manual is addressed to MLT lecturers and is to be used in conjunction with the training guide + game tutorials (video's) created for MLT students. See QR code below for access to the game download, trailer, installation guide and tutorials.



Figure 5. QR code for access to FunForLab VR game.

The pedagogical tool: understanding virtual reality training

Serious Game definition: *A serious game is an “educational application, whose initial intention is to combine, coherently and at the same time, serious aspects, in a non-exhaustive and non-exclusive way, teaching, learning, communication, or even information with the fun aspects of video games” [ALV 07].*

From: [Connected Healthcare for the Citizen, 2018](#)

The serious game described in this manual, developed during the FunForLab project, is a virtual reality game (VR) that relies on two types of competences (input) and expertise: the game designer/developer and the MLT teacher/lector. Yet, it remains a challenge in creating a serious game that is both amusing and educational. Using the different expertise and know-how of all the partners involved, a VR game was built in a cooperative way aligning both “fun & facts” so that the final VR game is able to educate MLT students and allow them to practice in a virtual laboratory.

What is virtual reality (VR)?

Virtual Reality is a computer-generated environment that simulates a **realistic** 3D experience, **immersing** users in an **interactive** and **engaging** environment. In other words, a digital/virtual MLT laboratory environment was created allowing the player to experience the different aspects of this work environment and learning how to handle samples and in an interactive way, including receiving feedback and integrating laboratory knowledge.

During the development of this serious game, the 6 aspects of game design were taken into consideration. These are depicted below in Fig. 6. Since our FunForLab consortium consisted of different partners with different areas of expertise, each partner provided feedback on the game and was either part of the pedagogical expert group or the game design/development team.

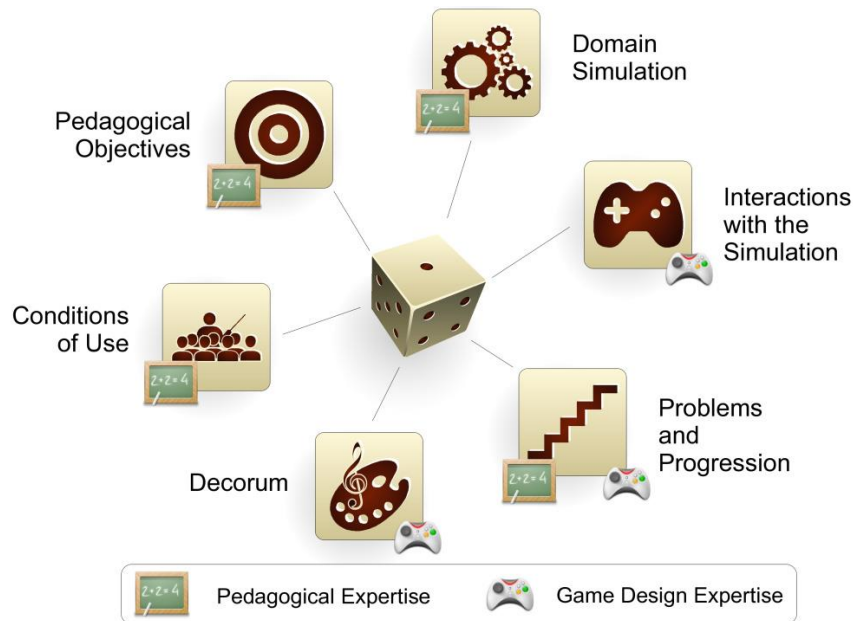


Figure 6. Graphical representation of The Six Facets of Serious Game Design. For each facet, each type of expertise is shown by an icon. Source: Marne et al. 2012. "The Six Facets of Serious Game Design: A Methodology Enhanced by Our Design Pattern Library

Benefits of VR training

During MLT training most laboratory techniques are taught by using manual methods which is in contrast to the automated methods in most clinical diagnostic laboratories. The FunForLab serious game offers virtual reality training that is realistic, safe, and provides repeatable scenarios, enhancing learning retention and engagement while minimizing risks. A hands on approach in a virtual "classroom" allows the player "to learn by doing", which has been proven to be the best way to learn and retain the information + skills.

Serious Game advantages in a MLT education context:

- Motivation and engagement: serious games can capture the students' attention and motivate them, consequently improving their engagement and participation rates.
- Experiential learning: serious games provide simulations of real-life situations that allow students to discover for themselves the consequences of their actions and decisions.
- Immediate feedback: serious games provide immediate feedback, allowing students to correct mistakes and quickly understand good practice without being judged.
- Collaboration: serious games provide opportunities for collaboration and competition between students, which stimulates communication and teamwork.
- Customisation: students make progress at their own pace.

Considerations for integration in MLT courses

The FunForLab VR game is best suited for students who already have some experience in the laboratory, especially considering training objectives. We recommend using the game as an additional pedagogical tool during laboratory training (2nd year of the MLT training) and as an

introduction to the laboratory environment before internships. Furthermore, the content of the game is designed for a level further than “newbie” and the user experience and game goals were also specifically developed with MLT students in mind. Nevertheless, any player with an interest in the game, can download the FunForLab VR game and play it in combination with a VR headset and controls (Meta Quest, meta.com).

Finally, safety precautions should be taken into consideration when playing a VR game, like creating a safe boundary and space for playing in the chosen location. When setting up the VR headset, this is a prerequisite to continue playing.

Game story

It's the year 2051. Despite numerous warnings from scientific experts and alarming reports from the Intergovernmental Panel on Climate Change (IPCC) over the past decades, not enough has been done to combat climate change. Natural disasters, wars and virus epidemics have increased. Melting ice is causing the waters to rise, making many parts of the world inhospitable. With the help of the largest multinationals, the governments of many countries have organised the colonisation of the planet Mars to save humanity. This mission is called EMR (**E**arth to **M**ars **R**escue). Priority is given to people with useful capabilities that needs to be certified by laboratories. Rumour has it that some labs are run by mafias and falsifying results. A young MLT is hired by the European secret services to verify the validity of results coming out from one suspected lab and help dismantle a local mafia. If they succeed, they will be rewarded with a MLT job on a spaceship going to Mars. They will be allowed to bring along their asthmatic little sister who's suffering from Earth's climate change.

The story takes place in the future, it is a dystopia where climate change has made the earth inhospitable. The subject is topical and interesting to discuss with pupils:

- a) Environmental awareness: understanding humans' impact on the environment and the resulting imbalances in ecosystems.
- b) Learning about sustainability: educating encouraging eco-friendly behaviour.
- c) Developing a sense of responsibility: learning that the way we live has an impact on the environment, therefore reinforcing commitment.
- d) Understanding collective action: explaining how collective actions have enhanced impact, emphasising the importance of solidarity in setting up collective projects.

Teaching pupils about the causes and consequences of climate change makes them more likely to take a pro-active and positive approach to the environmental challenges they will face in their daily lives.

Pedagogical sequence for MLT Students

The scientific method

The scientific method is a systematic approach used to investigate and understand the natural world. It involves a series of steps that scientists use to formulate and test hypotheses, evaluate evidence, and draw conclusions.

Observation	Government hired us to redo some laboratory tests from another laboratory. They think the results from this other laboratory were not up to standards.
Formulating a question	Are those results trustworthy or not? Is the sample healthy or pathological?
Developing a hypothesis	If we retest samples in our laboratory and find different results, we could think their results are not to be trusted: falsification of medical data occurred.
Designing an experiment	Testing of 2 samples from this laboratory in which we suspect data falsification
Collecting and analysing data	Comparing results between our lab and the one from the suspicious laboratory. They are not the same.
Drawing conclusions	The suspicious lab published falsified results
Communicating findings	Communicating of correct results to the Government

Target skills

To provide students with general knowledge enabling them to use haematological cytology techniques (FHL, diagnosis of leukaemia), haemostasis exploration techniques, immune-haematology and transfusion techniques and automated systems (haemogram, flow cytology and cell recognition) in order to make the student fit to work in the haematology laboratory, in routine and research.

At the end of this activity, the following processes will be carried out:

- Compare physiological data from a healthy person and a person suffering from an infectious disease (blood test, urine test, microscopic observations, etc.).
- Use the theoretical foundations of haematology to apply them to scientific reflection
- Interpret graphs and tables obtained from analytical assays.
- Interpret results by analyzing and arguing.

Course and duration

This pedagogical sequence is an example of how the VR game can be used for training MLT students. Ofcourse you can use the VR game in another way, during MLT training and laboratory courses.

- 3 lesson periods of 1 hour each for theory concept and clinical cases (chapter 1-3)
- 3 VR Game testing sessions to illustrate the clinical cases: 15 minutes/session

Prerequisites

- To know how the eukaryotic cell functions and is organized, as well as the basics of cell biology.
- Know how to use an optical microscope.
- Be familiar with the content of the haematology course namely :
 - the process of haematopoiesis and the characteristics of the different blood cells;
 - physiology and pathology of blood and marrow cells;
 - diagnostic analyses ;
- know the values of the haemogram of a healthy patient and discuss the results.

Instructions for using the VR game

In this instruction manual, we will provide an overview of the game. Specific tutorials and instruction video's can be found online (see link: <https://funforlab.eu/nl/virtual-reality-2/> or QR code in figure 5 for immediate access). After installing the game, setting up the VR headset, and entering the game, you will see the main menu and an overview of the chapters (Fig. 7). As a first time player, you should start at the introduction, then the tutorial, followed by chapters 1, 2 and 3 and finish the game with the conclusion. Ofcourse, you can repeat chapters too and play in a different order if that is what you wish to do.

Note: For extra pedagogical material and teachers resources, see further in this manual.

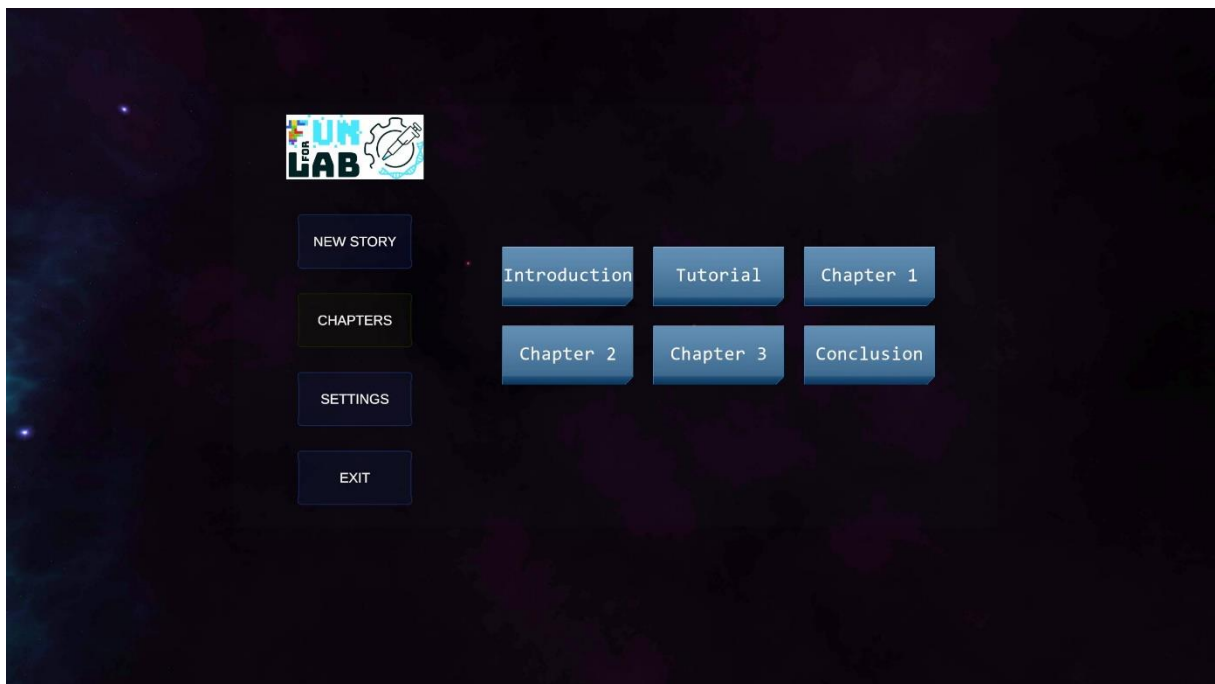


Figure 7. VR game – main menu with chapters.

1. Introduction

The context story of the game and the introduction is explained by the robot AILA.



Figure 8. VR game – Introduction

2. Tutorial

The tutorial is about how to play the game. The player will be given instructions on how to interact in game and will be given tryout. The robot gives a lab tour explaining the purpose of all the rooms.

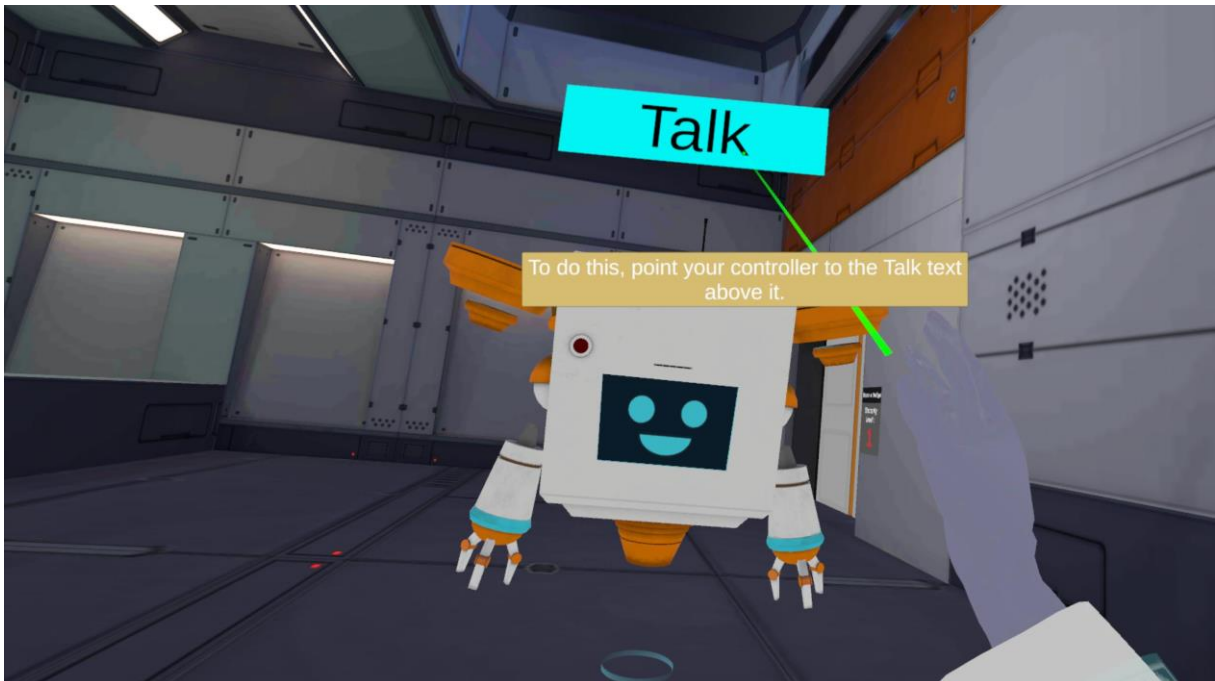


Figure 9. VR game – How to play.



Figure 10. VR game – How to move around.

3. Chapter 1

The player will perform their first CBC analysis with the automaton on the sample of Sylvia. The player will be tested on their knowledge through one questionnaire.

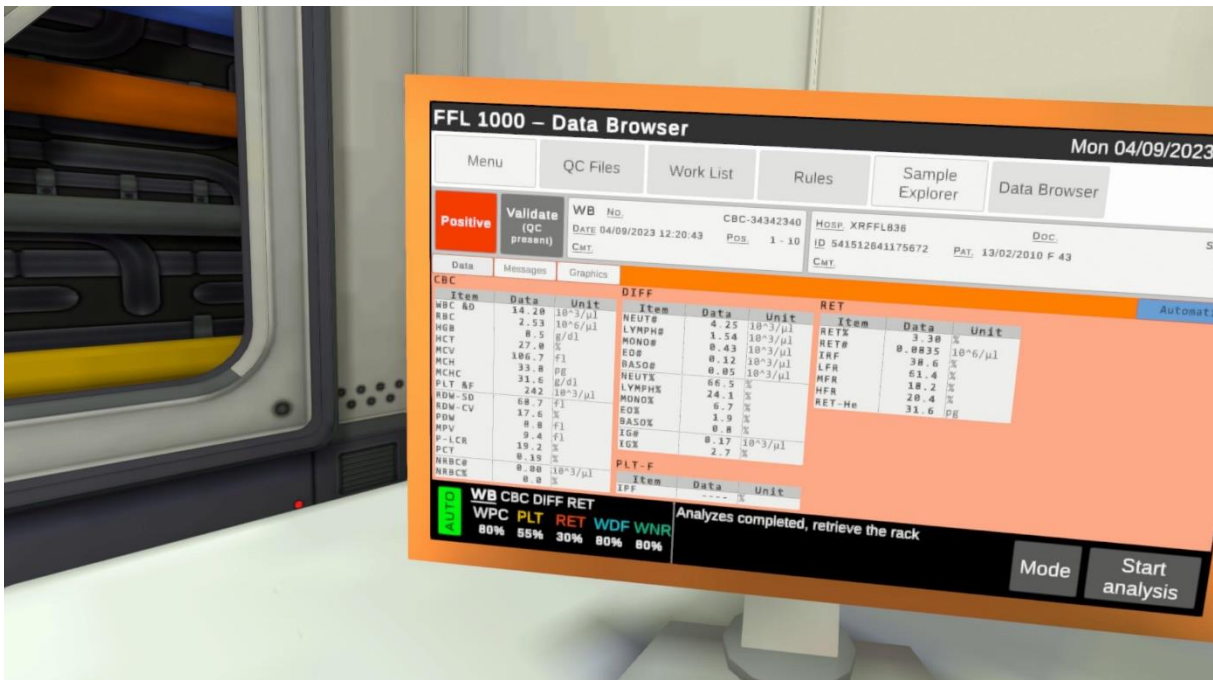


Figure 11. VR game – Automaton results.



Figure 12. VR game – Example of a quiz.

Interpretation and conclusion: the haemogram is normal.

Robot: "Right, we can phone the onboard doctor. He can tell Sylvia that everything's OK!"

4. Chapter 2

During the second chapter, the player will analyze the samples of Olaf. This clinical case will introduce the pathology of Beta thalassaemia, the different haemoglobin fractions and the Sebia capillary automated system. A haemogram will be carried out using the automaton and a blood smear will also be tested.



Figure 13. VR game – The Hemato lab.

5. Chapter 3

In the third chapter, we will focus on Aureliano Foguinho. This case introduces CRP analysis and the suspicion of meningitis by microbiological analysis.



Figure 14. VR game – The CRP lab.



Figure 15. VR game – Archiving the sample.

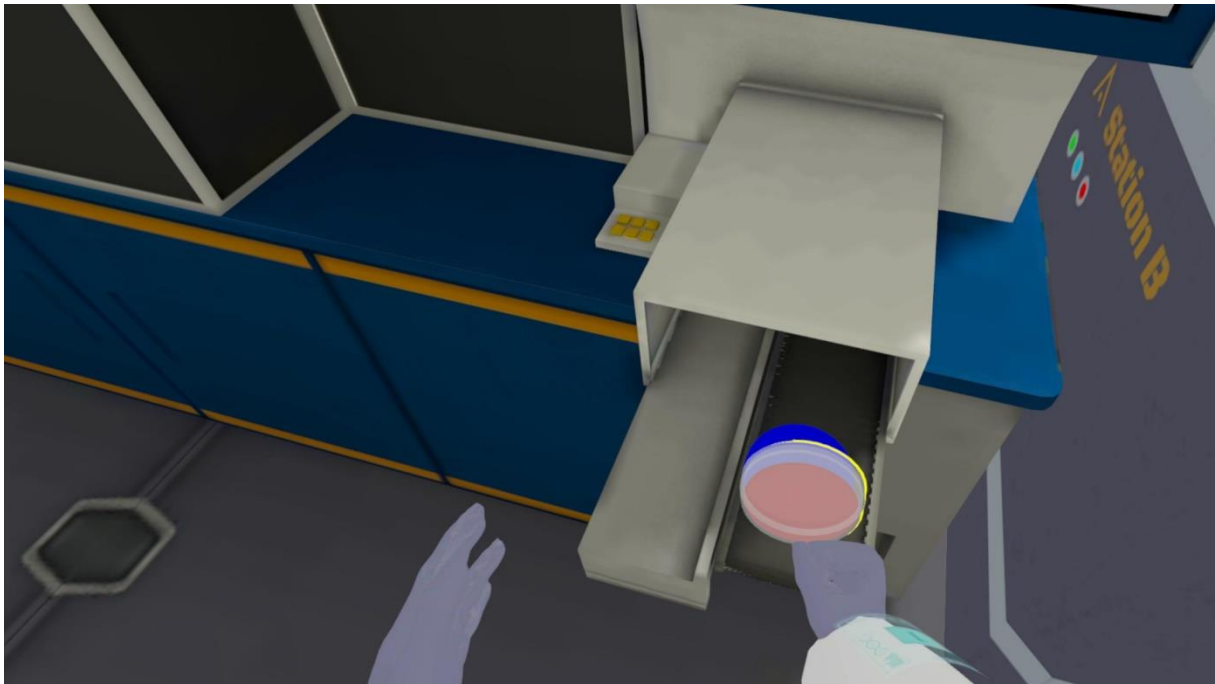


Figure 16. VR game – Microbiology automaton.

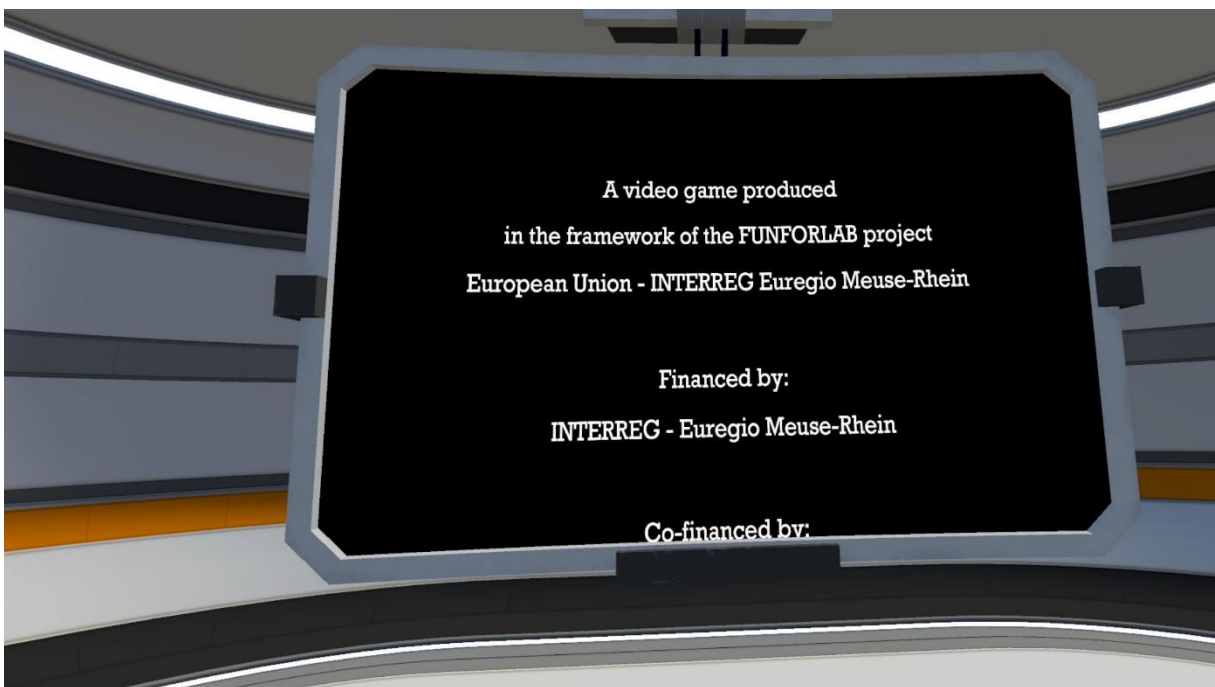


Figure 17. VR game – Outro of the game.

VR Game FAQs

For an up-to-date version of the FAQs we refer to the FunForLab website (funforlab.eu) and the forum (<https://funforlab.eu/community/>).

1. What do I need to play the game?

In order to play the VR game, you need a VR Headset and controls (such as the Meta Quest). You also need a WiFi Connection.

2. How do I install the game?

Download the apk data via our website or click on the QR code below. To install the game, download the Sidequest app and connect your headset. Chose the funforlab.apk data and click start to transfer. On your headset, chose 'unknown source', the FunForLab game should show up here. Select the game to play.



3. How to move the avatar?

Click the handset on the back button. A blue line should show you where to go, click again to follow the line. During the tutorial you can practice moving your avatar. Also see Figure 10.

4. The avatar doesn't follow my instructions?

If there is a text, have you clicked 'continue' yet?

5. How can I change the language?

The game can be played in 4 languages (English, Dutch, German and French). Language can be changed by going to Settings > change language



Figure 18. VR game – Settings – choose your language.

6. How can I change the name of the player?

Launch tutorial and change the name.

7. How to put on the lab coat (protective gear)?

Go to the changing capsule (Fig. 18) in the spaceship, get in and select the lab coat (Fig. 19).

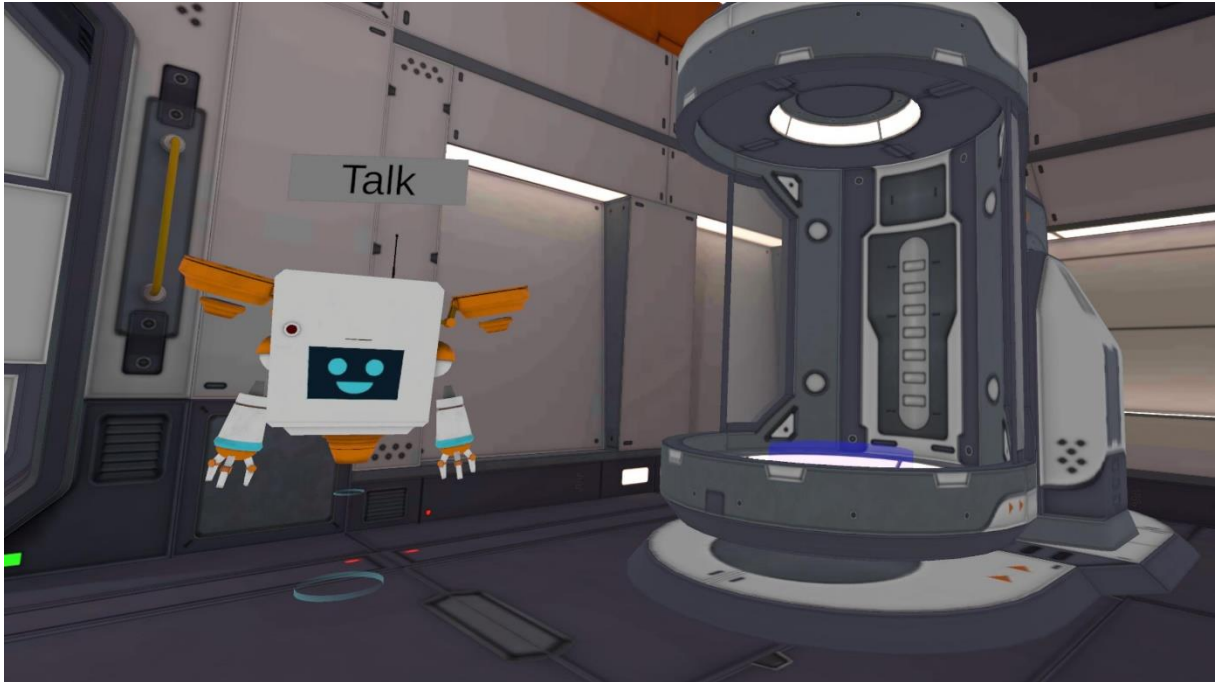


Figure 19. VR game - changing capsule



Figure 20. VR game - changing capsule – select lab coat.

8. I'm stuck, the game doesn't load!?

Go back to the main menu and resume the game.

9. How to resume the game?

If you quit and you were in the middle of a case, you will automatically be brought back to the middle of the case.

10. My question is not in the FAQ.

Go to the FunForLab forum (click on the QR code below) and ask your questions. Check back later to see the answer.



Continuous Improvement and Future Developments

In the course of the coming years, when the FunForLab VR game will be integrated into the different curricula of the teaching institutions, it will be reviewed how the game has an impact on the MLT training. To do this, the partners and lecturers involved will be asked to assess the impact of VR training on laboratory performance. To keep the discussion going, the FunForLab community (forum) is the place to connect and share practical advice and findings.

Further, every partner can expand the training scenario's/chapters so that the FunForLab game evolves and covers a broader range of skills and situations.

Conclusion

Integrating a serious virtual reality game into laboratory training can significantly enhance the effectiveness and engagement of training programs for MLT students. By following the guidelines outlined in this manual, MLT lecturers can ensure a seamless integration process that maximizes the benefits of virtual reality training and introduction to the use of automatons. Regularly assess the training program's impact and remain adaptable to advancements in VR technology for continuous improvement.

Teaching resources

- FunForLab's serious game: the data for the cases to be analyzed are part of the game.
- HAFERLACH Torsten, BACHER Ulrike, THEML Harald, DIEM Heinz, 2013, *Atlas de poche Hématologie (3^e Éd.) Coll. Atlas de poche. LAVOISIER.*
- <https://hematocell.fr>
- « *Hématologie*, par la Société Française d'Hématologie (SFH), 2^{ème} édition, 2014. Elsevier/Masson, 358 pages (collection : Référentiels des Collèges) »
- « Landrieu, Valentin, et al. Cas cliniques en hématologie immunologie. Belgique, De Boeck supérieur, 2018. »

Teaching aid: Theory concepts

Constitution of blood

Blood is a liquid tissue: a suspension of cells in a complex liquid: plasma. Plasma is made up of water, mineral salts and organic molecules (carbohydrates, lipids, proteins, etc.). After coagulation, the fibrinogen-free plasma becomes serum. Cells that can be separated by centrifugation fall into three categories: red blood cells or erythrocytes, white blood cells or leukocytes, and platelets or thrombocytes. These different groups of cells will be studied in detail later. Let's briefly recall that red blood cells are anucleate cells, specialised in the transport of O₂ and CO₂ thanks to the haemoglobin they contain, that white blood cells are the body's defence cells, which are all nucleate but can be divided into several classes (origin, role, morphology), and that platelets are anucleate cell fragments, essential for haemostasis.

NB. The average blood volume in adults is 5 litres.

Preparation of plasma and serum for analysis

Obtaining serum

If you want to obtain serum, you take blood without anticoagulant and leave it to coagulate. Once the clot has formed, the serum is mechanically separated from the clot. It should be noted that there are collection tubes containing a gel that facilitates the separation of serum and clot. Serum is used for most clinical chemistry measurements. It has the advantage of containing no chemical additives likely to interfere with the analyses. The serum obtained should be clear, light yellow. Sometimes the serum is coloured pink, more or less dark. This is because red blood cells have burst during the formation of the clot. The serum is then said to be haemolytic.

In general, this haemolyzed serum cannot be used in analyses because it leads to errors. However, some machines have a correction programme that allows these sera to be used. In other cases, the serum is too yellow, and is said to be icteric. This particular colouration is due to the presence of excess bilirubin (a metabolite of haemoglobin, eliminated in the bile), which

can also lead to analysis errors. Finally, the serum may also be cloudy, which is determined by the excess presence of certain lipoproteins, such as chylomicrons.

Note: Some clinical biochemistry machines can, to a certain extent, correct results obtained with haemolytic, icteric or turbid sera.

Obtaining plasma

To prepare plasma, blood is drawn in the presence of an anticoagulant: usually sodium citrate, oxalate, EDTA or heparin. This produces "whole blood", which is used as it is in haematology (basic test or haemogram). The whole blood is then centrifuged to separate the red blood cells or plasma. Plasma has the advantage over serum of still containing fibrinogen (a protein in the blood; key to coagulation) which can be measured. But the anticoagulant additives it contains can alter its properties, notably by inhibiting certain enzymes. In terms of biochemical analysis, it should be borne in mind that not all plasmas are equivalent, but that their properties depend on the nature of the anticoagulant. Heparin does not inhibit plasma enzymes in general, but its action is not reversible. Citrate, oxalate and EDTA have reversible actions (mechanism: see chapter on coagulation) but their action on enzymes is more important.

Finally, we will see on various occasions, particularly in the clinical chemistry course, that the cation which balances the citrate, oxalate, EDTA or heparinate anion must also be taken into account. (Na⁺, K⁺, Li⁺...)

Origin of the figurative elements in blood

Blood cells are produced by the red bone marrow (in normal adults). Within the marrow, there are two physiologically different, although closely intertwined, tissues: myeloid tissue and lymphoid tissue. The lymphoid tissue of the marrow produces mature B lymphocytes, but the maturation of T lymphocytes takes place in the thymus.

Myeloid tissue gives rise to cells of very varied appearance and function:

- red blood cells (transport of O₂, CO₂)
- neutrophils (antibacterial defence)
- eosinophilic polynuclear cells (helminth defence)
- basophilic cells (inflammation)
- monocytes (macrophage precursors)
- platelets (primary haemostasis)

Lymphoid tissue is made up of lymphocytes and plasma cells, which support specific immune reactions. (Plasma cells¹ are active B lymphocytes, producing antibodies or immunoglobins).

N.B.: the "white blood cells" category therefore includes cells belonging to two different tissue lineages (polymorphonuclear cells, monocytes, lymphocytes). The different cell types found in blood are described at the end of this chapter (ADDENDUM: mature blood cells).

Myeloid cells are produced in the embryo by the liver, spleen and marrow. After birth, only the marrow is normally haematopoietic. Lymphoid tissue is present not only in the bone marrow but also in the lymph nodes, spleen, Peyer's patches and thymus. It is therefore not surprising that the volume of these organs is altered in lymphoid tissue diseases. However, in haematological malignancies, the liver, spleen and even lymph nodes may become the site of ectopic production of (myeloid) blood cells. Physiologically, to ensure the renewal of myeloid and lymphoid cells, there are so called "stem" cells in the body.

Stem cells perform two functions: their own renewal and the production of differentiated cells. There are stem cells common to all myeloid cells, which explains the frequency with which myeloid tissue is affected as a whole in pathology. Lymphoid stem cells also exist, but are less well known. There is probably a common ancestor between lymphoid and myeloid stem cells, but it is probably relatively remote and, in pathology, damage to myeloid cells is not accompanied - at least not generally - by damage to lymphoid cells.

Myeloid stem cells are the best known. There are two levels:

- pluripotent stem cells
- pre-differentiated" stem cells

Pluripotent stem cells are the only true stem cells capable both of giving rise to any myeloid cells and of ensuring the constant maintenance of a pool of totipotent cells. Predifferentiated or predetermined stem cells are derived from the previous ones by progressively differentiating into a specific myeloid lineage (e.g. erythroblastic, platelet, polynuclear lineages, etc.). Pre-differentiated stem cells undergo numerous divisions before definitive differentiation. Totipotent stem cells have a low rate of renewal. As a result, they rarely undergo mitosis, which makes them relatively immune to certain aggressive agents such as ionising radiation and anti-mitotic (i.e. anti-cancer) chemotherapy.

Pre-differentiated cells have a faster rate of renewal the closer they are to mature cells. All these stem cells, whether totipotent or pre-differentiated, are present not only in the marrow but also in the blood. This certainly explains why diseases that begin in the myeloid stem cells, such as myeloid leukaemia, are always spread throughout the marrow.

Examination of blood

Figurative elements: haemogram

The haemogram is taken on an anticoagulant sample, either venous in adults or capillary in infants. It comprises two types of analysis:

- quantitative analysis

- morphological examination of the cells

Quantitative analysis

It is used to calculate the absolute number of cells contained per unit volume of blood. The classic manual technique has now been abandoned. It consisted of placing blood diluted in a reagent appropriate for the category of cells to be studied (Thomas cell) in a glass cell of exactly known volume. Under these conditions, the elements fall to the bottom of the cell in a few minutes, where they can be counted under a microscope. A simple calculation, taking into account the dilution and the volume of the cell, will give the number of elements per mm^3 . The disadvantage of this manual technique was that it was both time-consuming and inaccurate (10-20% error rate). It is currently being replaced by electronic counters which allow measurements to be made much more quickly and with a much smaller margin of error (2 to 6% for red and white blood cells, 15% for platelets). These automatic counters will be the subject of a specific chapter in this course, which will be studied when the course is more advanced.

Quantitative measurements of red blood cells and their contents

The quantity of red blood cells (and, to a certain extent, the quality) in a sample can be assessed by 3 measurements:

- the number of red blood cells
- haematocrit
- haemoglobin levels.

As changes in these three measures can be observed separately, it is essential to measure them together. Modern electronic meters provide these three measurements simultaneously. The principles of these meters will be studied in the laboratory. Normal number of red blood cells per mm^3 . It depends on gender and age.

Men: 4.5 to 6.2 10^6 per mm^3

Women : 4 à 5,4 10^6 per mm^3

Children aged 2 to puberty: see women

Children aged 1: 3.6 to 5 10^6 per mm^3

Newborn : 5à 6 10^6 per mm^3

Haematocrit

By centrifuging a small volume of blood in a graduated tube, the relative volumes of plasma and red blood cells can be read directly (the other cells form a thin, negligible layer on the

surface of the red blood cells). Measurements are taken in capillary microtubes centrifuged at high speed (= reference technique)*.

Note that in automatic meters, the haematocrit is calculated from the mean corpuscular volume and the number of red blood cells per ml of blood.

Normal haematocrit values :

Men: 40 à 54%

Woman: 35 à 47%

Child 1 year: 36 à 44%

Newborn: 44 à 62%

The haemoglobin level

There are various dosage methods E.g.: the cyanmethaemoglobin method, in which haemoglobin and all its derivatives are converted by a hydrocyanic acid-based reagent into cyanmethaemoglobin, which is measured using a spectrophotometer. Of course, the red blood cells must first be haemolyzed (osmotic shock) to bring the haemoglobin into solution.

Normal results are as follows:

Men: 13 to 18g/100 ml

Woman: 12 to 16 g/100 ml

Children over 2 years old: 12 to 16 g/100 ml

Newborn: 14 to 20 g/100 ml

Volume and content of red blood cells: WINTROBE magnitudes

The content of the red blood cell depends on the amount of haemoglobin synthesised during erythropoiesis and cell growth. (Erythropoiesis: formation of red blood cells in the red bone marrow from a stem cell).

They are mainly assessed using WINTROBE sizes:

- mean corpuscular volume M.C.V.
- average cellular (corpuscular) haemoglobin concentration C.C.M.H.
- average cellular (corpuscular) haemoglobin content T.C.M.H.

- Mean corpuscular volume M.C.V.

It is calculated by dividing the volume of red blood cells in 1 mm³ of blood (provided by the haematocrit) by the number of red blood cells in the same volume (provided by the blood count). However, haematology machines measure it directly.

$$\text{VGM} = \frac{Ht}{\text{number of G.R.}} \quad (\text{Ht} = \text{haematocrit})$$

The normal range is between 85 and 95 μ³. Below 85 μ³, the term microcytosis is used; above 97 μ³, the term macrocytosis is used. Within normal limits, normocytosis. In small children there is a microcytosis which appears to be physiological (75 to 80 μ³).

- Mean corpuscular haemoglobin concentration M.C.H.C.

The calculation involves dividing the haemoglobin result by the haematocrit result. This is how the quantity of haemoglobin is related to the unit volume of red blood cells

$$\text{C.C.M.H.} = \frac{[\text{Haemoglobin}]}{Ht}$$

The normal result is between 0.32 and 0.36 (32 and 36%). The C.C.M.H. can be lowered below 32% when the haemoglobin content of the red blood cells per unit volume is insufficient: this is hypochromia. When the C.C.M.H. is between 32 and 36%, this is known as normochromia.

On the other hand, C.C.M.H. above 36% is never observed (unless there is a technical error): there is no hyperchromia.

- Mean corpuscular haemoglobin content M.C.H.T.

It is obtained by dividing the haemoglobin assay result by the number of red blood cells in the same volume and indicates the average mass of haemoglobin per cell (~29 +/- 2 10⁻¹²g).

Reticulocyte count

Reticulocytes are "young" red blood cells that have just been released from the marrow, still contain RNA and bind basic dyes. They retain their characteristic appearance (filament and basophilic granules) for around 24 hours (whereas the life of red blood cells is around 120 days). Reticulocytes therefore normally represent just under 1% of red blood cells. To measure them, they are detected in blood smears using certain basic dyes such as methylene blue, which bind to the RNA that is totally absent in mature red blood cells. The percentage of reticulocytes in 1000 red blood cells is estimated. For this result to be meaningful and interpretable, it must be expressed as an absolute number by relating this percentage to the

total number of red blood cells per mm³. In pathology, the same reticulocyte count has a completely different meaning depending on whether anaemia is present or not. The normal number of reticulocytes is between 25,000 and 100,000 per mm³ for a normal haemoglobin level.

Quantitative study of white blood cells

Blood count

Blood smears can be examined to identify the different types of leukocytes (see addendum at the end of the chapter) and to establish their relative proportions: this is the blood or haemoleukocyte count. The blood count varies with age. Before drawing conclusions from an observation, it is therefore important to know the patient's age.

The normal adult formula is as follows:

Neutrophils 45 à 70% 1700 to 7000/mm³

Eosinophilic polymorphs 1 à 5% 50 à 500/mm³

Basal Polynuclear Cells 0 à 0,5% 10 à 50/ mm³

Lymphocytes 20 à 30 1500 à 4000/ mm³

Monocytes 3 à 10 100 à 1000/ mm³

In fact, the child's blood count is very different. In newborns, it is close to that of adults, but during the first month, a predominantly lymphocytic blood count is established, with a tendency towards a higher total leucocytosis (up to 15,000/mm³). The transition to the adult formula takes place between 4 and 10 years of age.

Note: at present, there are automatic counters which produce haemoleukocyte formulae (complete or approximate), but the laboratory technician must perform the formula on a smear under the microscope, as soon as the counter indicates an anomaly.

White blood cell count in suspension. Quantitative study of white blood cells.

It is generally carried out on the same sample as the study of red blood cells, using the same methods (automatic counters). They differ in size: they are larger than red blood cells. Normal values are between 4,000 and 10,000/mm³ in adults.

Quantitative study of platelets

It is carried out by automatic meter. The normal range of variation is very wide, from 150,000 to 450,000/mm³. Note: Platelets have a tendency to aggregate, which can lead to errors in

automatic counting. The counter may mistake a platelet aggregate for a red or white blood cell.

Morphological study of the figurative elements of blood

It is performed on a blood smear, obtained by spreading a fine drop of blood on a glass slide and examining it under the microscope after staining (the most commonly used stain is MAY-GRUNWALD-GIEMSA or MGG). MGG staining: the principle of this staining consists of placing blood cells in the presence of a mixture of basic dyes (azure, methylene blue) and acid dyes (eosin). The so-called basophilic constituents of cells (nucleic acids, for example) bind basic dyes and appear blue or violet, while the so-called acidophilic constituents (haemoglobin, for example) bind eosin and are coloured red-orange (acidophilic elements are often called eosinophils). This examination is used to study the morphology of red and white blood cells. The haemoleukocyte count is determined on the same smear.

Examination of red blood cells on the smear

Normally, all red blood cells are approximately the same shape, colour and diameter. Any change in these data indicates a pathological state. Examples:

- red blood cells of unequal size: anisocytosis
- red blood cells of variable shape: poikilocytosis

It should be noted that anisocytosis and poikilocytosis both suggest a disorder of erythropoiesis (dyserythropoiesis).

- discoloured red cells: hypochromia
- red blood cells more blue than orange: polychromatophilia (they have retained basophilic constituents) (but beware of staining artefacts!). These two anomalies indicate pathological conditions: hypochromia is the consequence of a disorder in haemoglobin synthesis, while polychromatophilia is the sign of accelerated erythropoiesis and hyperreticulocytosis. In some cases, there are also red blood cells with very specific shapes, indicative of certain haemolytic anaemias, or intraerythrocyte inclusions, which are also of great diagnostic value.

Investigation of the bone marrow

The myelogram

The red marrow in the epiphyses of the long bones and flat bones is an enormous diffuse haematopoietic organ (+/- 1l of active marrow in adults), with intense mitotic activity enabling it to produce 100 to 250 billion red blood cells, 70 to 150 billion platelets and several tens of billions of white blood cells every day. The bone marrow also contains diffuse lymphoid tissue and produces all the lymphocyte stem cells, although the genesis of these cells ends in other organs (lymphoid organs). In current practice, cytological examination of the bone marrow or

myelogram provides information on the state of this haematopoietic organ. The examination is performed by trocar puncture of a fertile epiphysis, usually the sternum or posterior iliac spine (a fairly painful procedure). The marrow is aspirated with a syringe, and a smear is prepared and stained as for blood. This examination gives no absolute figures, only percentages reflecting the relative proportions of the various normal bone marrow cells. It is important to know whether the smear is rich in cells or not, as this gives a rough idea of the cellular richness of the marrow and makes it easier to use the percentage data. E.g.: A high rate of lymphocytes on a very poor smear suggests bone marrow aplasia and is mainly due to the scarcity of other cells; the same rate on a rich smear suggests lymphocytic leukaemia with invasion of the marrow by lymphocytes. Marrow cells are grouped into "lineages", which are all the precursors of a type of circulating cell. In practice, it is above all the variations in the percentage of all the cells in a lineage that are important to study. If the myelogram is normal, the figures are as follows:

Red blood cell lineage 8 à 30%

Neutrophil cell lineage 50 à 80%

Eosino- and basophil lineages 2 à 4%

Megakaryocytes present

Monocyte lineage 2 à 3%

Stem cells 1 à 2%

Non-myeloid elements 20% standards

There is a balance within the lineages, with the most mature cells being the most numerous. A disturbance in this balance (excess of very immature forms) suggests a maturation disorder. Remember that the practical reading of the myelogram involves three stages:

- appreciation of wealth
- verification of the normality of the percentages of each lineage
- checking the "pyramid" balance of each line.

Biopsy of marrow

This is a less frequently performed examination, the results of which supplement the data from the myelogram. It is essential for diagnosing certain diseases. A special trocar is used to cut out a small bone fragment under local anaesthetic. The aim is to carry out a histological study of the marrow in place, undilacrated (as it is during aspiration and smear preparation). A biopsy provides a better assessment of the cellular richness of the marrow and is the only way to discover certain lesions (e.g. marrow fibrosis, nodular invasion by cancer metastases, etc.). Cellular richness is assessed on the basis of the ratio of surface area occupied by myeloid cells and fat cells, which is normally 50%. 2 Non-myeloid elements are more abundant in very young children (up to 50%) When richness is increased, the surface area occupied by fat cells

decreases and vice versa. The disadvantages of bone marrow biopsy are the reading time, which is several days (whereas the result of a myelogram is available within a day), and the quality of the cytological study, which is much lower than that of a myelogram.

Examination of lymphoid organs

Basically, the lymph nodes and spleen are examined. Nodes: adenogram by puncture lymph node biopsy: diagnosing the cause of adenopathy Spleen: splenogram: rapid puncture without aspiration rarely necessary in the diagnosis of splenomegaly, risk of splenic rupture.

ADDENDUM: Mature blood cells

The different cell categories mentioned will be studied later in the course, but it is important to learn to recognise them from the start.

- Red blood cells have no nucleus and are discoid in shape. In the May, Grünwald and Giemsa (MGG) stain - which is the basic, routine stain for blood smears – they are coloured orange if done correctly, but can sometimes be grey-green (excess stain).
- The white blood cells are nucleated, which is clearly visible on the MGG smear as the nuclei are stained violet and contrast with the lighter cytoplasm. Polynuclear cells or granulocytes are white blood cells with a single nucleus that is lobed to a greater or lesser extent and whose cytoplasm appears to contain granules. Polynuclear neutrophils These are cells with a strongly lobed nucleus (usually at least 3 lobes) and a finely granular cytoplasm. The small granules bind both acidic (pink eosin) and basic (methylene blue) dyes. These are the most abundant white cells in adults.
- Eosinophilic polymorphonuclear cells : eosinophils have a nucleus that is generally bilobed, biscuit-shaped or lorgnon-shaped; their cytoplasm contains abundant granules that are larger than those of neutrophils and stained with eosin (orange to purple).
- Basophilic Polynuclear Cells Basophils are the rarest cells in a normal smear. Their cytoplasm contains large granules of variable size, partially masking the constricted nucleus. These granules are coloured blue (sometimes almost black).
- Monocytes are the largest cells in the blood smear. Their nucleus occupies around 50% of the cell and is usually kidney-shaped. The cytoplasm is sparsely granular.
- Lymphocytes These are cells with a round nucleus. Morphologically, a distinction is made between small and large lymphocytes, which are differentiated by their cytoplasmic content, which is much more abundant in large lymphocytes. Note the basophilicity of this cytoplasm, which therefore appears light blue in colour.

N.B. Plasma cells or B lymphocytes can sometimes be seen synthesising antibodies. They are characterised by a clearly off-centre nucleus

Clinical cases: pedagogical material

Earlier in this manual, an overview of the VR game and its chapters was given. In this section, you may find extra lesson material to be used in conjunction with the VR game.

Introduction case: Anaemia

This clinical case is introduced in order to discuss the values of haemogram analyses and to introduce the pathology of anaemia and more specifically iron deficiency microcytic anaemia. Answers to the questions below are in **bold** type.

Mr N., aged 61, was admitted to emergency for a fall at home. A haemogram was taken when he was admitted to hospital. The results were as follows:

Hb: 7.8 g/dl

VGM: 70 fl

Reticulocytes: 35 giga/l

Platelets: 110 giga/l

Leukocytes: 3.6 giga/l

Neutrophils: 1.3 giga/l

Eosinophils : 0.3 giga/l

basophils: 0 giga/l

lymphocytes: 1.8 giga/l

monocytes: 0.2 giga/l

1. Interpret the biological follow-up (review all parameters + clinical statement). Please use precise terms.

-**anaemia (severe) aregenerative**

- **thombopenia**

- **leukopenia**

- **neutropenia**

2. What additional tests would you order to confirm your diagnosis and establish a prognosis? What results are you expecting?

- **Myelogram : morphological abnormalities in one or more blood lines**

- Blood smear : morphological abnormalities in one or more blood lines

3. In addition to this haemogram, iron metabolism tests were carried out on the same sample, with the following results:

- Iron = 3 $\mu\text{mol/L}$ (9 - 30.4 $\mu\text{mol/L}$)

- Ferritin = 4 $\mu\text{g/L}$ (6-67 $\mu\text{g/L}$)

Based on these results, what is your conclusion about the pathogenesis of the disease?

Microcytic anaemia of the iron deficiency type

4. How can it be seen on a blood smear?

Result for red blood cells of the digital microscope analysis of the blood smear from your sample

5. Name three diseases linked to haemoglobin abnormalities

Anaemia, sickle cell anaemia, thalassaemia

Chapter 1: Sylvia

This VR game case is directly linked to the game and allows us to study techniques used by automatons.

Here are the results of his haemogram which was carried out on the Beckman Coulter 780 automaton :

- Red blood cells: 4 $10^6/\text{mm}^3$
- Haemoglobin: 120 g/l
- Haematocrit: 36%
- MCV 85fl
- MCHC: 32%
- Platelets: 300 giga/l
- Reticulocytes: 0,5%
- Leukocytes: 8.5 giga/l

1) Interpretation and conclusion :

The haemogram is normal.

➔ Robot: "Right, we can phone the onboard doctor. He can tell Sylvia that everything's OK!"

- 2) Explain Coulter's principle (description of the physical principle), used in particular in the BECKMAN Coulter 780 PLC. Be as complete as possible. What haematological parameters can be measured using this physical principle?

Coulter's principle is based on the variation in electrical impedance

The cells, which are non-conductive, are dissolved in a conductive liquid (or electrolyte solution). The 2 electrodes produce an electric field in the solution . The cells are guided through a small orifice. Each time a cell passes through the orifice, there is a variation in potential between the 2 electrodes because the cells prevent the current from passing . A detector detects this increase in electrical resistance, or impedance variation, and converts this signal into an electrical pulse .

The value of the pulse is proportional to the cell volume and the number of pulses corresponds to the number of cells that have passed through the orifice . The computer uses these pulses to create histograms of the distribution of RBC and PLQ volumes.

The parameters measured are: RBCs, PLQs , RBCs , RBC volume (and PLQ volume) .

- 3) How is MCV calculated?

Mean corpuscular volume M.C.V. It is calculated by dividing the volume of red blood cells in 1 mm³ of blood (provided by the haematocrit) by the number of red blood cells in the same volume (provided by the blood count). However, haematology machines measure it directly.

$$\text{VGM} = \frac{Ht}{\text{number of G.R.}} \quad (\text{Ht} = \text{haematocrit})$$

- 4) How MCHC is calculated ?

The calculation involves dividing the haemoglobin result by the haematocrit result. This is how the quantity of haemoglobin is related to the unit volume of red blood cells.

$$\text{C.C.M.H.} = \frac{[\text{Haemoglobin}]}{Ht}$$

Chapter 2: Olaf

This clinical case will introduce the pathology of Beta thalassaemia, the different haemoglobin fractions and the Sebia capillary automated system.

On clinical examination, the doctor noticed that Olaf's face and conjunctivae were pale. He also tells you that she frequently loses her hair and feels very tired.

A haemogram was carried out, showing the following results:

- Sg erythrocytes: 4.3 T/L
- Sg haemoglobin: 82 g/L
- TCMH: 25 pg
- CCMH: 30
- VGM: 68 fL
- Sg platelets: 465 G/L
- Sg leukocytes: 6 G/L
- Sg reticulocytes: 55 G/L
- Leukocyte count: normal

- Blood smear analysis:
 - o Poikilocytosis
 - o Target cells

*Abnormally long and heavy periods with bleeding outside the menstrual cycle.

1. Analyse the biological follow-up
 - **Normal erythrocytes**
 - **Hb → anaemia ++**
 - **Microcytic**
 - **Hypochromic**
 - **Aregenerative**
 - **normal leucocytosis**
 - **thrombocytosis**

In the patient's case, β -thalassaemia is suspected.

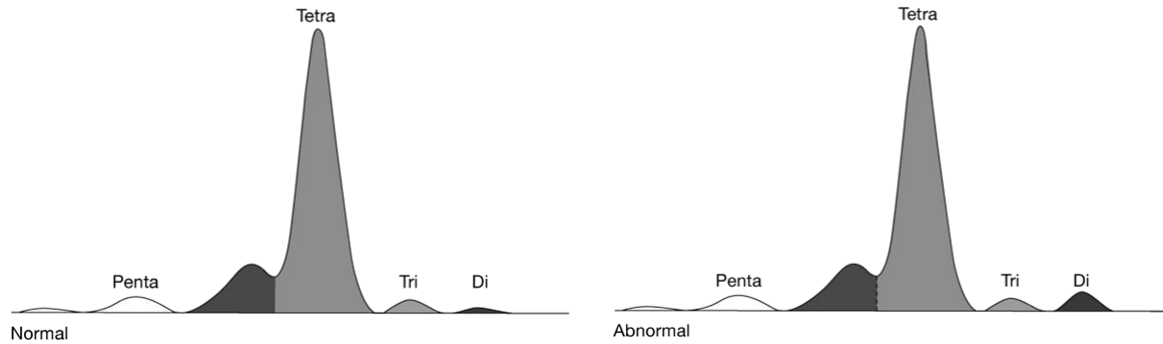
2. What biological analysis could you carry out to confirm this and using which technique?

Analysis of the different haemoglobin fractions. Capillary electrophoresis

3. Which automated system could you use to carry out this analysis? Explain the principle.

SEBIA capillary , The machine is based on the principle of electrophoresis. This method is based on the migration of ions in an electric field. Once the molecules have been separated, an optical detector is used.

4. This automated system can also be used for other analyses. Here is an example of the results obtained. Comment on these graphs and explain what they identify.



Analysis of CDT (carbohydrate-deficient transferrin) in a healthy sample with alcohol consumption. The sebia is designed to quantify CDT by capillary electrophoresis in patient serum samples. During the analysis, serum transferrin isoforms are separated into five major fractions according to the level of sialylation.

5. What quantitative deficit is observed in β -thalassaemia and what is the consequence on the composition of adult haemoglobin? Justify your answer.

In Beta thalassaemia → Quantitative deficit in β globin synthesis → synthesis of exaggerated alpha chains :

- Accumulation of α chains in inclusion bodies because not enough taken up by AHSP (alpha Hb stabilising protein) → makes the RBC fragile
- Alpha inclusion bodies

Chapter 3: Aureliano Foguinho

This case introduces CRP analysis and the suspicion of meningitis by microbiological analysis.

Clinical biology gives us the following information:

- o lymphopenia 800/mm³
- o neutropenia 830/mm³
- o thrombocytopenia 89 000/mm³
- o Sedimentation rate: 14 mm/h 2-10 mm/h (men)
- o CRP: 34 mg/L 0 - 5 mg/L
- o Fibrinogen: 6.2 g/L 2 - 4 g /L
- o Orosomuroid: 2.25 g/L 0.3 -0.9 g/L
- o Haptoglobin: 5 g/L 1-2 g/L

- o LDH: 353 IU/L < 250 IU/L
- o Normal liver function tests

Infectious diseases :

- o Positive for Neisseria meningitidis (PCR + Western blot performed)

1. What is the patient suffering from?

Inflammatory syndrome because - CRP elevated - Fibrinogen elevated - Orosomuroid elevated - Haptoglobin elevated - LDH elevated)

2. Which biological parameter measured here is the most representative of this syndrome? What do you know about its kinetics?

CRP - Is one of the group of inflammatory reaction proteins whose concentration increases the most (up to 100x) - Is synthesised in hepatocytes under the action of pro-inflammatory cytokines. The gene coding for CRP contains binding sites for transcription factors (NF-κB, etc.) that are sensitive to IL6, IL1-β, etc. CRP- increases very rapidly after inflammation (between 6 and 12 hours), reaching a maximum after 24 to 40 hours and returning to normal after 3 to 4 days - As its transcript is highly unstable, its synthesis is rapidly reduced as soon as IL-6 becomes normal. Its half-life is short (+/- 12h) - No CRP deficiency is known in humans.

3. What other laboratory technique can be used to detect meningococcus?

Bacterial culture on culture medium

This species grows best on enriched culture media: blood agar or “cooked” blood agar (+++), incubated at 37°C under 5% CO₂.

Media education activity

Target skills

As part of this teaching activity, your students have used VR games as a learning tool. When media education is introduced, it is interesting to propose a **media education** activity: getting the MLT Students to question the use of the medium itself: the reliability of the information, the message conveyed by the work, the ideological and societal issues linked to the use of this work.

With this in mind, we're offering you a questionnaire to give to your MLT Students at the end of the activity. It allows MLT Students to take a step back, debrief and discuss their perceptions and the way in which they experienced the game. It also questions their use of the medium in order to stimulate their reflexivity and critical thinking.

Methodology

The FUNFORLAB VR game focuses on three areas of media education:

- The ideology of the work: what message does the video game convey to the player? How does it portray the future? (on the profession of medical laboratory technologist, but also on the issues of climate change and ecology, the dystopian dimension, etc.).
- The educational aspect of the work: How did you experience the video game in class? What did you learn? Did you find it difficult to play the game? (reflective approach to the player's experience, questions about the digital divide and the different levels of digital skills of players).
- Reliability of information: are the elements presented in the game scientifically valid? Who created this game? Is it a reliable source and why (stimulating players' critical thinking about the reliability of information and checking sources)?

Course and duration

30 min in hematology courses

Prerequisites

- Have played the FunForLab VR Game

Activity sequence

Each teacher is free to adapt or modify this proposal according to his or her own identity, school context and professional experience.

-Each student answers questions 1 to 5 individually (10 minutes)

-Place the MLT Students in a circle and set up a moment of debate during which the MLT Students can exchange ideas, proposing questions arising from the three areas of media education detailed below. (15 minutes)

-Each student responds individually to question 6 by drawing a picture: what have I learnt from this activity? (5 minutes)

Teaching aid: Media literacy questionnaire



Hello dear student, you have just taken part in an educational activity involving a video game. We're going to ask you to answer a few questions that will help you to think about your experience.

1. What do you think is the message of this game?

.....

.....

.....

2. Which elements of the "VR" game seem realistic to you? Which elements are less realistic or purely fictional?

.....

.....

.....

3. Is the information presented in the game scientifically valid? How can we check this?

.....

.....

.....

4. How do the media influence our understanding of science? Can you give some concrete examples of how the media can shape our perception of scientific subjects?

.....

.....

.....

5. In your opinion, what are the advantages and limitations of using video games to learn science? Has it made you want to explore these subjects further outside the game?



.....

.....

.....

6. What do you take away from this activity? Answer this question in the form of a drawing (summarising your thoughts, presenting certain elements, taking elements from the questionnaire, etc.). Don't be afraid to be creative!

Appendix A

Abbreviations for haematological analyses

Abbreviations	Meanings	Brief definition	Unit (Symbol)	Unit
WBC	White Blood Cell = Globules Blancs (GB) Totaux	Cells involved in immune defence. They play a key role in the body's defence against viruses and bacteria, which can cause infections.	Number of cells/nl	per nanolitre (10 L) ⁻⁹
RBC	Red Blood Cell = Globules Rouges (GR)	Cells responsible for transporting oxygen. Their number depends on sex and age.	Number of cells /pl	per picolitre (10 L) ⁻¹²
HB	Haemoglobin	Haemoglobin, the major component of the red blood cell (erythrocyte or haematopoietic cell), is made up of a pigment (haem, which binds iron) responsible for the red colour of the blood and a protein part (globin). It transports oxygen (O ₂) from the lungs to the body's tissues. Haemoglobin also performs the opposite function, transporting carbon dioxide (CO ₂) from the tissues to the lungs.	g/l	gram/litre
HCT	Haematocrit	Volume occupied by red blood cells in the blood in relation to the total volume of blood.	%	Percentage
MCV	Average blood volume (of RBCs)	The average volume of red blood cells.	fl	femtolitre (10 L) ⁻¹⁵
MCH	Average corpuscular haemoglobin content	This is the average haemoglobin level per red blood cell.	Pg	picogram (10 ⁻¹² g)
MCHC	Mean corpuscular haemoglobin concentration	This is the average haemoglobin level in the volume occupied by red blood cells in the blood.	g/l	gram/litre
PLT	Inserts	Platelets are also known as thrombocytes. They are manufactured in the bone marrow and help the blood to clot.	Number of cells /nl	per nanolitre (10 L) ⁻⁹
ESR (VS)	Sedimentation rate	The sedimentation rate (SR) is also known as the Biernacki reaction. It is the rate at which red blood cells suspended in the blood sediment, i.e. settle to the bottom of a test tube.	mm/h	millimetre per hour

Appendix B

Normal values: see below

CBC parameter	Normal adult values	Adult men	Adult women	units
WBC	4-10			/nl
RBC	-----	4,4 - 6,0	4,2 - 5,5	/pl
HB	-----	140 - 180	120 - 160	g/l
HCT	-----	40 - 54	37 - 47	%
MCV	82 - 97			fl
MCH	27 - 36			pg
MCHC	320 - 360			g/l
PLT	140 - 400			/nl
ESR (VS)		< 22	< 24	mm/h

Remarks:

- *RBC, HB ,HCT and ESR (VS) are the only parameters that vary according to gender*
- *Normal values depend on the measurement method, the reagents used and the automata! → There may therefore be some variability in the normal values for different automata even if they use the same measurement principle.*