

iSTAGE 3

FOOTBALL IN SCIENCE TEACHING





IMPRINT

PUBLISHED BY

Science on Stage Deutschland e.V.
Poststraße 4/5
10178 Berlin · Germany

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CREDITS

The authors have checked all aspects of copyright for the images and texts used in this publication to the best of their knowledge.

DESIGN

WEBERSUPIRAN.berlin

ILLUSTRATION

Tricom Kommunikation und Verlag GmbH
www.tricom-agentur.de

SUPPORTED BY

SAP

PRINTING

trigger.medien Berlin

PLEASE ORDER FROM

www.science-on-stage.de
info@science-on-stage.de

ISBN (PDF) 978-3-94-2524-40-7

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First edition published in 2016
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GREETING



Football is more than a game. No other sport brings together more people all over the world. Football used to consist of a combination of strength and stamina, and its training methods corresponded to these requirements. But today, in order to “put the ball in the net”, sports clubs are increasingly using innovative technologies to quickly identify the best players on the market, develop the clubs’ own talented players in more targeted ways and win these players’ long-term loyalty, adapt the clubs’ philosophy of the game as necessary, and develop successful strategies. That applies to players, trainers, talent scouts, medical teams, and the clubs’ business processes.

With state-of-the-art tools such as *SAP Sports One*, games can now be analysed digitally in real time on a smartphone. Players and their trainers can use ultramodern information and communication technology (ICT) to analyse performance parameters and thus prepare themselves for a game even more effectively. The German national team won the world championship in Brazil

in 2014 with the help of this analytic tool. Clubs such as FC Bayern München also use it for their training sessions. Thanks to SAP solutions for the sports sector, they are gaining a competitive advantage and are always a step ahead of rival teams.

But games and game analysis are by no means only for professionals. They can also be integrated very effectively into STEM instruction in the classroom! Using football as an example, many interdisciplinary questions from the fields of science and technology can be investigated directly in practical ways. Students’ enthusiasm for this sport can spark their desire to find out more, and it may even be the beginning of a career. Especially for us as an IT company, this is very important.

That is why SAP has made it a special priority to encourage young people’s interest in the STEM subjects by using practical methods at an early stage. The brochure *iStage 3 – Football in Science Teaching* shows how this can be done successfully. The material offers many examples of creative classroom instruction that teachers and students alike will long remember.

I am delighted that we are able to support Science on Stage Deutschland e.V. in this project. I am convinced that after the two previous brochures, *iStage 1 – Teaching Materials for ICT in Natural Sciences* and *iStage 2 – Smartphones in Science Teaching*, the new brochure will also be a big success. My special thanks go to Science on Stage Deutschland for our smooth cooperation, and especially to the teachers from 15 different European countries who made this brochure possible through their intense personal commitment and hard work!

MICHAEL KLEINEMEIER

Member of the Board, SAP SE

iSTAGE 3: MADE BY TEACHERS FOR TEACHERS!

THE TEACHER AND THE TOPIC ARE THE THINGS THAT MATTER.

Back in 2000, hundreds of teachers from all over Europe responded to a call of the European Union and EIROforum to improve scientific literacy in the EU. We gathered at CERN for the “Physics on Stage” event, the predecessor of the Science on Stage festivals that are now celebrated every other year in different European countries. At that time, long before the famous survey conducted by John Hattie, it was already becoming clear to us that one of the most crucial factors in successful teaching is the teacher.

In order to give European teachers more opportunities to share their great ideas, Science on Stage has developed follow-up activities in addition to the festivals. One of these activities is iStage, which is kindly and generously supported by SAP. In iStage 3 we cover a topic that matters a great deal to our students: football!

20 of the best teachers from 15 European countries worked together for one and a half years to share their expertise. They created teaching units for the fields of biology, chemistry, physics, computing, and mathematics about our biosphere, the human body, the ball, and big data. Here we can see that football really lends itself to the teaching of natural science.

The process of creating these iStage brochures is special, as we focus strongly on the professional skills of the teachers. During personal meetings, these experts from different countries develop the ideas for the brochures, bearing in mind the situation in their own schools. The teaching units are also tested in real



lessons by the participants, and as a result we are confident that we are presenting examples that actually work in real life. In order to create this brochure, the participants of iStage 3 worked hard in their free time besides their normal jobs. Thank you for this endeavour—the results are great!

Our iStage trilogy is now complete. Of course we will continue our work, since Science on Stage knows very well that the teacher and the topic are the things that matter.

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BIOSPHERE

The fundamental process of science involves looking around to understand the way “nature” is working, thinking about how to describe it, and experimenting with different theories in order to be able to validate some of them.

Doing this in a classroom is sometimes difficult, as teachers can have a hard time getting their students to feel really involved in a “discovery”. This task becomes easier if we can find a way to attract their attention. By linking our experiments to football, we are making things more accessible, as most of the students like this sport and soon get enthusiastic about their growing ability to connect their favourite sport to science.

In the Biosphere section, we focus on the environmental aspect of football. The first task is to study the football field itself and to look more closely at the grass upon which the game takes place. In the teaching unit “The Green, Green Grass of Dome”, students grow a few seeds of grass in a CD case under varying conditions of light, humidity, temperature etc. and analyse the properties of the grass while getting a unique view of how the roots are developing.

The second teaching unit in this section, “Stamping on the Carbon Footprint”, is a serious game concerning the environmental impact of a football championship such as the one in France in 2016. In this card game, the students have to find ways of reducing the carbon footprint of a football stadium and creating a healthier environment, taking into account the stadium’s effects on noise, water etc. This game, which combines open-solutions research and limited-choice questions and is similar to a pair card game, should be fun for students from different age levels, as it can easily be adapted to your students’ requirements. Furthermore, you can invent your own questions, as every teaching unit in this booklet is designed to be adaptable to the curriculum of every country. To make it easy for your students to formulate questions, we will provide additional documents on the Science on Stage website ^[1].

During the process of creating iStage 3, our English colleague Richard Spencer, who in 2015 was named one of the ten best teachers in the world, heard that parasites known as nematodes were a big problem for football fields. He had the idea of



trying out different ways of eradicating them. With his students, he went to a stadium to get some soil samples. The class had a big brainstorming session to determine how to structure the experiments: counting the nematodes, experimenting with different methods of killing them and then checking the final results. Unfortunately, after hours of preparation the students discovered that there were very few nematodes in the samples they had collected, making the eradication pointless. They also learned a very important thing about science in the process: even an unsuccessful experiment can teach us something! Because the students had already spent a lot of time studying grass, they discovered that in some stadiums artificial light was used to accelerate the field’s recovery after a match. This inspired them to propose the teaching unit “Pitch Perfect” focusing on the effects of light of different wavelengths on the growth of grass.

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^[1] www.science-on-stage.de/iStage3_materials

MÁRTA GAJDOSNÉ SZABÓ · JANINE HERMANN · MAAIKE SMEETS

THE GREEN, GREEN GRASS OF DOME



- 🔧 football turf, grass morphology, grass species
- 📖 biology
- 👥 12–15 years
- 🔍 Students have to know how to use an optical microscope.

1 | SUMMARY

This teaching unit is about identifying the properties of the grass that is needed for growing the best football turf. What qualities does it need?

Different species of grass have different qualities. Certain qualities are needed in football turf, whereas others are not important. In this project we aim to find the perfect grass species for football turf and to compare its morphology to existing grass species.

2 | CONCEPTUAL INTRODUCTION

Different grass species have different qualities. What qualities are needed for the turf on a football pitch?

- A firm root system prevents grass flying around.
- More-horizontal growth forms are more durable (less likely to be damaged by trampling by football boots).
- Fewer stomata make grass more drought-resistant.

For this project you will need:

- CD cases (to grow the grass, **FIG. 1**)
- potting compost
- seeds (ryegrass (*Lolium perenne*), Bermuda grass (*Cynodon dactylon*), *Poa annua*, any other grass species that might be suitable)
- a microscope (to see the stomata)
- nail polish
- packing tape
- hand lens

3 | WHAT THE STUDENTS DO

3 | 1 General introduction to football turf

Football-turf grass suffers a lot. It is trampled and worn by players slipping and cutting up the surface. However, it is important to have beautiful green turf throughout the year, particularly for premier league and international matches. Approximately 8,000 different species of grass exist all over the world. Not all grasses are suitable for football turf. Two of the qualities needed by football turf are roots that are firmly attached to the soil and leaves that are not damaged by trampling. You are going to design the perfect football turf grass and compare its features with the grasses used on actual football pitches.

3 | 2 Design the perfect football turf grass

Draw a grass plant (root system, leaves, stems) that would be perfect to play football on. Think of the following:

Find a picture of a grass on the Internet in order to see the general growth form of grasses. Bear in mind that the grass must

not be damaged too much by trampling and should be firmly attached to the soil, as well as having other desirable qualities.

3 | 3 Grow football grass

Fill half of a CD case with compost and plant the seeds 1 cm under the surface. Stand the CD case on its side in a tray filled with 2 cm of water (so that the soil stays damp). It should look like the picture shown in the figure below (**FIG. 1**). Let it grow for a period of time (**FIG. 2**) on a sunny windowsill and check regularly to ensure it has plenty of water. Do this for ryegrass, Bermuda grass, *Poa annua* and other species found growing outside of your school or home. Each species should have its own CD case and stand on the same windowsill.



FIG. 1 *Cynodon dactylon*

It takes time for grass to germinate and grow to a size so you can study it. Below you can see how much time it takes (**FIG. 2**).

FIG. 2 Time of growth

Species	Days to germination	Days to study
<i>Cynodon dactylon</i>	11	More than 30
<i>Poa annua</i>	5	30
<i>Lolium perenne</i>	4	30

3 | 4 Study the stems and leaves

Your grass has grown—well done! You are now going to make two drawings per grass species. The first drawing is of the stems and leaves to show how they are distributed in the CD case (you can open the CD case to get a better view). The second drawing is of the stem and leaves of one piece of grass.

Answer the following questions:

- How long is the stem?
- At what distance does the first leaf appear?
- How many leaves have formed?
- How long are the leaves? How wide are they at their widest point?
- What species comes closest to your ideal football turf grass?

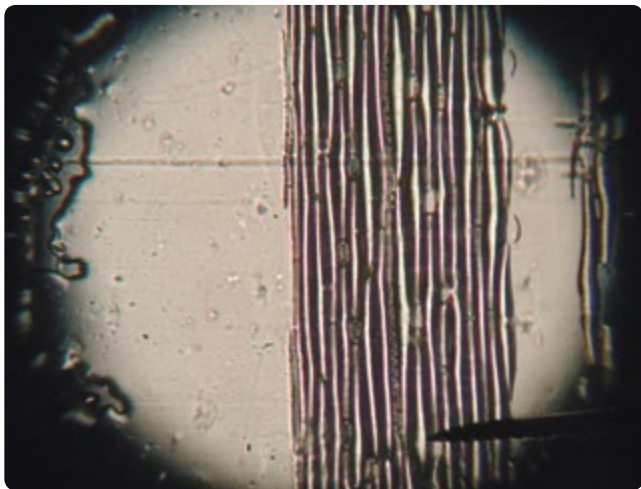


FIG. 3 *Poa annua* stomata 100×

3 | 5 Study the stomata (FIG. 3)

The stomata on the underside of the leaves make the exchange of gases possible. When the stomata are open, carbon dioxide comes in and oxygen goes out in order to facilitate photosynthesis.

Water also leaves the plant via the open stomata. This keeps water flowing through the grass, and this flow is essential for the plant's uptake of minerals. But on a very dry day and on a dry turf, the grass will wilt and eventually die if the stomata stay open. Lots of stomata increase the amount of photosynthesis but also increase the risk of wilting.

You are going to count the number of stomata for all of your grasses, according to the following instructions (FIGS. 4–7):

- Paint clear nail polish on the bottom of the first leaf. Let it dry.
- Use packing tape to remove the nail polish and place the packing tape (with the print of the nail polish) on a slide (mark the slide).

Put the slide under a microscope and magnify 400×. Draw one stoma, together with the surrounding cells. Then magnify 100×, define the leaf surface in the field of view and count all the stomata that are captured in the field. Calculate the number of stomata per mm². Repeat with all the species.

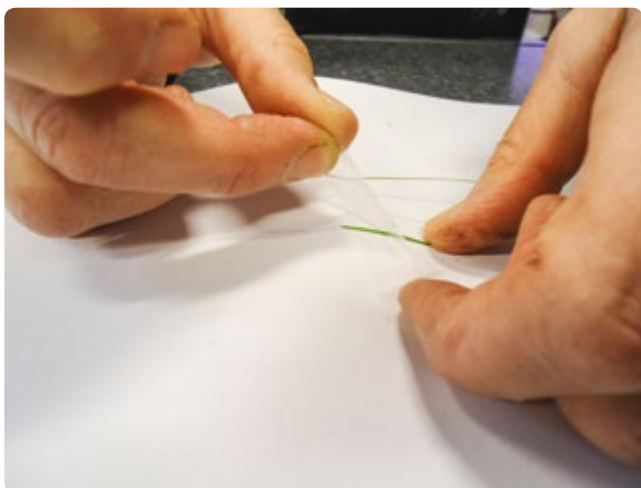
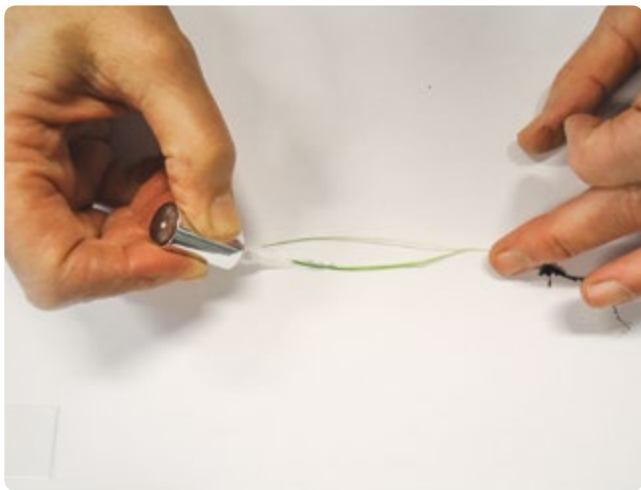


FIG. 4–7 Technique to find out the number of stomata

Answer the following questions:

- What was the number of stomata per field of view for each species of grass?
- Which one is best adapted to a dry climate?
- Which one is best adapted to a wet climate?
- Which one would grow best in your country? Explain why.

3 | 6 **Study the root system**

Now that the grass has grown, we can study the roots as well. The first drawing you should make is of the way the roots are organised in the CD case (you can open the CD case to get a better view). The second drawing is of the root of one piece of grass. Carefully pull one out and use a hand lens to magnify it.

Answer the following questions:

- How long is the root?
- How many divisions does the root have?
- On what part of the root (upper, middle, lower) are the divisions?
- Is/are the root(s) capable of keeping the soil together? (Think of a way to test this.)
- What species comes closest to your ideal football turf grass?

4 | **CONCLUSION**

You have designed the perfect grass for a football turf and you have grown different species of grass in order to study their qualities. Explain which grass species best fits the title “best football turf grass” for your country.

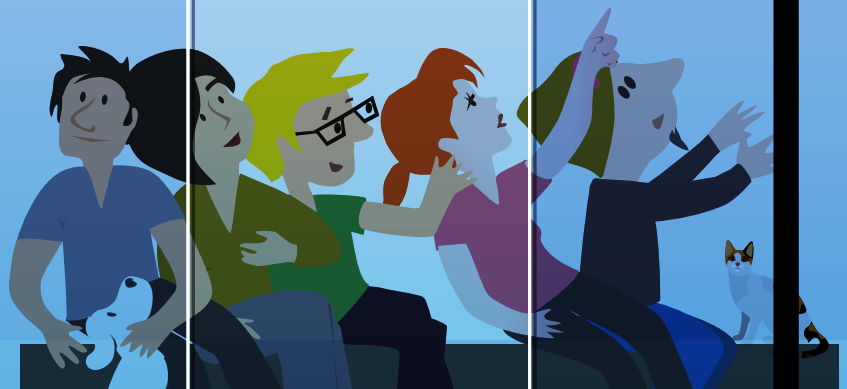
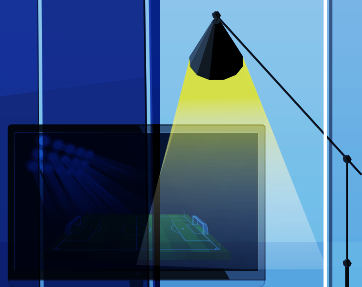
We have assumed the best turf is a monoculture, but perhaps a mixed culture would be better. Give two reasons why a mixed culture may be preferable to a monoculture.


5 | **COOPERATION OPTIONS**


Students can work together with their peers in different countries and compare the best grass species for their own respective countries. The grass that is best for the Netherlands may be different from the best grass for Hungary. The students can think about what factors are contributing to good growth (light, humidity, temperature etc.). By comparing the respective climates of your partner countries, try to explain why they chose their particular grass species.


MÁRTA GAJDOSNÉ SZABÓ · JANINE HERMANN · GIORGIA MESSORI · MAAIKE SMEETS · RICHARD SPENCER


STAMPING ON THE CARBON FOOTPRINT



-  carbon footprint, sustainability, noise pollution, air pollution, greenhouse effect, environment

-  chemistry, mathematics, physics, biology, geography, ecology, integrated language (age level 14–16)

-  10–16 years

-  Materials: All the additional documents can be downloaded from the Science on Stage website ^[1].
Pair cards for the game (see p. 77), information cards, examples of questions and solutions, calculator

1 | SUMMARY

Football is a popular sport in most European countries. In recent years major (premier) clubs have become increasingly interested in the environmental impact of football and how to reduce its carbon footprint. The goal of this project is to educate the students about the environmental and ecological impact of football and to increase awareness of how premier football clubs could become more environmentally sustainable.

Today's world demands a global outlook in every subject and every classroom. As educators, our task is to help the students by giving them the skills, tools and perspectives they need in order to become fulfilled human beings, responsible global citizens and effective promoters of a sustainable future.

2 | CONCEPTUAL INTRODUCTION

We have created a serious game for the students that will make them think about the carbon footprint of a major sports event.

There are six sets of cards, each focusing on one aspect of sustainability. To complete the game, the players will need to cover all of them. The game is appropriate for a wide curriculum range for students aged 10–16 years. By answering the questions the students learn about the complicated effects of a big international sports event. It helps them to realise the responsibility we bear for wasting or using energy and resources such as food and water and to discover how fragile our earth is.

We picked six aspects of how a big sports event affects its natural surroundings. The six topics studied are: light, travel, green grass, waste, noise pollution and food.

What the teacher has to do

In the first lesson the teacher helps the students to review their existing skills and knowledge by:

- asking questions (What is the ecological footprint? Where can we find information about this topic? What do we know about the production, distribution and consumption of energy?) and clarifying the purpose of the activity,
- activating previous knowledge through brainstorming (using keywords),
- explaining the structure and the rules of the game.

The teacher prints out the pair cards and the information cards.

In the development lesson, the teacher explains the rules of the game, forms groups of four students each (depending on the class), identifies a group leader for each one and plays the game.

The information cards report details of the following aspects: the values of the carbon dioxide emissions of different types of transport, the combustion reaction of the various fuels, information about ways to save carbon and water, the meaning of luminous efficacy and the electrical power consumption of different kinds of bulb, a map of the efficiency of a distribution grid, the speed of sound and the level of acoustic pressure and so on. All of the data is useful for solving problems.

During the last lesson, the students should reflect on the topics of the lesson and the difficulties they encountered. All of the students should learn to overcome difficulties together and self-evaluate their group.

3 | WHAT THE STUDENTS DO

The game is played as a pair card game: 12 cards, 6 pairs, 2 cards per topic.

Topics: light, travel, green grass, waste, noise pollution, food

Working rules: Divide the class into groups named after their favourite football teams. Then spread all the cards face down on the table (option: use a Smart Board). Let the first group pick one of the cards, turn it over, look at the symbol and have a group member explain what the symbol means in a limited amount of time (e.g. use an egg timer—our suggestion is five



minutes for a higher level and two minutes for an easier one). Younger students can use keywords and terms in the information cards to help them. We suggest that older students use their personal background knowledge.



Options: Older students may check the Internet to research relevant scientific data. The group leader has to tell the rest of the class what he or she has found out about the topic.

After the given time has elapsed, the teacher can award the team between one and five points. (Our suggestion: The teacher should not tell the group the points awarded until all the other groups have made their statements.) Then the group picks a second card; if the second card matches the first symbol, the team has to answer the teacher's question about this special topic and may score additional points (up to a maximum of five points). If the team finds a pair, the cards are removed from the game.

Each pair of cards gives you a maximum of ten points.

If the team does not find the second card matching the first symbol, it is the next group's turn. The next group can either pick up a new card or the same card, but in the case of the same card the team is not allowed to give the same explanation as the first group. This team will have the same amount of time as the first one, and it will also be awarded points by the teacher.

At the end of the game, when all the cards are gone from the table, the sum of all the points will reveal who the winner is.

4 | CONCLUSION

As teachers, we should educate our students about the importance of sustainability and instil in them a sense of personal responsibility. The subjects that are covered in the game concern natural science and mathematics, and with the data they obtain the students can reflect on ecology, their carbon footprint, and the sustainability of their daily actions.



Some questions can be simplified by using the data on the information cards, because some problems (that were read only once) were difficult to solve. We might also print out the tasks in order to facilitate collaboration within the groups as they work out the solutions. When we tested the game in our classes (aged 14), all of the teams tried to solve the problems in order to be able to respond and to score two additional points if the other teams made a mistake. The game was coordinated by one student from a higher class in order to encourage peer-to-peer education.

Example of a student game session

After giving some information to the students about the topics covered by the game, the teacher puts the cards on the table.

Example of the teacher's introduction for LIGHT

"When we sit in a stadium, we rarely think about the way the energy we are using is produced and distributed, or whether the primary source is renewable or not. When we look at the results and the highlights of a match on a video screen, we do not know if the screen has been made with LED technology or whether the stadium is using an energy-saving light source. We have to change the way we think, and we must aim to make sustainable living our second nature."

The first group picks a card and discovers the light symbol. The teacher asks the team manager to explain what the team knows about the production, distribution and consumption of energy and what the difference between energy efficiency and energy conservation is. The teacher writes on the blackboard some keywords that will be useful for the class as it organises its thoughts on the subject of LIGHT. A maximum of five points is assigned.

The group picks up a new card, if it is lucky, it will get a card in the same category. Now the group has to solve one problem using the information available on the information cards. The teacher reads a question and all of the groups have to make their calculations within five minutes.

Sample task: “Check your daily electrical consumption at home (suppose your family consists of four persons).”

To answer the question, all of the teams must look at the information card to find the formula required for the solution:

Daily home electrical consumption:

$$\frac{(\text{Number of persons} \cdot 500 \text{ kWh}) + 500 \text{ kWh}}{365 \text{ days}}$$

$$\text{Answer: } 2,500 \frac{\text{kWh}}{365 \text{ days}} = 6.8 \frac{\text{kWh}}{\text{day}}$$

A correct answer adds five points to a team’s score; a wrong answer adds two points to the other teams’ score. The pair of cards is removed from the table and then it is another team’s turn.

Some questions for the game

TRAVEL topic example:

What do you know about the carbon footprint? How many kg per km of carbon dioxide are produced by the fans (40,000 per match) over 51 matches of the 2016 UEFA European Championship if $\frac{1}{4}$ of the fans travel to the matches by train, $\frac{1}{4}$ by bike, $\frac{1}{4}$ by bus and $\frac{1}{4}$ by plane?

Answer: The one-way total is $295,800 \frac{\text{kg}}{\text{km}}$.
($591,600 \frac{\text{kg}}{\text{km}}$ is the two-way total)

FOOD topic example:

What is the production cycle of food? Look at the information card to find the carbon and water footprints of some foods and calculate how many litres of water are saved by eating 1 kg of potatoes per week instead of 1 kg of beef.

Answer: 15,214 L saved

NOISE topic example:

What is the range of the human acoustic threshold? The WHO (World Health Organisation) has determined that the acoustic threshold of risk is 85 dB and the acoustic threshold of pain is 120 dB. How big is the increase in sound intensity?

Answer: 3,125 times

GRASS topic example:

If we cut the grass (2.5 cm) of a stadium (120 m × 60 m), what will the volume of the cut grass be in cubic meters?

Answer: 180 m³

WASTE topic example:

How many m³ of garbage will be produced by the use of 7,000 paper cups if each one occupies a volume of 0.25 dm³?

Answer: 1.75 m³

5 | COOPERATION OPTIONS

- Share the questions and topics with other schools or classes.
- Each class that tests the game should write a new question and share it with classes in other countries.
- The game can be inserted into a multimedia platform and played in different places at the same time.
- If you involve the English teacher, you may have a win-win situation when you introduce this interdisciplinary game.

RESOURCES

- ^[1] All additional materials (information cards and example questions) available at www.science-on-stage.de/iStage3_materials.



MÁRTA GAJDOSNÉ SZABÓ · JANINE HERMANN · GIORGIA MESSORI · MAAIKE SMEETS · RICHARD SPENCER

PITCH PERFECT



grass, football pitch, photosynthesis, light-dependent reaction, wavelength, absorption spectrum, redox indicator, chlorophyll, chloroplast

biology

16–18 years

1 | SUMMARY

In this project, students use different coloured lights to investigate the effect of the wavelength of light on the rate of photosynthesis and growth of grass. After evaluating the experimental evidence, they will be able to recommend which colour of light should be used in lighting rigs to best support the growth and recovery of grass on football pitches between matches.

2 | CONCEPTUAL INTRODUCTION

In temperate regions, natural daylight is limited during much of the football season, particularly during the short days of the winter months. Lighting rigs are used to speed up grass growth on the parts of a pitch that are shaded and to encourage the rapid recovery of grass damaged by wear and tear during a football match (FIG. 1).



FIG. 1 Lighting rigs to speed up grass growth

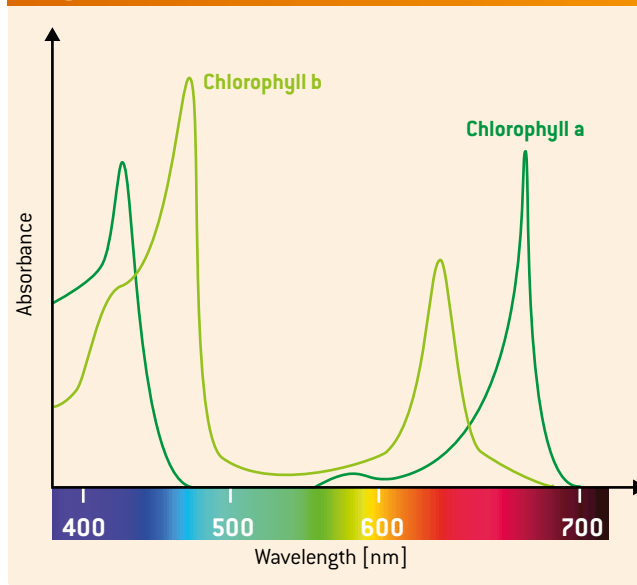
FIG. 2 The visible spectrum [1]



V: violet, B: blue, G: green, Y: yellow, O: orange, R: red

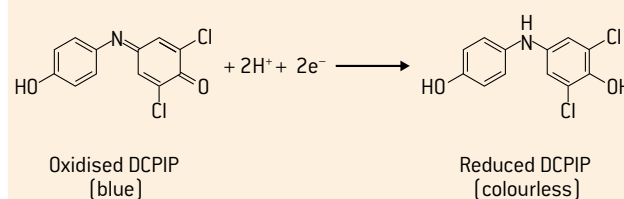
The visible spectrum is made up of a range of different wavelengths of light, i.e. different colours (FIG. 2). The most common photosynthetic pigment, chlorophyll, is actually a mixture of two pigments (chlorophyll a and chlorophyll b) that absorb some wavelengths of light more than others, showing maximum absorption of red and blue light and minimum absorption of green light (FIG. 3).

FIG. 3 Absorption by chlorophyll depending on wavelength of light [2]



The energy absorbed by chlorophyll is used in the light-dependent reactions of photosynthesis to excite its electrons to higher energy levels. The energy gained by these electrons is subsequently used in redox reactions to release energy, which is used to make ATP. This product, alongside another product of the light-dependent reactions (reduced NADP), is used by the plant in the Calvin cycle to make glucose. The plant uses glucose as an energy source and a raw material for the synthesis of a wide range of organic materials required for healthy plant growth.

FIG. 4 DCPIP: 2,6-Dichlorophenolindophenol



The rate of photosynthesis can be investigated using a redox indicator called DCPIP, which is blue when oxidised and colourless when reduced (FIG. 4). When DCPIP is added to chloroplasts freshly extracted from plants, it is reduced by the electrons (and protons) produced during the light-dependent reactions of photosynthesis when the chloroplasts are illuminated. The faster these reactions occur, the faster the rate at which DCPIP is reduced. In one investigation, the students determine the rate at which DCPIP is reduced (decolourised) under different coloured lights in order to determine the effect of the wavelength of light on the rate of photosynthesis. In a second investigation, the students illuminate trays of grass for one week using different coloured lights and then harvest the grass to find its fresh mass as a measure of how much the grass has grown. The stu-

dents then evaluate the results of both experiments in order to recommend which colour of light should be used in lighting rigs to most effectively support the growth and recovery of the grass on a football pitch.

3 | WHAT THE STUDENTS DO

3 | 1 Safety advice

The chemicals used in this investigation are low-hazard, but students need to be aware of the general risks in using electrical equipment (lamps, blender and electronic balance) and must wear safety goggles as part of good laboratory practice.

3 | 2 Preparations

A complete list of all necessary materials can be downloaded on the Science on Stage website.^[3]

1. Sow ryegrass seeds in seven small trays (8 cm × 16 cm × 5 cm depth). Each tray must contain the same mass of potting compost and must be seeded evenly with the same mass of grass seed (sufficient to cover the surface of the compost). Place the seed trays on a sunny windowsill and grow for five weeks. Water regularly as required to keep the compost moist, using distilled water and adding the same volume of water to each tray. It is not possible to control environmental factors such as humidity and temperature, but as all of the trays are kept in the same location, each tray of grass is subject to the same environment fluctuations.
2. After five weeks, harvest the grass using scissors, leaving a sward height of 3 cm. Use the harvested grass for the “rate of photosynthesis” investigation (steps 3–12) and the seven trays of grass for the “rate of growth” investigation (3.4). Both investigations require seven bench lamps, each fitted with a RGB 3W B22 LED Global Bulb Light (these bulbs are available at low cost from common online stores). Each bulb is supplied with a remote control that can be used to set the colour to either red, orange, yellow, green, blue, violet or white (FIG. 5). The same seven lamps and bulbs can be used for both investigations in order to cut costs.



FIG. 5 The lamps were fitted with RGB 3W B22 LED Global Bulb Lights, which are supplied with a remote control to set the light colour to either red, orange, yellow, green, blue, violet or white.

3 | 3 Effect of the wavelength of light on the rate of photosynthesis

3. Add approximately 30 g of fresh grass leaves (harvested in step 2) to 250 cm³ of cold sucrose/pH 7.5 buffer solution. This is prepared by dissolving 2.7 g hydrated disodium hydrogen phosphate, 1.0 g anhydrous potassium dihydrogen phosphate, 33 g sucrose and 0.25 g potassium chloride in 250 cm³ distilled water.
4. Blend for 60 seconds to break open the cells and release the chloroplasts. Filter using a muslin cloth to remove cell debris. Store the filtrate on ice.
5. Dip one end of a capillary tube into the chloroplast extract so that the extract is drawn up into it. Remove the capillary tube and use a tissue to dry off the outside of the capillary tube. This tube is your colour reference tube (it is coloured green).
6. Use a Pasteur pipette to add 1.0% DCPIP solution to the rest of the chloroplast extract, one drop at a time, shaking the bottle gently to mix it. The DCPIP solution is prepared by dissolving 0.1 g DCPIP and 0.4 g potassium chloride in 100 cm³ distilled water. It must be freshly prepared.
7. Add enough DCPIP until the extract changes colour permanently from green to blue-green, then wrap the whole bottle in aluminium foil as quickly as you can to keep the chloroplast + DCPIP extract in the dark.
8. Position a bench lamp with a violet bulb 8 cm above a white tile (do not switch it on yet). Place the coloured reference tube from step 6 on the tile. Now dip three capillary tubes into the chloroplast + DCPIP extract, dry them off as before and place them beneath the violet lamp next to the colour reference tube. Do this as quickly as possible. These are your experimental tubes (FIG. 6).
9. Switch the lamp on and start the stopwatch.
10. Record the time required for the colour of each experimental tube to match the colour of the reference tube (t) in a suitable table (sample data is given in FIG. 7). Because the colour of the tube contents is very difficult to see under dif-

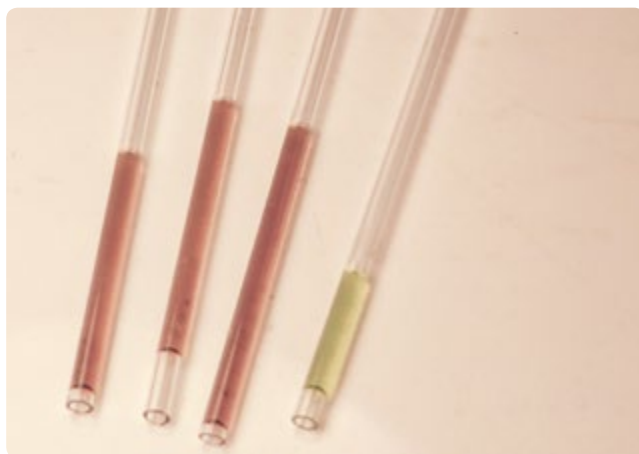


FIG. 6 Comparison of the colour of the experimental tubes (containing chloroplast extract + DCPIP) before illumination compared to a colour reference tube (containing chloroplast extract without DCPIP).

FIG. 7 Sample data on the effect of wavelength on rate of reduction of DCPIP (as a measure of the rate of photosynthesis)

Bulb colour	Wavelength of light [nm]	Time taken for experimental tube to match colour reference tube [s]				Mean rate of DCPIP reduction = $\frac{1,000}{t}$ $\left[\frac{1}{s}\right]$
		Tube 1	Tube 2	Tube 3	Mean	
Violet	420	660	660	640	653	1.53
Blue	450	520	520	520	520	1.92
Green	520	>900	>900	>900	>900	0.00
Yellow	570	680	740	760	727	1.38
Orange	620	520	520	560	533	1.88
Red	680	440	420	400	420	2.38
White	/	500	520	540	520	1.92

ferent coloured lights, the remote is used to switch the coloured bulb to “white” for one second every 20 seconds to check the colour matching.

- Repeat steps 9 and 10 for the other five bulb colours and for a bulb emitting white light (FIG. 8).
- Calculate the mean reduction time and record the mean rate of colour change ($1000/t$). If there is no colour change after 15 minutes, record “no change” and record the rate of colour change as “0”.


FIG. 8 The experimental and colour reference tubes were illuminated with different colours of light, recording the time for colour matching as an indication of the rate of decolourisation of DCPIP and thus the rate of photosynthesis.

3 | 4 Effect of the wavelength of light on growth rate

Place the seven trays from step 2 in a darkened room, illuminating each tray with a bench lamp fitted with a RGB 3W B22 LED Global Bulb Light. For each tray, use the remote control provided to set the colour to either red, orange, yellow, green, blue, violet or white. Leave the trays fully illuminated for six days and water periodically as required (FIG. 9).

After six days, harvest the grass from each tray using scissors [cut the grass down to the base of the stem] and use an electronic balance to find the fresh mass of the grass harvested from each tray. Record the data in a suitable table [see sample data in FIG. 10].


FIG. 9 Trays of grass were illuminated using different coloured lights for six days before harvesting the grass to measure fresh mass as an indication of growth rate.

FIG. 10 Sample data of the effect of the wavelength of light on the fresh mass of grass harvested after six days of illumination (as a measure of the rate of grass growth)

Bulb colour	Wavelength of light [nm]	Fresh mass of grass harvested after 6 days illumination [g]
Violet	420	4.15
Blue	450	6.02
Green	520	3.66
Yellow	570	4.09
Orange	620	5.54
Red	680	6.23
White	/	5.43

4 | CONCLUSION

The students who participated in this project gained a better understanding of the light-dependent and light-independent reactions [Calvin cycle] of photosynthesis, in particular how the products of the light-dependent reactions are used in the Calvin cycle and how this affects plant growth rate. Students benefited from discussing the importance of controlling as many variables as possible during the germination and growth of the grass

seedlings (e.g. depth of compost, watering regimes, distance of coloured lamps from trays of grass) and also during the investigation of the rate of photosynthesis (e.g. distance of the coloured lamps from the chloroplast-containing extract). These discussions gave students a better understanding of the importance of valid experimental design in investigations.

After evaluating the results of both experiments, the students concluded that there was a correlation between the rate of photosynthesis and the rate of grass growth for different coloured lights and that the rate of photosynthesis and growth was highest in red light and lowest in green light. These results were as expected, given the absorption spectrum of chlorophyll (FIG. 3).

The results for blue light were not as high as expected, and this generated an interesting discussion on why this might be. Students suggested that this could be related to the different proportions of chlorophyll a and chlorophyll b in the chloroplasts (since chlorophyll a absorbs less blue light than chlorophyll b). Even so, blue light has more energy than red light and therefore in theory should excite more electrons than red light, leading to a faster rate of photosynthesis and a faster rate of growth. Further research revealed a possible explanation: chloroplasts contain another group of photosynthetic pigments called carotenoids, which include orange pigments (carotenes) and yellow pigments (xanthophylls). These pigments show maximum absorption of blue light and, like chlorophyll b, they transfer the energy they absorb to chlorophyll a to bring about the excitation of electrons in the light-dependent reaction. However, the transfer of energy is inefficient. Although this dissipation of energy may seem wasteful, it may be necessary to protect the plant from the potentially damaging effects of the high energy of blue light.

In making their final recommendations, students suggested that lighting rigs could lead to more efficient grass growth and recovery if they used red light, but football grounds use high-pressure sodium (HPS) lights. The inventor of mobile lighting rigs (Kolbjørn Saether—personal communication) explained that his company had been involved in several research programmes together with the Norwegian Crop Research Institute to find out about the effect of artificial lighting on grass growth. They investigated several parameters, such as light intensity, light amount per day, temperature and nutrition. However, they did not investigate the effect of the wavelength of the light, and they are very interested in the outcomes of our investigation.

Personal experience

During chloroplast extraction, blending releases enzymes that damage the chloroplasts and slow down the rate of photosynthesis (the activity of these enzymes is reduced by using a cold extraction buffer and keeping the chloroplast extract on ice). During the investigation, students became aware of the fact that chloroplast extracts lose activity over time. To overcome

this problem and to make valid comparisons, students set up the rate of photosynthesis experiments as quickly as possible, staggering the experiments and using different bulbs in the shortest time possible so that all of the extracts used were as fresh as possible.

It was impossible to compare the colour of the chloroplast extracts in the experimental tubes with the colour reference tube under different lighting regimes. This was one of the benefits of using bulbs that could be controlled using a remote to periodically switch the bulb to “white” to check for colour matching. Another benefit of these bulbs is that they did not heat up, as any increase in temperature would have affected both the growth rate of the grass and the rate of decolourisation of DCPIP. This also enabled students to leave the lamps on continuously and safely for six days.

The figures recorded in FIG. 7 and FIG. 10 for the wavelength of light of different colours must be considered approximate, since each colour is made up of a range of wavelengths in a continuous spectrum.

5 | COOPERATION OPTIONS

Students from different schools and colleges could compare their results for both investigations, their improvements of the experimental design, and their investigations of the effects of the wavelength of light on the rate of photosynthesis in other plant species.

REFERENCES

- ^[1] https://commons.wikimedia.org/wiki/File:Linear_visible_spectrum.svg (08/03/2016)
- ^[2] Chlorophyll_ab_spectra2.PNG: Aushulz derivative work: M0tty [CC BY-SA 3.0 (<http://creativecommons.org/licenses/by-sa/3.0>) or GFDL (<http://www.gnu.org/copyleft/fdl.html>)], via Wikimedia Commons (08/03/2016)
- ^[3] www.science-on-stage.de/iStage3_materials

BODY

In this booklet we address the science that is relevant to different aspects of football. First, in the Biosphere section, we look at the very large scale. Then we study the main components of the game—the ball and the players—in the Body and the Ball sections. Finally, we look at what happens in the game itself in the Big Data section.

The Body section, by focusing on the active human element of the game, provides projects with which the students can maximally identify, because the students can take on the roles of the players or even actually participate in games. In these projects, the students' own experience will help them not only to understand science better but also to learn about their own biology.

As we move during active participation in a football game, our bodies accelerate and change shape according to the laws of physics. They require water, salts and nutrients according to our biochemistry, and our muscles wear down but also adapt and develop physiologically. Thus by using our own bodies we can learn about how physics, chemistry, biology and physiology determine our lives and influence our physical movements. Great football stars such as Pelé, Maradona, Cristiano Ronaldo, Messi and Romario also obey the same rules of nature. Can science tell us something about the secrets that made them so special?

Well, yes! For one thing, professional football players spend most of their time training. In "Let's Get Physical", the students will come to understand why this is the case, and they will experience for themselves the positive influence of physical practice on their own exercise performance. This could be a life-changing experience!

Proper hydration and nutrition are very important for a healthy lifestyle and also for good sport performance. We often see football players being provided with water bottles, particularly when the match is advanced and the weather is hot. In "Drink and Think", the students will have the chance to discuss this aspect of football. This project may bring them an awareness of the hype and myths surrounding supposed "power drinks" and may also spark discussions among older students about thorny topics such as doping and its effects on athletes' health.



Now what's all the fuss about not using your hands in football? In "Handling the Ball", the students will come to realise that this is actually a very important rule that changes the physics of football at many different levels. If we were allowed to use our hands, football would be a very different game! Every player, including Diego Maradona (a.k.a. the Hand of God), knows this very well!

A final note of caution: as always, take care that your students perform physical activities in safe environments and follow the instructions for the respective units. Whether the students are experimenting with hydration fluids or with elements of the sport, it is your responsibility to ensure that these activities are safe.





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LET'S GET PHYSICAL



-  exercise performance, fitness, enhancement, measurement
-  physical education, physics, biology, mathematics, computer science
-  all age levels
-  football, medicine ball (2 kg), stopwatch, measuring tape, three adjustable hurdles, five poles, chalk, dark wall or gym mat (2 m × 4 m)

1 | SUMMARY

In this unit we present a series of exercise performance tests that apply to different aspects of football. Students should then devise an exercise programme that enhances their exercise performance. A student training diary is provided to enable them to monitor and discuss their progress.

2 | CONCEPTUAL INTRODUCTION

2 | 1 Aims

Physical fitness and exercise are not only essential for football players; they also provide several health benefits.

2 | 2 Background information

The ability to exercise a football skill is dependent on several factors. These factors must combine in the player to produce a high-quality performance. Several lists of such factors exist (e.g. Davis, B. et al. (2000) Training for physical fitness; Tancred, B. (1995) Key Methods of Sports Conditioning). All of them include a certain level of fitness and strength, a certain level of balance and a mental commitment to the task. It is worth considering these lists. Ignoring any one factor can severely inhibit overall performance. If we take commitment to the task as a given, we can divide the ability to perform well into “skill” and “fitness”. In simple terms, skill can be improved through practice and fitness through exercise. The combination of improvement in these two factors will result in a measurable improvement of performance. Each task should be seen as one that, if developed, will improve overall performance in the sport. These broad divisions can be subdivided, for there are a number of different types of skills:

- Cognitive – intellectual skills that require thought processes
- Perceptual – interpretation of presented information
- Motor – movement and muscle control
- Perceptual motor – involving thought, interpretation and movement skills

The skills associated with football that are part of this experiment will mostly be motor skills. The measure of fitness is associated with the numerous muscles of the body and their strength, suppleness and endurance. Different tasks require different muscles to function efficiently, whether this involves the leg muscles, core strength or upper body strength. In the different exercises that are suggested, we can say we are targeting one particular set of muscles but also various components of fitness.

- Test 1 · Slalom: will test the athlete’s coordination as well as strength in the leg muscles.
- Test 2 · Vertical jump test: jumping to head a ball will test the athlete’s coordination as well as strength in the core and leg muscles.
- Test 3 · Overhead medicine ball throw: will test the athlete’s power, coordination, balance and strength in the upper body.
- Test 4 · Hurdles boomerang run: will test the athlete’s movement coordination, balance and leg strength.
- Test 5 · Cooper test: will test the athlete’s fitness level and endurance capacity.

2 | 3 Interdisciplinary possibilities

This project can enable interdisciplinary collaboration in the subjects of biology (e.g. heart rate, breathing rate, muscles), physics (e.g. acceleration, velocity, measurements), physical education (background information about training), mathematics and computer science (e.g. statistics, graphs, correlations).

2 | 4 Precautions

Even though exercise performance tests are non-invasive, please ensure that the safety and health rules for your institute/school are adhered to. All exercise performance tests and follow-up training sessions should be within the capabilities of the students. Warming up before the exercise performance test and the training sessions is essential.

3 | WHAT THE STUDENTS DO

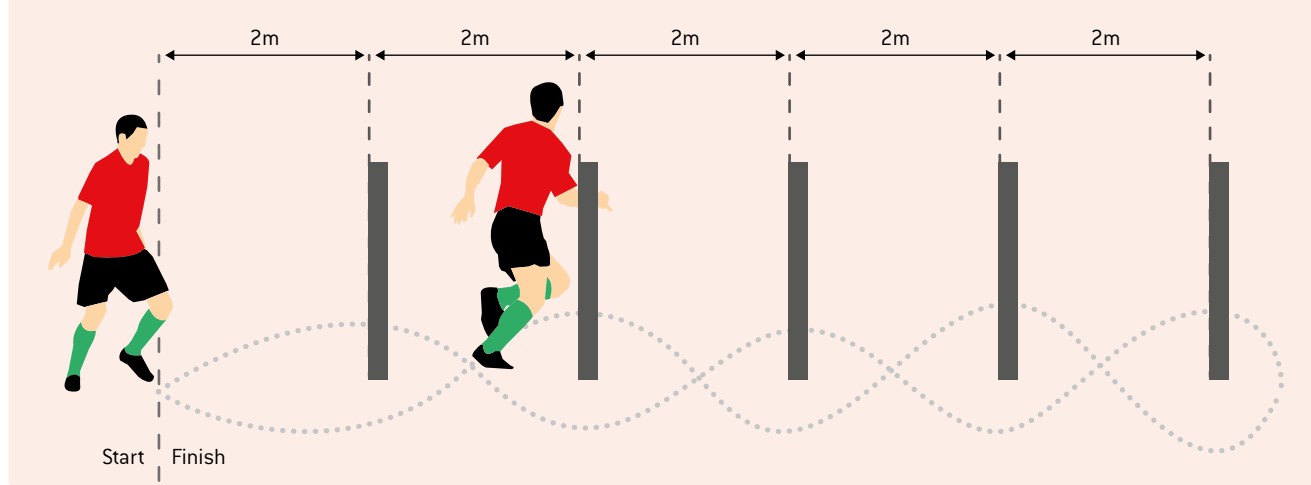
The students need to perform five different exercise performance tests at different times. The follow-up training period should enhance exercise performance, which is tested in a second exercise performance test at the end of the training period. The appropriate training methods have to be selected individually. Constructive suggestions corresponding to the training schedule can be provided by each teacher. The individual training sessions should extend over a minimum of three and a maximum of six weeks. The students should be encouraged to develop their own exercise regimens. Suggestions are given for teachers in the additional material ^[1]. The training programme can include both targeted exercises and physical activities (e.g. cycling, running, etc.). In addition, the training needs to be documented in the training diary.

The number and frequency of the follow-up exercise performance tests can be individually regulated but must be arranged with the respective teacher. The exercise performance tests must be performed as shown below, although this order is not mandatory.

3 | 1 First skill: acceleration and speed—slalom

- **Equipment needed:** five poles, measuring tape, a stopwatch and a football
- **Setup:** Define the start and finish zones. Set five poles in a straight row with two metres between each one. For time-keeping use a stopwatch or ideally a light barrier control.

FIG. 1 Slalom test



- **Test A:** Run in a slalom pattern between the sticks, turn at the last pole and run back to the finish line in the same way (FIG. 1). Measure the time as accurately as possible and record it.
- **Test B:** Repeat test A while dribbling a ball. Focus on keeping the ball close to you and under control. Record the time required.
- Perform three trials each and highlight the best one. If a pole falls over or the slalom is not properly completed, the attempt does not count.

3|2 **Second skill: vertical jumping power and strength—vertical jump test**

- **Equipment needed:** dark wall or gym mat (2 m × 4 m) and, if available, alternative measuring equipment, chalk, measuring tape and a stepladder
- **Setup:** There are several common methods of measuring vertical jumping height. Please check the available measuring equipment (e.g. force plate, video systems, “Vertec” etc.). However, the simplest method is to measure the jump against a dark wall (e.g. with dark paper affixed to the wall) or a thick gym mat (recommended height approx. 4 m). If you are using a mat, lean it against the wall and make sure it does not fall over. Additional equipment includes chalk, a measuring tape and, if required, a stepladder.
- **Test:** Start by standing beside the mat. Use the chalk to mark your finger on the hand closest to the wall. Then reach up as high as possible and mark this height on the mat or the wall. Please note that both feet need to be on the ground! Now mark your finger again, stand slightly away from the wall and jump as high as possible, using both arms and legs to assist. Attempt to touch the mat or the wall at the highest point of the jump. Measure the distance between the standing reach height and the maximum jump height, and that is your result. Perform three trials each and highlight the best one.

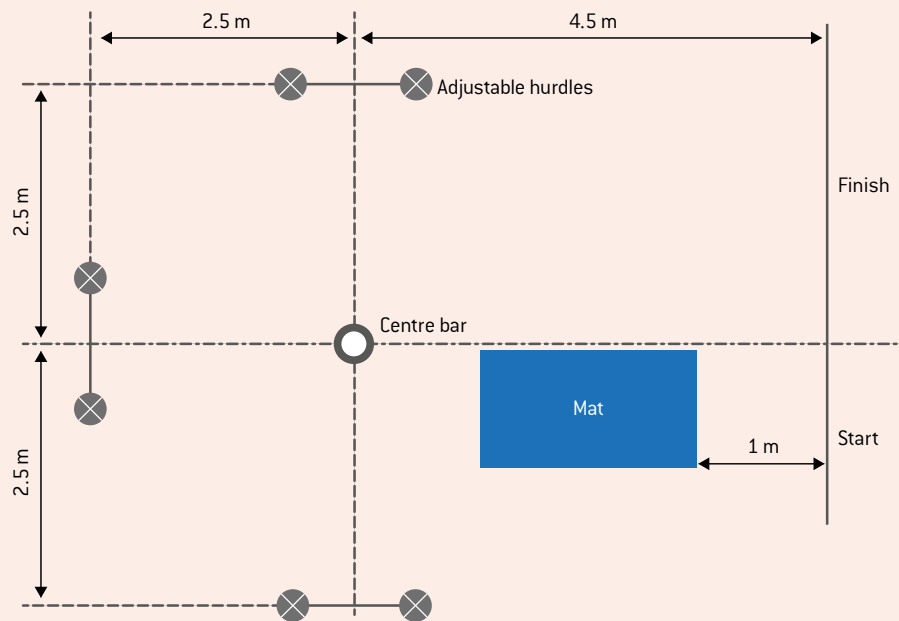
3|3 **Third skill: upper limb core strength and explosive power—overhead medicine ball throw**

- **Equipment needed:** medicine ball (2 kg) and measuring tape
- **Setup:** Choose an appropriate room that permits long and high-distance throws. When performing outdoor tests, be aware of wind conditions that could influence the test results. Define a starting line and place distance marks to simplify the measurement of the throwing distance.
- **Test:** Stand at the starting line and face the direction in which the ball is to be thrown. Your feet must be positioned side by side and slightly apart. Hold the ball in both hands at the sides and slightly behind the centre. Bring the ball back behind your head and bend your knees slightly. Then vigorously throw the ball forward as far as possible while performing an up-and-forward motion. You are permitted to step over the starting line after the ball is released. Taking a run-up to enhance the throw distance is prohibited. Perform three trials; only the best trial will count.

3|4 **Fourth skill: movement coordination agility and acceleration—hurdles boomerang run**

- **Equipment needed:** central pole, a mat, adjustable hurdles (plug hurdles, exercise hurdles), tape measure and a stopwatch or a light barrier control
- **Setup:** Set up the testing area as illustrated in FIG. 2.
- **Test:** Before starting the test, adjust the hurdles according to the individual's body height—compare FIG. 3. In order to avoid frequent adjustments of the hurdles, it is recommended to group the students according to height. Have the individuals run the course anticlockwise as fast as possible. If the central pole or one of the hurdles falls over, the attempt does not count. Stand in an upright position at the starting line. Begin the test with a forward roll on the mat. Make a quarter-turn around the central pole, jump over a hurdle and immediately return and crawl beneath it. Run back to the central pole, make another quarter-turn and take the next hurdle. Thereafter, run back to the central pole, make a quarter-turn and jump across/crawl beneath the third hurdle.

FIG. 2 Hurdles boomerang run



Run back to the central pole, perform a last quarter-turn and cross the finish line.

FIG. 3 Appropriate hurdle height for body heights

Body height [cm]	Height of hurdles [cm]
121 – 125	50
126 – 130	52
131 – 135	54 etc.

3 | 5 Fifth skill: physical fitness and endurance capacity—Cooper test

- **Equipment needed:** flat running track (e.g. 400 m tartan track or similar) and a stopwatch
- **Setup:** No special measurement arrangement is required.
- **Test:** The students should run as far as possible in 12 minutes. Begin the test after sounding a starting signal. After 12 minutes have elapsed, the assistant sounds a signal and the completed distance is recorded.

4 | CONCLUSION

In this unit we have provided a series of suggestions regarding motivational exercises related to the skills used in football. Through these activities, students at all levels of ability may experience an improvement of their measured performance. The suggestions are applicable to both boys and girls. Scientific skills are also developed through the process of making measurements, devising and recording training programmes, and interpreting the results.

The key is the motivation of students. This can be achieved as the teachers monitor the students' progress through the programme, and also as students actually experience their own

achievement of skills. Our experience is that if the programme is applied, even the weakest student will be able to see improvement, and those who are more able will be inspired through their own increased levels of performance.

5 | COOPERATION OPTIONS

Since many schools will participate in this project, Science on Stage provides a list of the schools and contact details. Please check out the iStage homepage ^[1].

Data could be used for displays, to enhance motivation, as real data for statistical analysis and to reward improvement and achievement. Comparisons can be made, e.g., between regular players, genders, ages, etc.




REFERENCES

- ^[1] All additional materials can be found at www.science-on-stage.de/iStage3_materials.

KIRSTEN BIEDERMANN · EMMANUEL THIBAUT

DRINK AND THINK



-  energy drinks, isotonic drinks, caffeine, sugar, effort
 -  chemistry, biology, physics, mathematics
 -  part 3.1: 14–18 years and part 3.2: 8–18 years
- Studies of the components of energy drinks and the dangers they pose to health are appropriate for all ages 8–18 years.

1 | SUMMARY

On the market we can see a number of energy, energetic or energising drinks containing recognisable components that can improve the drinker's performance but also present dangers for his or her health. Here we give suggestions on how to teach about these drinks and about methods for finding out their contents and their effects on brain and muscle activity.

2 | CONCEPTUAL INTRODUCTION

This teaching unit deals with drinks related to football and sports in general. Today, more and more drinks are being launched on the market in order to improve consumers' physical and mental performance.

These are the main questions of this project:

- What are these drinks made of? How can we analyse their contents?
- What are their effects on mental and physical activity? How can we measure these effects?

This project focuses on three different kinds of drinks:

- Energy drinks: increase your heart rate and blood pressure
- Isotonic drinks: provide sugars and minerals to enhance muscle and brain activity
- Vital drinks: just water

3 | WHAT THE STUDENTS DO

3 | 1 Energy drinks

Energy drinks are drinks designed to give their consumers an energy boost, using a mixture of different stimulating ingredients. These ingredients include caffeine, an alkaloid that acts as a stimulant and a psychotropic. They may also include taurine, an amino acid whose effects on the human body are still unknown today.

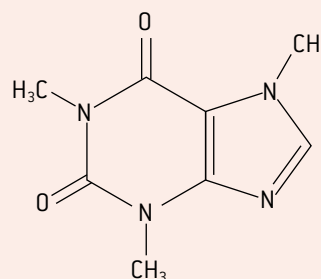
Biology

First, students of any age can discuss energy drinks and investigate their caffeine content by looking at the labels of some commercial products (for this, the students can just take photos at local stores; they do not even need to buy the drinks). They can do research on the caffeine content and then compare their results with the caffeine content of an espresso and discuss the related health issues.

Conclusion

Caffeine, whose effects on the human body are well known today, is the ingredient that has by far the greatest effect, whether good or bad, in drinks of this kind.

FIG. 1 Caffeine



A can of an energy drink (250 mL) contains about 80 mg of caffeine, which is approximately the same as a cup of strong black coffee. This amount is very close to the dose where side effects can be expected (100 to 160 mg) and is also very close to the upper limit of daily permissible consumption (for adults 200 mg/day). The risk for athletes lies not in testing positive in an anti-doping control, but in absorbing a toxic dose.

Chemistry for 14- to 18-year-olds

The analysis of popular commercial products in chemistry laboratory courses is an established method of promoting student engagement, interest and understanding. Many analyses can be done at different levels and using different methods and materials.

3 | 1 | 1 Extraction and identification of caffeine

A qualitative analysis using classical thin-layer chromatography can be carried out to verify that energy drinks contain caffeine. First the students will have to extract the caffeine by using an innocuous solvent such as ethyl acetate after a basic treatment in order to solubilise the acids and eventually the tannin.

Extraction method:

- Take 50 mL of the drink and stir it with a glass rod to degas it if necessary.
- Add a 1 mol/L solution of washing soda (sodium carbonate) while shaking the container, so as to obtain a pH close to 9.
- Extract using 15 mL of solvent and a separating funnel.
- Collect the phase containing the caffeine in a beaker.
- Repeat the extraction with 15 mL of solvent.
- Collect the organic phases and dry them using anhydrous magnesium sulphate.



FIG. 2 Checking the basification with pH paper



FIG. 3 Solvent extraction of the caffeine

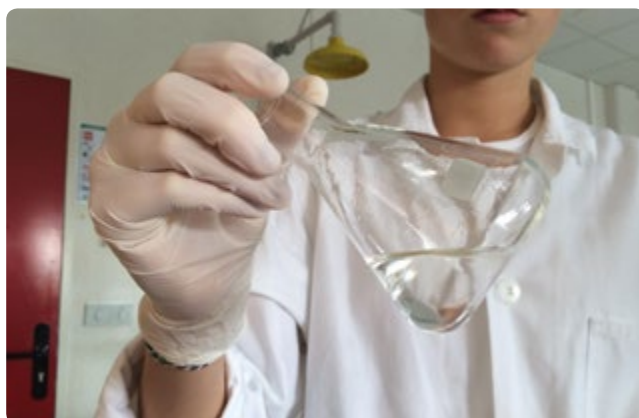


FIG. 4 Drying the organic phase using a desiccant



FIG. 5 Chromatography of the organic phase

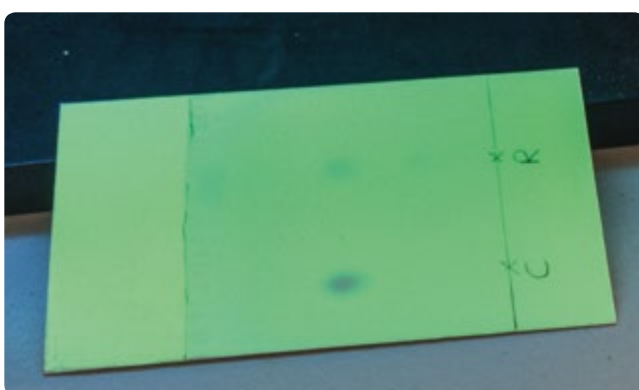


FIG. 6 Visualisation of the chemical species with ultraviolet light

The results of the chromatography must be recorded at the end of this step before the vaporisation of the solvent.

- Eluent (mobile phase) for caffeine: a mixture of formic acid and butyl acetate (30 mL/50 mL)
- Stationary phase: a thin layer of silica
- Visualisation: UV
- Caffeine as a reference dissolved in ethanol or the eluent.

Using chromatography, the students can identify caffeine and another compound that produces a separate spot (indicating that this second compound cannot be neglected in the organic phase after the extraction). After reading the composition of the drinks, students could deduce that this second compound could be a vitamin that has lots of double bonds, particularly B3 or B6.

FIG. 7 B6 (pyridoxine) & B3 (niacin or niacinamide)

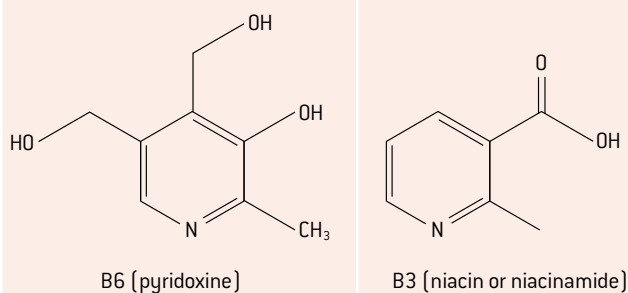


FIG. 8 Evaporation of the solvent using a rotary evaporator (left) · Powder on the side of the flask after the evaporation of the solvent

3 | 1 | 2 Dosage of caffeine

First, an analysis can be carried out using the Beer-Lambert Law.

- The students can determine the spectrum of an aqueous caffeine solution and of energy drinks in order to find the maximum absorption level. They can prepare a solution con-

taining the approximate caffeine concentration claimed by the manufacturer. Because of absorbance saturation, they will have to dilute the solution. They should decide to work at 271 nm, because there is an absorption peak at this wavelength.

- They can then produce a calibration curve with various aqueous solutions of caffeine and they can test it on a chosen energy drink diluted 20 times.
- Using this method they can deduce that the energy drink contains 17 % more caffeine (373 mg/L) than is claimed (320 mg/L) by the manufacturer. Of course the manufacturer did not cheat on the figures, because it has internal and external quality control procedures. However, the second compound that was found by the chromatography (vitamin B6 and/or B3), which also absorbs in the UV region, has an effect on their calibration curve.

FIG. 9 Caffeine absorption spectrum

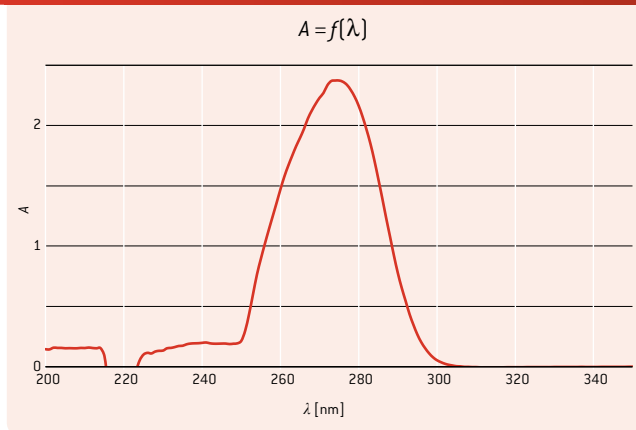
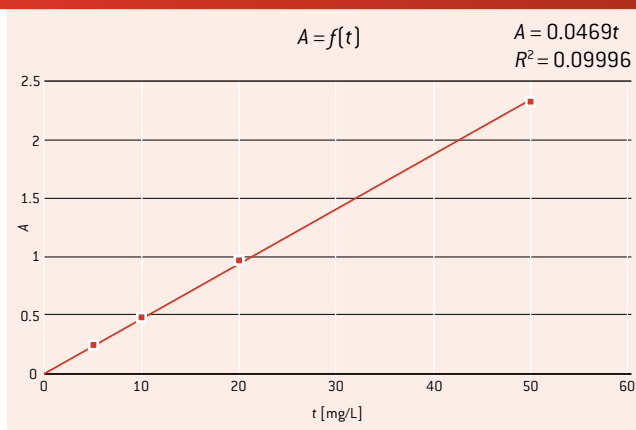


FIG. 10 Calibration curve of absorption linked to caffeine concentration



To get a better calibration curve:

- The students can produce the absorption spectrum of vitamin B6 and/or B3 to determine whether they absorb strongly at the wavelength that was previously chosen. According to the result, they can decide to choose another wavelength. Now that they have the spectra of B6 and B3, they can choose a wavelength at which the absorption is low (for example, between 240 and 250 nm).

FIG. 11 Absorption spectrum of vitamin B6

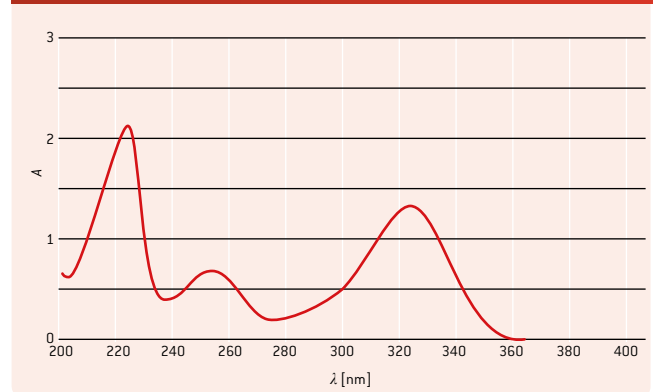
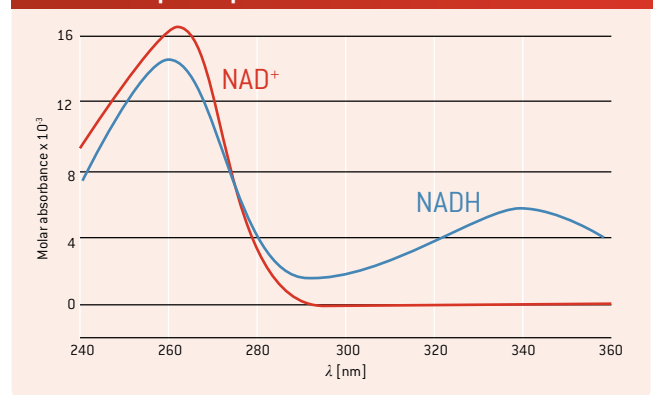


FIG. 12 Absorption spectrum of vitamin B3^[1]



- It would also be very interesting to motivate the students to find another method of analysis such as HPLC in a laboratory; this would enable them to obtain a better result.

3 | 2 How to measure the effect of isotonic drinks and water on brain activity

Our bodies need water, sugar and minerals in order to work well. You can see a very impressive demonstration of that in a video of Gabriela Andersen-Schiess at the Olympic marathon in 1984, who failed to take a drink at the last beverage station. You can find several videos of this on the Internet.

We will develop methods, design a study and think about objectivity, validity and reliability as we measure the effect of isotonic drinks and water on brain effectiveness.

Biology:

Students of all ages should begin by pooling their knowledge. Students of age 13+ might go on to do research on various brain activities (sensors, actors, modal and intermodal activities, etc.) and the influence of water and isotonic drinks. Then they can present their results on posters before they start thinking about how to measure the effect mentioned above.

FIG. 13 Example of table for digit symbol substitution test

1	2	3	4	5	6	7	8	9
<	∩	Δ	X	+	⊥	∧	○	=
2	1	5	4	7	6	9	3	8
∩	<							
6	3	1	2	6	7	3	9	2

They may choose the following methods:

**[A] Number-symbol test (which is part of many IQ tests)—
advised for students age 13+**

This test, which is also known as the digit symbol substitution test (DSST), helps to assess whether the subject has normally functioning intermodal activity.

On a piece of paper there is a list of numbers from, e.g., 1 to 9. Each number is associated with a symbol (e.g., - / & / 0). Under this list is a table with a list of numbers repeated in random order. The subject has to put the associated symbol beneath every number as fast as possible.

A student from the subject group can be given, e.g., 90 seconds to complete the sheet of paper. At halftime, e.g. 45 seconds, he or she makes a pause. You can check later whether the student is getting faster at associating numbers with symbols. This is the kind of brain activity that is called learning.

Five minutes later the student could be asked to write down the correct symbols associated with the numbers, in order to see how much he or she remembers. This is another kind of brain activity known as long-term memory.

[B] Ruler test—recommended for all ages

The test administrator lets a ruler fall down between the thumb and forefinger of the subject, and the subject tries to catch it as fast as possible. The students may discuss what the best starting position for the ruler would be. They can find out quite easily how far the ruler must fall before the subject can catch it.

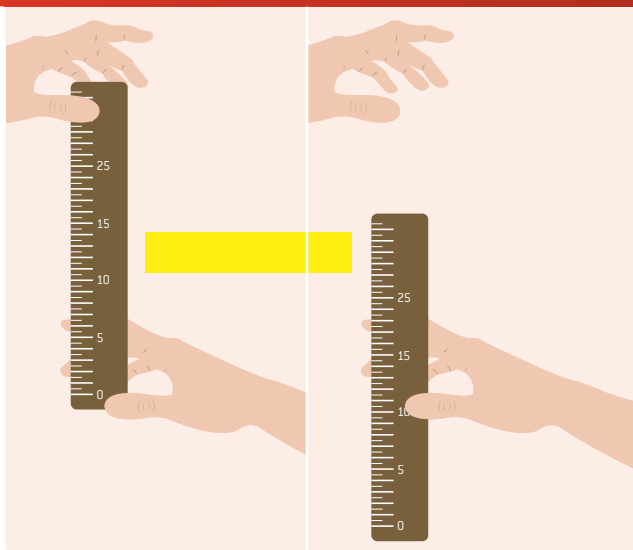
Moreover, they have to find out the best design for their study, including the time needed by a student who has not consumed any drink. This is of course an experimental control design, which means that you are simultaneously comparing two random groups (a control group and an experimental group). This setup makes it possible to compare the brain activity of two groups without any further influences or confounders apart from the factor of drinking. In further tests, the students can measure and compare the effects of different kinds of drinks.

Maths:

[for test A] The students (age 13+) will collect and analyse data and present what they have found out.

[for test B] The students will have to do some (mental) calculation in order to find out how many centimetres the ruler has fallen if they do not set the starting position of the subject's thumb at 0 cm. The youngest pupils might simply compare single results, whereas older ones might make calculations that take into account the uncertainties of measuring and then find the average of several measures.

FIG. 14 Ruler test



Physics:

[for test B] Students age 13+ might calculate the time during which the ruler was falling by using the height h they have measured.

$$E_{kin(1)} + E_{pot(1)} = E_{kin(2)} + E_{pot(2)}$$

$$E_{kin(1)} + 0 = 0 + E_{pot(2)}$$

$$\frac{1}{2} \cdot m \cdot v^2 = m \cdot g \cdot h \quad | : m$$

$$\frac{1}{2} \cdot v^2 = g \cdot h$$

with $v = g \cdot t$ because $v = a \cdot t$ and $a = g$

$$\frac{1}{2} \cdot a^2 \cdot t^2 = g \cdot h \quad | \frac{2}{g^2}$$

$$t^2 = 2 \cdot \frac{h}{g} \quad | \sqrt{\quad}$$

$$t = \sqrt{2 \cdot \frac{h}{g}}$$

a : acceleration [$\frac{m}{s^2}$]

h : height [m]

g : gravitational acceleration, $g = 9.81 \frac{m}{s^2}$

t : time [s]

v : velocity [$\frac{m}{s}$]

Finally, you are welcome to share the results you have found in cooperation with other schools. You find further information on our website. ^[2]

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4 | CONCLUSION

This project is adaptable and can be used to teach students ranging from ages 8 to 18 how to measure brain activity and how to optimise a method in order to minimise the need for evaluation by calculation, counting etc. Students will get to know the experimental control design and are welcome to bring in STEM aspects they have learned in biology, maths or physics.

5 | COOPERATION OPTIONS


We advise you to think about this project as an interscholastic and international project. If you do not have the required technical equipment for the chemistry part at your school, you could contact other schools nearby so that you can cooperatively conduct experiments with them. Your pupils will have to communicate their investigations and protocols to the other pupils; this makes much more sense for them than just writing down their results in their exercise books. This kind of cooperation and sharing generates further motivation and input and adds a bilingual option to teaching/learning STEM subjects.


You can compare drinks that are available in different countries and the attitudes toward consuming them. You can also discuss the design of the studies, gather more ideas and do the exercises at two or more cooperating schools in order to get more data for your analysis of the effects.


ANDREAS MEIER · CORINA TOMA

HANDLING THE BALL



 biomechanics, motion, acceleration, energy, power, reaction time, surface area

 physics, biology, mathematics, sports

 10–18 years

This unit may be used to teach students of different ages, primarily in middle and high school. Some parts of the unit can also be used in elementary school. Every part can be adapted to suit different levels.

1 | SUMMARY

This unit covers some aspects and activities involving the players' use of their hands and arms during a football match. It is divided into three sections:

1. Typical motions of a football player
2. The enlargement of the body's surface area
3. The players' reaction time

Furthermore, this unit aims to encourage the students to develop new methods of observation.

2 | CONCEPTUAL INTRODUCTION

Football is a very athletic and dynamic sport. Its intensity has increased considerably in recent decades. Endurance, speed and quick reactions are typical football skills, which every player has to coordinate during a regular match or even during training sessions these days. A player must use his arms and hands in order to perform better, run faster or jump higher. Because of this fact, there is the possibility that a player will handle the ball during a match, whether or not this handball is deliberate.

As a short introduction, we would like to give you some facts about the relationship between the human hand and football. First of all, let us take a short look at FIFA Law 12 ^[1], which says that "handling the ball involves a deliberate act of a player making contact with the ball with his hand or arm." So, normally, players are not allowed to handle the ball. Exceptions to this are usually termed "natural hand positions".

Ultimately referees have to decide whether contact is "unnatural" or not, and thus whether it is deliberate or not. If you follow football matches in a stadium or on TV, you will know that these on-the-spot decisions can lead to animated discussions. Some handball decisions have changed the course of a game. The best-known case of handling the ball is certainly the "Hand of God" goal by Diego Maradona for Argentina in the quarter-final of the 1986 FIFA World Cup game against England in Mexico – Argentina ultimately became the world champion in 1986 ^[2]. In the qualification match between Ireland and France in 2009, Thierry Henry created a goal for the French team by a handball. This led to a €5 million payment by FIFA to the Football Association of Ireland (FAI) ^{[3], [4]}.

These two examples show that arms and hands can play an important role in a football match. You can use these examples to motivate your students to take a closer look at the use of the hands in football.

2 | 1 Motion

As mentioned above, dynamics play an important role during a football match. In a first step, we would like to focus on the ergonomic aspects of a player's movements. We would like to focus on two typical types of movement that have to be coordinated by the player during a football match: running and jumping.

All of the observations can be recorded very easily with measuring tools such as measuring tape and stopwatch. If the students also use digital cameras or smartphones and video analysis, the results can be used to conduct further investigations into motion, acceleration, force, energy and power.

In order to move faster and jump higher, you have to use your hands. This is because the pendulum movement of the arms reduces the motion of the hips and the amplitude of the shoulder movement and thereby offsets the rotational acceleration of the body that results from the leg movement. Conversely, when an individual runs with his arms close to, or behind, the body, this leads to a lower linear velocity. ^[5] This can be shown by comparing the times that it takes to run the same distance with different arm movements (see **FIG. 1** ^[6]).

FIG. 1 Running in different ways (distance $s = 20$ m)

	regular motion time [s]	straight arms time [s]	arms on the back time [s]
Boy	3.12	4.03	4.03
Girl	4.07	5.03	4.18

The biomechanical concept of "starting power" explains why you can jump higher if you gain additional momentum by swinging your arms. By measuring and comparing the height of jumps of different kinds (arms close to the body, arms behind the back, swinging arms), the students can investigate the effect of swinging one's arms (see **FIG. 2**).

After measuring the various heights, the students can calculate the differences between the heights that were reached. The amount of energy gained can be calculated as follows:

$$\Delta E_{pot} = m \cdot g \cdot \Delta h.$$

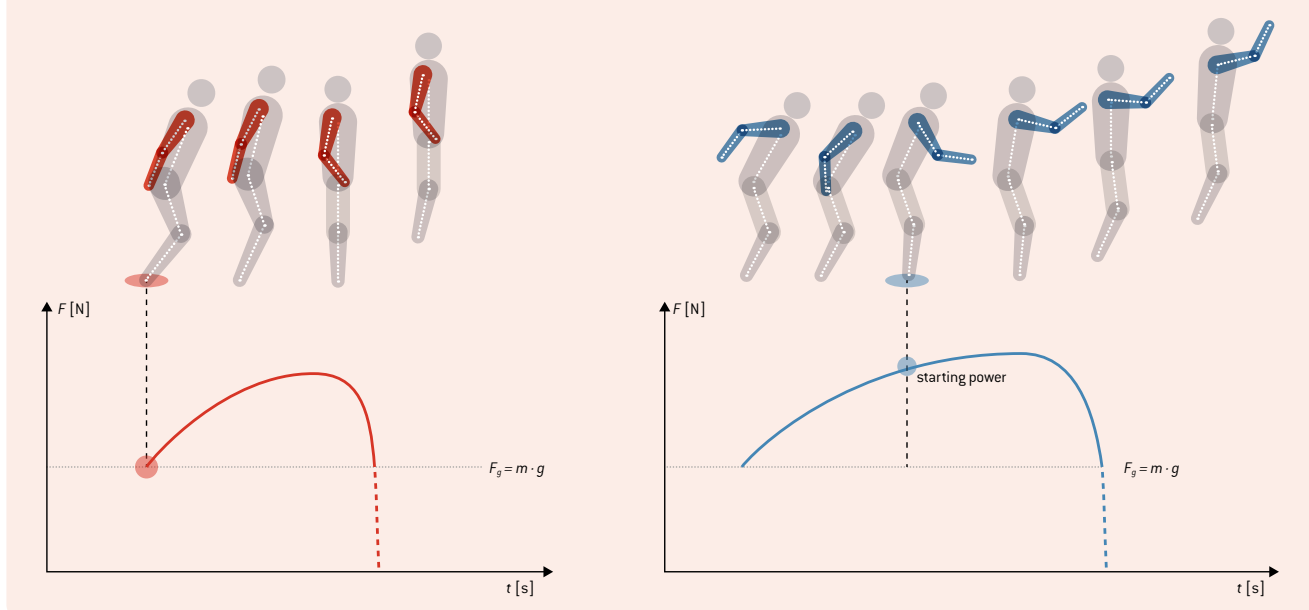
ΔE_{pot} : amount of potential energy gained [J]

m : mass of the jumping student [kg]

g : gravitational acceleration; $g = 9.81 \frac{m}{s^2}$

Δh : difference between the jumped heights [m]

FIG. 2 Forces according to different ways of jumping



By measuring acceleration (e.g. with smartphone sensors), the students can compare the maximum forces and find out the relationship between the motion and the acceleration diagram. By analysing a video, they can calculate the average power of the different ways of jumping as follows:

$$\bar{P} = \frac{W}{\Delta t} = \frac{(m \cdot g \cdot h)}{\Delta t}$$

\bar{P} : average power [W]

W : work by the increase of potential energy [J]

m : mass of the jumping student [kg]

g : gravitational acceleration; $g = 9.81 \frac{m}{s^2}$

h : jumped height [m]

Δt : time taken to stretch the legs [s] (from the lowest point of the motion until the feet leave the ground)

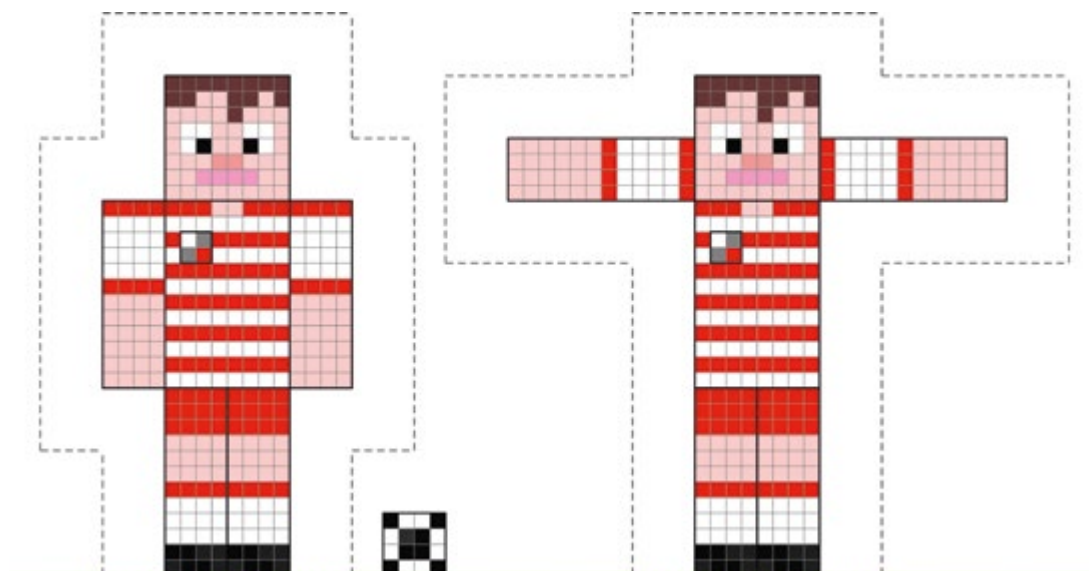
2|2 Surface area of the player's body

Stretching out the arms enlarges the surface area of the player's body that can be hit by the ball. This therefore increases a player's ability to prevent a pass or to give an advantage to his own team. The percentage of enlargement can be estimated by using mathematical methods.

In the first step, the shape of the human body can be easily simulated by creating Minecraft figure skins (which are well known to most of your students).^[7] The students can give their football players individual designs (see FIG. 3).

As the simulated body consists only of rectangles, it is easy to calculate the surface area that can be hit by the ball. The values

FIG. 3 Players' silhouettes – enlargement approximately 17% of the surface area



of the different surface areas can be compared and the difference can be expressed as a percentage.

In a more demanding approach, real photos of the students can be analysed. The students can use GeoGebra ^[8] to try to estimate the surface area of their bodies that can be hit by the ball (see FIG. 4). This method may also be used to motivate your students to use integral calculus to work out methods of numerical integration.

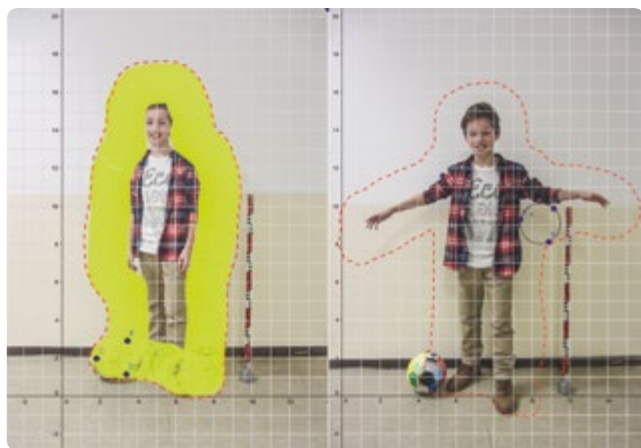


FIG. 4 Estimating the body's surface area with GeoGebra

2 | 3 Reaction time

In order to avoid handling the ball, a player, holding his hands in a natural position, has to react to other players' actions on the ball and to the trajectory of the ball. This reaction will depend on many parameters, such as the player's distance from the ball, the speed of the ball and the reaction time of the player herself or himself. The player's reaction time can be calculated by means of a very easy experiment. The students only have to measure the distance covered by a falling ruler.

This experiment can even be done by young, elementary school students, using a table for the evaluation of their experimental data (see FIG. 9). The experiment can also be done by means of calculation, using the rules governing free-falling objects (linear acceleration), see also the unit "Drink and Think", p. 30.

$$s = \frac{1}{2} g \cdot t^2$$

$$t = \sqrt{\left(\frac{2 \cdot h}{g}\right)}$$

t: reaction time [s]

h: distance covered [m]

g: gravitational acceleration; $g = 9.81 \frac{\text{m}}{\text{s}^2}$

3 | WHAT THE STUDENTS DO

All of the experiments can be done without any special technical equipment. For the use of video analysis or smartphones, please refer to the iStage 2 brochure ^[9].

Fundamental formulas, e.g. for calculating the area of a rectangle or expressing a result as a percentage, will not be explained at this point.

3 | 1 Motion

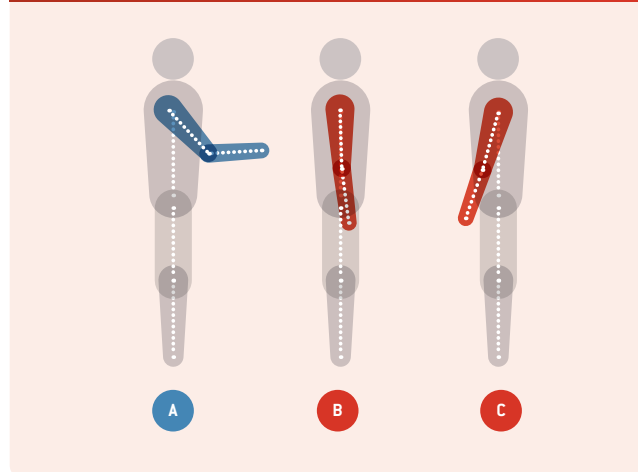
3 | 1 | 1 How to run fast

What you need: measuring tape, stopwatches, marking tools

For a more detailed analysis you need: a digital camera or smartphone, video analysis software (e.g. Tracker^[10])

- Mark out a running track (length: 15 m–20 m) with clearly visible starting and finishing lines. Place the starting point at a short distance (approx. 5 m) in front of the starting line.
- Record the times needed to run the distance with runners adopting the following positions of arms and hands: A) regular motion (normal), B) arms held straight down, C) arms behind the back (see FIG. 5). Runners should take a flying start.

FIG. 5 Different positions of arms and hands



- Repeat your measurement of the various types of running three times each (for one student). To get more data, let two or three students run simultaneously.
- Analyse and compare the measured times (after calculating the average time for each type of run). Are you moving faster when you use your hands as usual (as shown in FIG. 1)?

Additional activities:

- Make videos of the different runs. You can use the time code of your video to measure the time of the run.
- Use a fixed camera to take videos for use with video analysis software. The software automatically calculates the velocity and acceleration of the student in your video.

- Estimate the loss of energy when you run without using your hands (motion B and C). Calculate the average velocity and the kinetic energy for all three kinds of motion as follows:

$$E_{kin} = \frac{1}{2} m \cdot \bar{v}^2.$$

E_{kin} : kinetic energy [J]
 m : mass of the student [kg]
 \bar{v} : average velocity [$\frac{m}{s}$]

- Analyse further kinds of motion for the three hand positions typical for football, e.g. changing direction, start of motion.

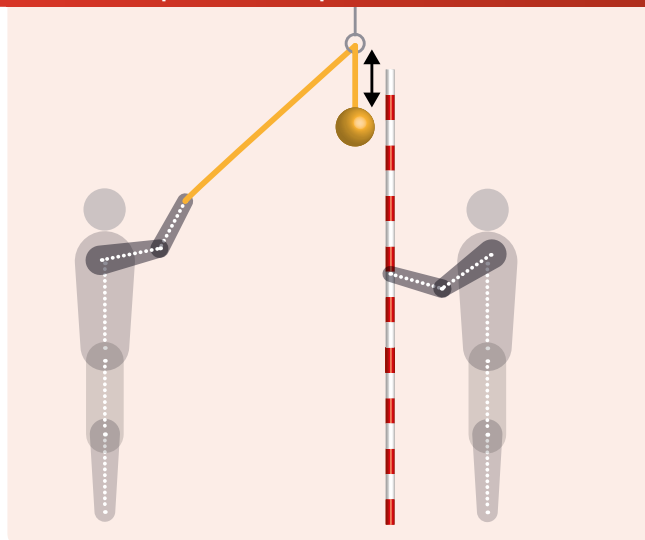
3 | 1 | 2 How to jump high

What you need: string (or rope), a soft ball (or any other object you can hit with your head), measuring stick

For a more detailed analysis you need: a digital camera or smartphone, video analysis software (e.g. Tracker^[10])

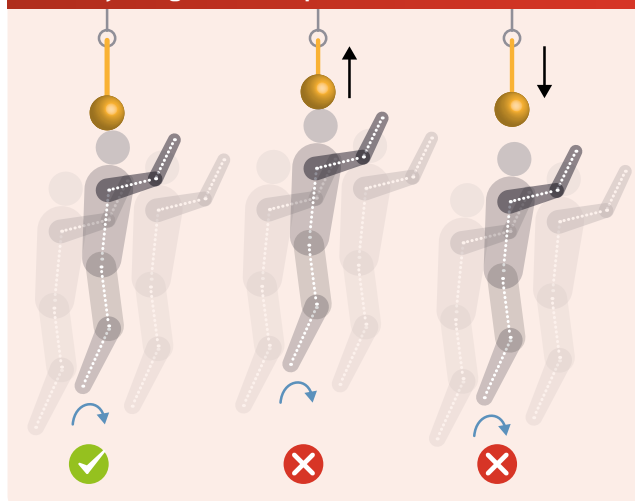
- Build a simple header pendulum (string, soft ball) (see FIG. 6). Be sure that you can vary the height of the pendulum easily.

FIG. 6 Header pendulum setup



- Measure the heights of jumps with arms in the following positions: A) arms held straight down, B) arms behind back, C) arms swinging (as usual). Adjust the height of the soft ball so that the student cannot touch the ball with his head while standing beneath it.
 - Stand directly under the ball.
 - Jump and try to hit the ball with your head.
 - If you can almost reach the ball with your head, measure the distance between the bottom of the ball and the ground. If you hit the ball, hang the pendulum higher and repeat your jump. If you cannot reach the pendulum, lower the pendulum and repeat your jump (see FIG. 7).

FIG. 7 Adjusting the header pendulum



Before you jump, adopt a crouch position. Be sure to start from the same position for every jump.

- Analyse and compare the measured height of your jumps. Can you jump higher if you swing and raise your hands? ^[6]

Additional activities:

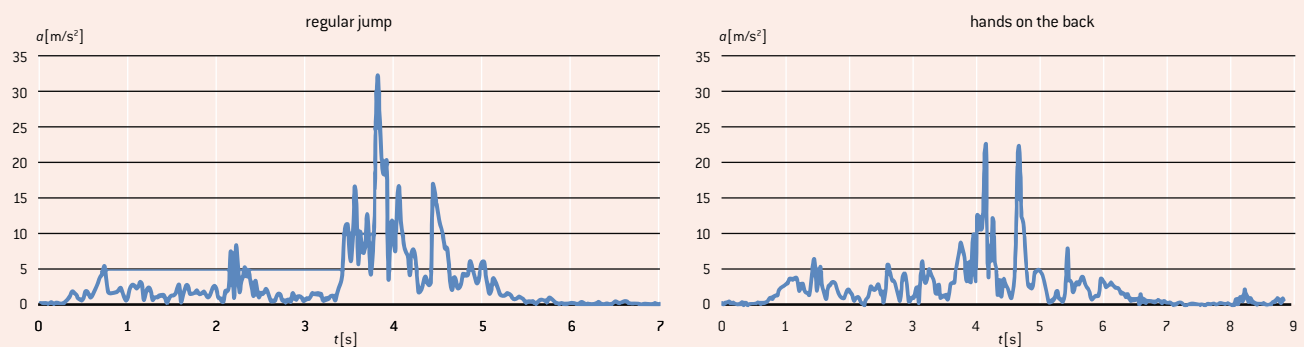
- Measure the height of your body (standing on tiptoes). Calculate the energy your body produces when you jump by using the formula in 2.1 Motion.
- Use a fixed camera to take videos for use with video analysis software. This way you do not need a pendulum. Remember to add a scale to your video so that you can identify the heights in your video. You can also approximate the time span of your jump (lowest point of hips—toes leaving the ground). In this way you can estimate the power your body produces when you jump, by using the formula in 2.1 Motion.
- Use the acceleration sensor of your smartphone. Attach it somewhere close to your shoulder ^[6] in order to record the additional acceleration resulting from the motion of your arms during the jump (see FIG. 8). You can also place your smartphone snugly in a pocket of your trousers to record the total acceleration of your centre of mass. What results do you expect to see?
- Analyse the spectrum of acceleration during your jump. Try to identify various positions during your jump.

3 | 2 Surface area of the player's body

What you need: graph paper, pencil, ruler

For a more detailed analysis you need: a digital camera or a smartphone, GeoGebra^[8]

- Draw the shape of a player's body by means of a Minecraft skin. (You can also use a skin editor, e.g. nova skin^[7].) Draw a second player with his arms held out horizontally. Add a

FIG. 8 Jumping acceleration recorded with the Accelerometer Analyzer^[11] smartphone app


ball to each of your drawings and mark the surface area where the ball could hit each of your players (see FIG. 3).

- Calculate the size of the surface area. Which player has a larger surface area that could be hit by the ball? Compare the two surface areas and express the difference as a percentage.

Additional activities:

- Take pictures of yourself with your hands held close to your body and, alternatively, the natural way you hold your hands. Try to imitate some of the typical movements of football players. Remember to add a scale and a football to your picture.
- Import these pictures into GeoGebra and try to estimate the amount of the body's surface area that could be hit by the ball. Add a circle (ball) and choose *Show Trace* in the context menu. After tracing the body, add an outline using the *Pen* (see FIG. 4). Try out different methods of estimating the surface area. How could your method(s) be optimised?

3 | 3 Reaction time

What you need: ruler (30 cm)

For a more detailed analysis you need: a digital camera or a smartphone

- The class must be divided into pairs. One of the students in each pair holds the ruler, the other one keeps his or her fingers close to the 0 cm mark.
- The first student drops the ruler, the other one tries to catch it as quickly as possible. Read the distance that the ruler has fallen.
- Now you can find out your reaction time by comparing this distance with FIG. 9.

FIG. 9 Reaction time

<i>h</i> [cm]	<i>t</i> [s]	<i>h</i> [cm]	<i>t</i> [s]	<i>h</i> [cm]	<i>t</i> [s]
1	0.045	11	0.150	21	0.207
2	0.064	12	0.156	22	0.212
3	0.078	13	0.163	23	0.217
4	0.090	14	0.169	24	0.221
5	0.101	15	0.175	25	0.226
6	0.111	16	0.181	26	0.230
7	0.119	17	0.186	27	0.235
8	0.128	18	0.192	28	0.239
9	0.135	19	0.197	29	0.243
10	0.143	20	0.202	30	0.247

Additional activities:

- Calculate your reaction time using the formula in 2.3 *Reaction time*.
- Prepare a table for the younger students that will help them find out their reaction time using this experiment.
- Develop an experiment to measure reaction time using digital media.

4 | CONCLUSION

This unit shows that a player's use of his arms and hands (even if she or he does not handle the ball) plays a key role in improving her or his performance in a match. At the same time, it increases the possibility of the player committing a foul.

To the best of our knowledge, this is the first examination of the different aspects of handling the ball in football. As a result, it only offers a few ideas for dealing with this topic.

Other important topics to think about might include the following:

- Protection (e.g. free kick): The players are not allowed to use their hands to protect their bodies (e.g. faces) against shots. The students calculate the force of the ball when it hits a player's body.

- Reaction time and hand movements: What is the fastest way to bring your hands close to your body? The students measure the time and trajectory of outstretched hands as they are moved close to the body.
- Handling from a goalkeeper's view: What is the best way to move/stretch out your hands/arms to prevent a goal?

5 | COOPERATION OPTIONS

You can share your results and ideas by

- uploading your results/files to a website/online platform. The uploaded data can be used by other students. ^[6]
- playing football with your friends and telling them about iStage 3.

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BALL

Let us now focus on the most important thing in football: the ball! The ball is what the game is all about. If you know how to manipulate (or should we say “pedi-pulate”?) this seemingly simple device, your chances of winning increase significantly. Science can tell you a lot about the complex behaviour of this simple spherical solid. Is it really spherical? Is it a solid? We will need to make some approximations, of course, but after we have done that we can predict a lot, just by means of what we have learnt in school.

Our participants have worked out three teaching units, each of which shines a light on different aspects of the physics of the ball.

Before the match we need to pump up the ball. In the teaching unit “Under Pressure” students will learn that air has a mass and that they can measure the weight of air with very simple household devices. Moreover, the amount of air inside the ball changes the pressure, which in turn changes the bouncing properties of the ball. The pressure inside the ball changes the coefficient of restitution, i.e. how high the ball bounces. All of this can be understood by considering air as an ideal gas consisting of roughly twenty per cent oxygen and eighty per cent nitrogen. The gas laws are useful!

In our next teaching unit we are right in the middle of the game. The goalkeeper thinks, “Don’t Touch the Ground!”, because he or she knows that the direction and the velocity of the bouncing ball can change dramatically when the ball hits the ground. Classical mechanics can help us to understand what is going on. By analysing a rotating ball that is bouncing off the ground, students will come to understand how the transformation of rotational kinetic energy into translational kinetic energy can lead to the strange effect in which a ball becomes significantly faster simply by hitting the ground. The ball’s change of direction can also be understood with the help of classical mechanics.

In order to change its direction, this seemingly simple sphere does not even need to hit the ground. The ball’s interaction with the surrounding air is enough to enable a player to shoot a banana kick. The teaching unit “Screwball Physics” is about the aerodynamics of a football. As we know from the work of Daniel Bernoulli, a faster movement of air leads to a reduction of pressure. By means of friction, the rotating ball changes the velocity of air on its one side relative to the other side. The resulting dif-



ference in pressure can change the ball’s path surprisingly; this is known as the Magnus effect. In reality this effect can be quite difficult to understand in detail, and football manufacturers spend a great deal of time and effort shaping the surface of the ball in order to get a good airflow, i.e. to ensure monotonically increasing air resistance with increasing velocity. However, our participants have developed a teaching unit that makes this rather difficult topic accessible to secondary school students by means of experiments and simulations.

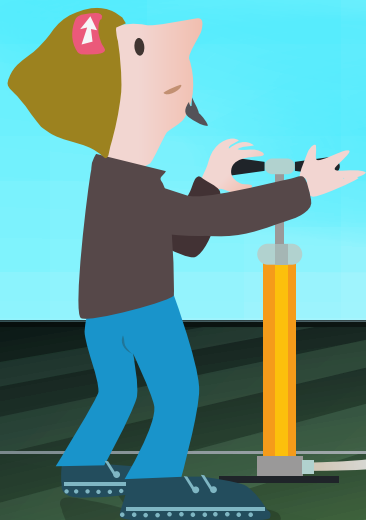
These three teaching units are outstanding examples that show how physics at the school level can explain the behaviour of a football, one of the most relevant real-life objects from the viewpoint of our students. This is really great work from some of the best physics teachers we have in Europe.


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UNDER PRESSURE



 ball, mass, balance, pump, pressure, ideal gas, elastic collision, coefficient of restitution

 physics, mathematics, ICT

 This unit can be used to teach students of different ages from primary, middle and high school. Both parts can be adapted to different levels:

Level 1: For primary school (age: 9–12 years)

Level 2: For secondary school (middle school, age: 12–15 years)

Level 3: For secondary school (high school, age: 15–18 years)

1 | SUMMARY

Did you ever wonder how important the pressure of the air inside the football is? This unit presents different activities focusing on this pressure. The first activity starts with the measurement of the mass of the air inside the ball and emphasises its direct proportionality with the inside pressure. The second activity studies the dependence of the maximum height reached by the ball after the first collision or bounce on the air pressure inside the ball and at the same time shows the importance of the surface condition of the ground.

2 | CONCEPTUAL INTRODUCTION

Our goal is to emphasise that with simple experiments the students can measure the mass of the air inside the ball and then verify the linear dependence between the pressure and the mass according to the ideal gas law. Finally, they will study the importance of pressure in the process of bouncing and will apply the law of the conservation of mechanical energy.

2 | 1 Part 1: Air mass versus pressure

See the details of the activities in part 3 *What the students do*.

Level 1:

Two different and independent activities can be carried out. The first one focuses on the mass of the air and how to measure the mass of the air inside the ball. The teacher could use an inquiry-based approach by asking students “how could you find the mass of air inside a ball?”. The students will propose and conduct experiments, such as using a balance, inflating the ball and checking the mass of the ball when it is inflated. In the second activity, the students will focus on the volume and on the methods of finding the volume of the ball (e.g. with a bucket of water).

Level 2:

Measure the mass of the air inside the ball at different pressures. Find the link between the pressure and the mass of the air (Assumption: the volume of the ball does not change when the pressure increases). The students can draw a graph of the mass of the gas versus the pressure. The students can also measure the volume of the ball. This experiment can also be used to discover the buoyancy of the ball (in air).

Level 3:

The students can do the same experiments as those of level 2. They will compare their graph of the dependence between the mass and the pressure of the air inside the ball with the ideal gas law and they will calculate different gas parameters on the basis of the slope of the graph.

2 | 2 Part 2: Bouncing height vs. pressure

Level 1:

Focus on differences between the heights (qualitatively): Drop two balls from the same height and note the direct effect of different pressures within the ball. Choose a procedure, choose the data you will collect, collect the data, and discuss them after the experiment is finished.

Level 2:

Focus on differences between the heights (qualitatively): Measure the maximum height after the first bounce, then repeat the experiment ten times, looking for a way to detect the height, for example by making a high-speed film with a smartphone. Learn about random and other factors that account for different results, and calculate the average height.

Level 3:

Focus on using a mathematical model of free fall to analyse the data. Starting with level 2, analyse the data in order to find the loss of energy by using the formula $E_{pot} = m \cdot g \cdot h$ and comparing the energy at the beginning of the experiment ($h = 1$ m or another value) and after the ball's first contact with the ground. The students can also calculate the time of a bounce and the maximum speed of the first contact with the ground, and then try to measure it. Finally, they can compare the potential energy and the kinetic energy (E_{pot} and E_{kin}) and calculate the coefficient of restitution (see 3.2.1).

E_{pot} : potential energy [J]

m : mass of the ball [g]

g : gravitational acceleration; $g = 9.81 \frac{\text{m}}{\text{s}^2} = 9.81 \frac{\text{N}}{\text{kg}}$

h : height attained by the ball [m]

Part 2 can be done on different surfaces, such as grass, the gym floor, asphalt, concrete, wet grass, short and higher grass and finally sand. Students on all levels should state their hypotheses, discuss them and analyse the experiments on different levels. Going further, it could be interesting to develop a table that shows the pressure that is necessary in order to get the same height of bounce on different surfaces, for instance in different stadiums.

3 | WHAT THE STUDENTS DO

This unit is divided into two parts: measuring the mass of the gas versus the pressure inside the ball, and measuring the dependence between the height of the bounce and the pressure inside the ball.

There are two different ways of measuring the pressure.

The relative pressure is the difference between the pressure inside the ball and the atmospheric pressure (outside the ball); a manometer is used to measure the relative pressure. We use this pressure in part 1.

The absolute pressure is the total amount of the pressure. We use this pressure in part 2.

3|1 Part 1: Measure the mass of gas vs. the pressure

Equipment needed: a pump, a manometer (pressure measurement system), a balance (with an accuracy of 0.1 g and a range of measurement between 0 and 1,000 g), a nozzle to inflate the ball, a glass to put the ball on the balance, a football.

If the school does not have this equipment, the experiment can be done with cheap devices.

(The easiest way is to have the manometer on the pump. If this is not the case, it is easy to find a cheap manometer for car tires; the nozzle is the same as the one used for a ball.)

3|1|1 Procedure

We describe all the details of our suggested procedure here. Some parts of it may be left out if they do not fit the level of your group of students.



FIG. 1 Ball inside the bucket

▪ Measure the volume of the ball (with and without air inside)

To measure the volume of the ball, you can use a bucket filled with water and measure the different levels of water with and without the ball. Be careful, because the football skin is made of leather and it could absorb water, which would increase the mass of the ball. To avoid this phenomenon, you can put the ball in a plastic bag. The pressure of



FIG. 2 Measure the level to get the volume of water

the water around the ball will “stick” the bag against the ball. The volume will be the same with and without a bag.

If you make the measurement without a plastic bag around the ball, do it after the mass measurement.

The volume can be measured with different levels of the water inside the bucket. If the students cannot calculate the volume of the water in the bucket, they can fill the bucket completely, push the ball inside, and measure the volume of the water that overflows.

In this case the volume of the empty ball is 1.65 L and the volume of the full ball is 5 L. This means that $5 \text{ L} - 1.65 \text{ L} = 3.35 \text{ L}$ of air is inside the ball.

▪ Measure the mass with air inside

Put the glass on the balance, tare the balance, put the ball on the balance, measure the mass.

In this experiment we use a balance with an accuracy of 0.1 g (between 0 and 1,000 g), a football and a pump with a manometer.



FIG. 3 The ball on the balance



FIG. 4 Measure the mass of the empty ball

- **Measure the mass of the ball without any air inside** (for instance $m_{ball} = 408.0 \text{ g}$)
- **Inflate the ball to get the same pressure inside and outside the ball**
The relative pressure, or the difference between the pressure inside and outside the ball, is $P = 0 \text{ bar}$. Measure the mass of the ball $m_{ball} = 408.0 \text{ g}$ (The same mass as before!).

3 | 1 | 2 **Analysis: Why is the mass the same both with and without air inside the ball?**

- **Hint:** The air around us is a fluid and it creates a force that has the same properties as the force created when we put something into water.
- **Answer:** The mass of the air inside the ball is balanced by the buoyancy of the air around the ball.
- Measure the mass of the same ball with a different pressure. The manometer will give the relative pressure.
- Collect the data in a spreadsheet. For instance, you can measure the mass for a relative pressure $P = 0.35 \text{ bar}$; $P = 0.5 \text{ bar}$; $P = 0.6 \text{ bar}$; $P = 0.75 \text{ bar}$; $P = 0.9 \text{ bar}$; $P = 1.05 \text{ bar}$, or choose other pressures.
- Draw the curve m vs P .
- Find the best fit of the curve (it is a linear function).
- Find the link between the slope of the straight line and the ideal gas law: $P \cdot V = n \cdot R \cdot T$

To help the students understand the ideal gas law, the teacher can give a few hints.

- **First hint:** The linear curve has the formula

$$m_{total} = a \cdot P + m_{ball}$$

$$\text{or } m_{total} = m_{gas} + m_{ball}$$

It means that: $m_{gas} = a \cdot P$.

- **Second hint:** $n_{gas} = \frac{m_{gas}}{M_{gas}}$.

- m : mass [g]
- P : relative pressure [Pa]
- a : coefficient of the slope of the curve [$\frac{\text{g}}{\text{bar}}$]
- V : volume [m^3]
- n : amount of substance [mol]
- M : molar mass [$\frac{\text{g}}{\text{mol}}$]
- R : ideal gas constant, $R = 8.31 \frac{\text{J}}{\text{K} \cdot \text{mol}}$
- T : temperature [K]

- **Third hint:** The gas (air) is roughly composed of 20 % of oxygen and 80 % of nitrogen.

$$M_{O_2} = 32 \frac{\text{g}}{\text{mol}} \text{ and } M_{N_2} = 28 \frac{\text{g}}{\text{mol}}$$

3 | 2 **Part 2: Measure the bouncing height vs. the pressure**

3 | 2 | 1 **Theory**

Have you ever wondered how important the inside air pressure is for a ball? We will show that the coefficient of restitution e (elasticity) depends on this pressure.

What is the coefficient of restitution? When a ball is falling, it lands at a certain velocity with respect to the ground, which is called its velocity of approach. After the elastic collision with the ground, the velocity of separation will have a value that is different from the velocity of approach because a part of the initial kinetic energy will be lost:

$$e = \frac{v_{separation}}{v_{approach}}$$

It is very easy to calculate this coefficient if you measure the initial height h_1 from which the ball is falling and then measure the maximum height h_2 that can be reached after the ball bounces off the ground.

We use the law of the conservation of energy:

$$mgh_1 = \frac{mv_{approach}^2}{2} \quad mgh_2 = \frac{mv_{separation}^2}{2}$$

$$\text{So: } e = \sqrt{\frac{h_2}{h_1}}$$

- e : coefficient of restitution
- v : velocity [$\frac{\text{m}}{\text{s}}$]
- m : mass [g]
- g : gravitational acceleration; $g = 9.8 \frac{\text{m}}{\text{s}^2} = 9.8 \frac{\text{N}}{\text{kg}}$
- h : height [m]

3 | 2 | 2 **The experiment**

We drop the ball from a height (h_1) and then we note the height (h_2) of the ball's bounce after it hits the ground. We can measure these heights in the videos.



FIG. 5 Hold the ball at the height h_1 (left); drop the ball (right)

The experiment can be done with different kinds of balls and different kinds of surface [1].

4 | **CONCLUSION**

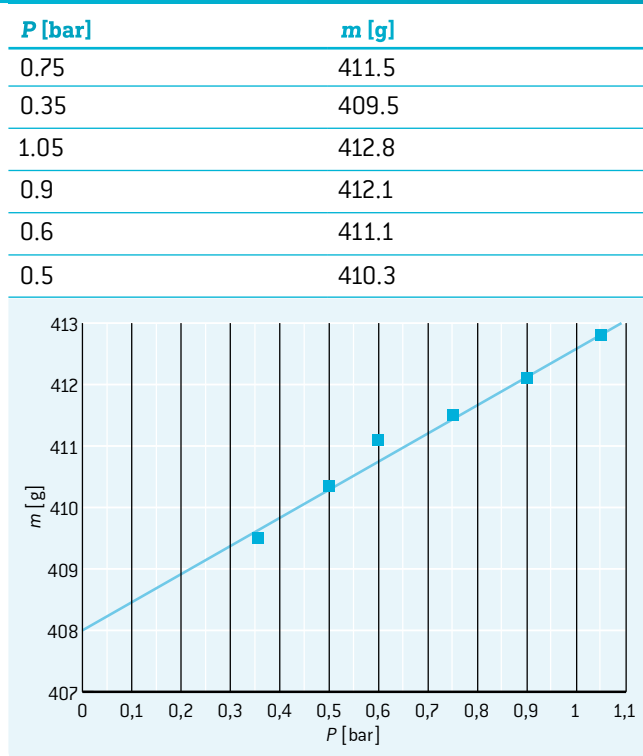
4 | 1 **Part 1: Measure the mass of gas versus the pressure**

4 | 1 | 1 **Example of measuring the mass vs. the pressure of a ball**

The mass of the ball is $m_{ball} = 408.0 \text{ g}$ at $P = 0 \text{ bar}$.

The volume of the air in the ball is $V = 3.35 \text{ L}$.

FIG. 6 $m[\text{g}]$ vs. $P[\text{bar}]$ (relative pressure)



4 | 1 | 2 **Example of calculation with the ideal gas law:**

Here the formula of the curve is $m = 4.5711 \frac{\text{g}}{\text{bar}} \cdot P + 408.0 \text{ g}$.

We see that the value 408 is the mass of the empty ball in grams.

or $m_{total} = a \cdot P + m_{ball}$.

m : total mass [g]

P : pressure [bar]

a : coefficient of the slope of the curve [$\frac{\text{g}}{\text{bar}}$]

In this case $a = 4.5711 \frac{\text{g}}{\text{bar}}$.

The value of a can be found by means of the law of ideal gases:

$P \cdot V = n \cdot R \cdot T$.

P : pressure [Pa], 1 bar = 10^5 Pa

V : volume [m^3]

n : amount of gas [mol]

R : ideal gas constant, $R = 8.31 \frac{\text{J}}{\text{K} \cdot \text{mol}}$

T : temperature [K]

M : molar mass [$\frac{\text{g}}{\text{mol}}$]

This means that $n_{gas} = \frac{P \cdot V}{R \cdot T}$ and $m_{gas} = M_{gas} \cdot \frac{P \cdot V}{R \cdot T}$

or $m_{gas} = \frac{M_{gas} \cdot V}{R \cdot T} \cdot P$

and we have already seen in 3.2.1 that $m_{gas} = a \cdot P$,

so $a = \frac{M_{gas} \cdot V}{R \cdot T}$.

The air is roughly composed of 20% of oxygen and 80% of nitrogen, so here

$M_{gas} = \frac{20 \cdot M_{O_2} + 80 \cdot M_{N_2}}{100}$

$M_{gas} = \frac{20 \cdot 32 \frac{\text{g}}{\text{mol}} + 80 \cdot 28 \frac{\text{g}}{\text{mol}}}{100}$

$M_{gas} = 28.8 \frac{\text{g}}{\text{mol}}$.

With this ball

$V = 3.35 \text{ L} = 3.35 \cdot 10^{-3} \text{ m}^3$

$T = 20^\circ\text{C} = 293 \text{ K}$

$a = \frac{M_{gas} \cdot V}{R \cdot T}$

$a = \frac{28.8 \frac{\text{g}}{\text{mol}} \cdot 3.35 \cdot 10^{-3} \text{ m}^3}{8.31 \frac{\text{J}}{\text{K mol}} \cdot 293 \text{ K}} = 3.96 \cdot 10^{-5} \frac{\text{g}}{\text{Pa}}$.

This is the value when P is measured in Pa. For P in bar, the value has to be multiplied by 10^5 (because 1 bar = 10^5 Pa).

$a = 3.96 \frac{\text{g}}{\text{bar}}$

The best fit of the curve is $a = 4.57 \frac{\text{g}}{\text{bar}}$.

If we compare the two results, the relative deviation between the two results is:

$$d = \frac{4.57 - 3.96}{4.57} = 0.13.$$

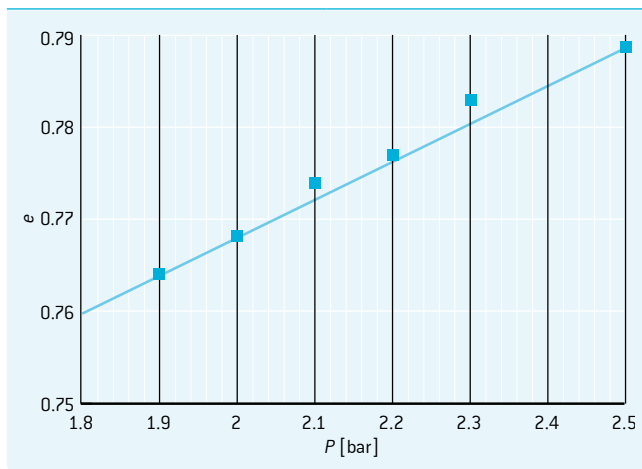
We can discuss the errors linked with the measure: Here the accuracy of the manometer is 0.05 bar on a measure of about 1 bar. There can still be air inside the ball when we measure the volume of the empty ball.

4 | 2 **Part 2: Measure the bounce vs. the pressure**

In our experiment we changed the inside air pressure in two different balls and we obtained the following results:

FIG. 7 Coefficient of restitution e vs. absolute pressure P (Ball 1)

P [bar]	e
1.9	0.764
2.0	0.768
2.1	0.774
2.2	0.777
2.3	0.783
2.5	0.789



Here P is the absolute pressure in bar.

For the first ball the dependence is linear because the pressure variation is not so large.

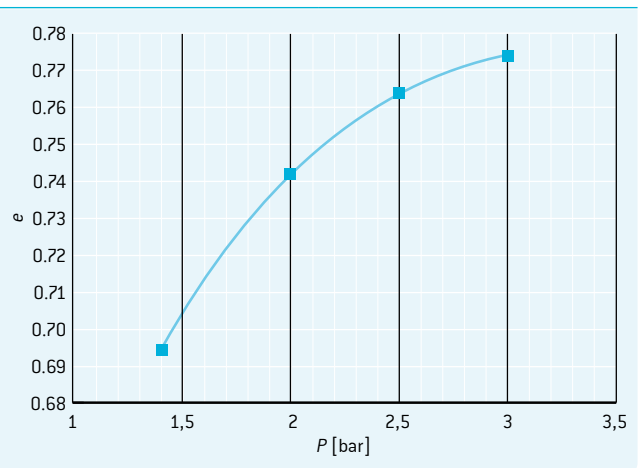
For the second ball we obtained a curve. When the pressure is too large the ball loses its elasticity and the coefficient of restitution seems to reach a limit.

In these two experiments the ball was dropped down on a floor, and you can see that the coefficient of restitution is about 0.77 for a pressure of 3 bar.

Then we changed the surface, but the inside air pressure remained 3 bar. On grass the coefficient of restitution was smaller: $e = 0.57$. On synthetic grass the coefficient became 0.74 [1].

FIG. 8 Coefficient of restitution e vs. absolute pressure P (Ball 2)

P [bar]	e
1.4	0.695
2.0	0.742
2.5	0.764
3.0	0.774



5 | **CONCLUSION**

Footballs are very good tools for studying the laws of gases, the property of pressure and the efficiency of the bounces. The students can study the laws of physics by means of a ball, which is a piece of sports equipment. They can see the links between the laws of physics, in this case the law of ideal gases, and daily life.

It is also interesting to see that the activities of this unit can be taught to students at different age levels, ranging from 6 to 18 years. It is easy to fit these activities into any kind of curriculum.

6 | **COOPERATION OPTIONS**

We can share our results for different experiments with footballs.

To share your results, download the file and follow the instructions [1].

We are sure that the students can share their ideas about the differences between their measurements or their experimental devices. They can imagine other experiments with the ball: for example, filming the deformation of the ball during its collision with the ground and the influence of pressure on this process.

REFERENCES

[1] www.science-on-stage.de/iStage3_materials



DIONYSIS KONSTANTINOU · ANDREAS MEIER · ZBIGNIEW TRZMIEL

DON'T TOUCH THE GROUND



🔧 motion, rotation, rolling motion, translational kinetic energy, rotational kinetic energy, friction

📺 physics, ICT

👥 Two sets of activities are provided. The first is suitable for students 14–15 years old, and both sets are suitable for 16–18 years old.

1 | SUMMARY

Students study the bounce of a ball in terms of motion, kinetic energy and momentum. They also discover that the kinetic energy of a real body consists of both translational and rotational kinetic energy.

2 | CONCEPTUAL INTRODUCTION

2 | 1 Abstract

Goalkeepers say that their job becomes more difficult if the ball bounces on the ground in front of them. In this teaching unit we show students how to investigate the factors that cause changes in the energy and motion of a ball when it bounces. In this context, students will encounter the laws of physics related to the translational and rotational motion of a solid body, especially with respect to a rolling motion. Two experiments are at the core of the unit. Students record the motion of a ball and analyse this with a video-analysis tool. Experiments have been chosen in a way that gives students the opportunity to study the respective phenomenon. As such, they will reach conclusions and will be able to explain the bounce of a ball in terms of force, motion, momentum and energy.

2 | 2 Required knowledge

Students should be familiar with the physics of motion, the role of force in motion, and potential and kinetic energy with respect to point masses. They also should be able to work with vector magnitudes such as velocity and linear momentum.

2 | 3 Theoretical background

2 | 3 | 1 Kinetics

Rolling motion is a combination of translational and rotational motion. In this type of motion:

1. The centre of mass (cm) moves with a translational motion. Its velocity with respect to the ground is \vec{v}_{cm} .
2. The rest of the body rotates around the centre of mass and demonstrates two types of motion, i.e. translational motion with \vec{v}_{cm} and rotational motion.

Let us consider point i of the body. In the second type of motion its absolute velocity, with respect to its cm , is $v_{rel,cm}^i = r_i \omega$.

Angular velocity is located on the axis of rotation. The velocity of point i with respect to cm is tangential to the path of point i . The two velocities are connected by the right-hand-rule.

r_i : distance of the specific point i from the axis of rotation [m]

ω : angular velocity of the body [$\frac{1}{s}$]

v : velocity [$\frac{m}{s}$]

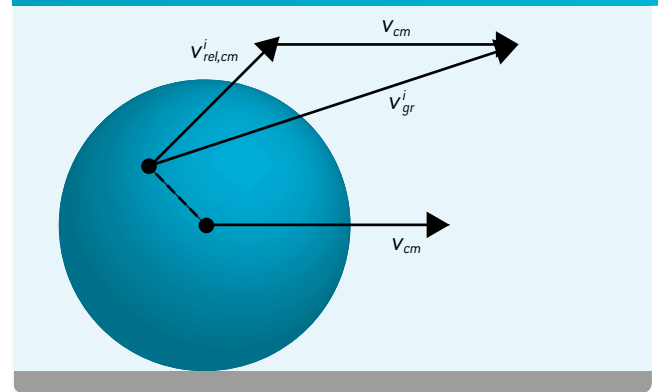
With respect to the points of the circumference, their $\vec{v}_{rel,cm}$ becomes $R\omega$.

R : radius of the body [m]

Therefore, the velocity of point i of the body with respect to the ground is the vector sum of the two velocities (**FIG. 1**).

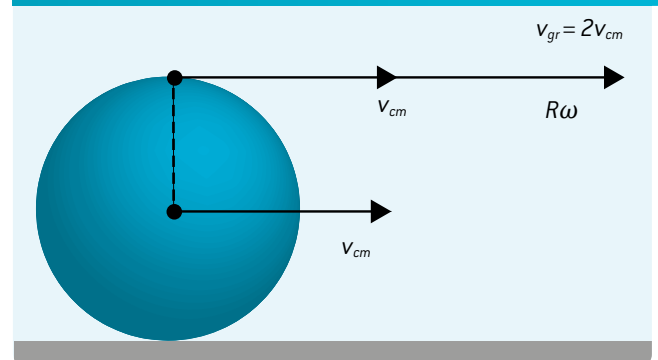
$$\vec{v}_{gr}^i = \vec{v}_{cm} + \vec{v}_{rel,cm}^i$$

FIG. 1



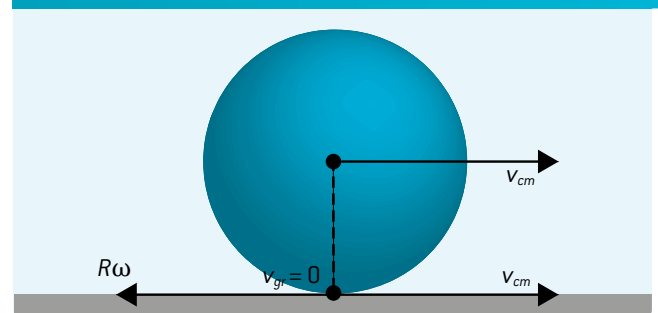
The \vec{v}_{gr} of the uppermost point of the body is equal to $2\vec{v}_{cm}$.

FIG. 2



The velocity \vec{v}_{gr} of the point in contact with the ground is zero, i.e. it is momentarily at rest (**FIG. 3**).

FIG. 3



Finally, the condition $v_{cm} = R\omega$ means that the body is rolling without slipping.

2|3|2 Kinetic energy

A moving spherical body has, in general, translational and rotational kinetic energy: $E_{kin,tr}$ and $E_{kin,rot}$ respectively.

$$E_{kin,tr} = \frac{1}{2}mv^2 \text{ and } E_{kin,rot} = \frac{1}{2}I\omega^2$$

m : mass [kg]

I : moment of inertia [$\text{kg} \cdot \text{m}^2$]

v : absolute velocity [$\frac{\text{m}}{\text{s}}$]

ω : angular velocity of the spherical body [$\frac{1}{\text{s}}$]

Let us consider such a body as it hits the ground, and let us focus on the short space of time, just before and just after impact, in which we can investigate the force acting between the body and the ground.

Before impact:

$$E_{kin,tr(1)} = \frac{1}{2}mv_1^2 \text{ and } E_{kin,rot(1)} = \frac{1}{2}I\omega_1^2.$$

After impact these two quantities still exist but with different values:

$$E_{kin,tr(2)} = \frac{1}{2}mv_2^2 \text{ and } E_{kin,rot(2)} = \frac{1}{2}I\omega_2^2.$$

The indices 1 and 2 correspond to the values before and after impact on the ground.

The force acting between the ground and the body consists of vertical and horizontal components. If we assume that the ball does not slip on the ground, the horizontal component is static friction. Its work on the ball is zero, while its torque causes angular acceleration. This means that the angular velocity changes in magnitude and sometimes in direction. Nevertheless, no energy is converted to heat, and we only get an exchange between translational and rotational energy. The vertical component and the weight of the ball produce vertical acceleration with respect to the ball. Given that the ball does not slide on the ground, we can apply the principle of conservation of mechanical energy:

$$E_{pot(1)} + E_{kin,tr(1)} + E_{kin,rot(1)} = E_{pot(2)} + E_{kin,tr(2)} + E_{kin,rot(2)}.$$

E_{pot} is potential energy, while the indices 1 and 2 refer to the states just before and just after the ball bounces.

Since we focus on the event of the ball bouncing on the ground, $E_{pot(1)} = E_{pot(2)}$

$$\text{and } E_{kin,tr(1)} + E_{kin,rot(1)} = E_{kin,tr(2)} + E_{kin,rot(2)}.$$

As a result of several factors, including the surface of the ground and the angular velocity of the ball just before impact, it is difficult to estimate the effect of friction. Therefore, it is not easy to

predict the data relating to the motion of the ball just after bouncing, especially the vector of its velocity.

2|4 Experiments and procedures

1. In order to awaken their interest, students are asked to drop a ball while simultaneously imparting initial rotation^[1]. Hopefully, students will associate the “kick” of the ball with the spin that has been imparted.
2. First experiment (first set of activities)
Students assemble a ramp consisting of two parallel bars. The distance between these two bars should be somewhat less than the diameter of the ball.



FIG. 4 The set-up for the first experiment.

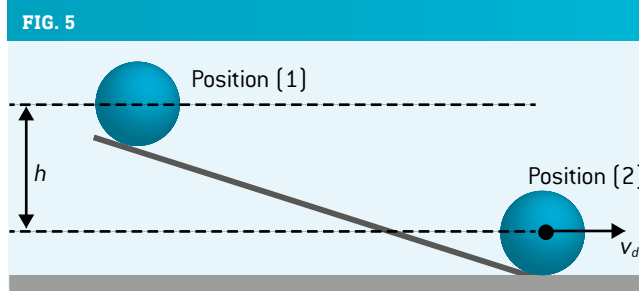
Students are asked to release a small ball from the top of the ramp, record its motion and analyse this with a video-analysis tool, for example Tracker^[2]. An extended presentation of this software can be found in the publication *iStage 1 – Teaching Materials for ICT in Natural Sciences*^[3]. It would be even better to use a “fast” camera (120 frames per second or more).

The solid ball (m, R) $I = \frac{2}{5}mR^2$ rolls without slipping from position (1) to the ground, i.e. position (2), and continues rolling along the ground (FIG. 5).

Remark: The moment of inertia for a ball used in football games is closer to $\frac{2}{3}mR^2$.

In the experiments a solid ball is used.

As the ball rolls down the ramp, its velocity v and angular velocity ω are changing according to $v = R\omega$.



The principle of energy conservation is as follows:

$$mgh = \frac{1}{2}mv_d^2 + \frac{1}{2}I\omega^2 = \dots = \frac{7}{10}mv_d^2.$$

\vec{v}_d is the velocity of the ball at the base of the ramp. The translational kinetic energy is equal to $\frac{5}{10}mv_d^2$, and therefore the rotational kinetic energy is equal to $\frac{2}{10}mv_d^2$.

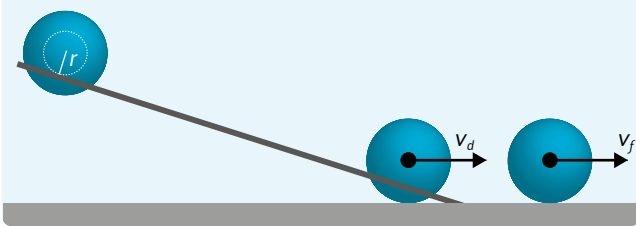
$$\text{Therefore } \frac{E_{kin,rot}}{E_{kin,tr}} = \frac{2}{5}.$$

In the proposed experiment, the motion of the ball on the ramp is according to $v = r\omega$, where r is the distance between the axis of rotation and the points at which the ball touches the ramp.

The experiment is set up (FIG. 6) such that $r < R$. Consequently the ratio $\frac{E_{kin,rot}}{E_{kin,tr}}$

is greater than $\frac{2}{5}$. Once the ball is on the ground, this will become equal to $\frac{2}{5}$, so that the rolling motion will assume a new configuration, whereby the distance between the axis of rotation and the point at which the ball touches the ground is equal to R .

FIG. 6



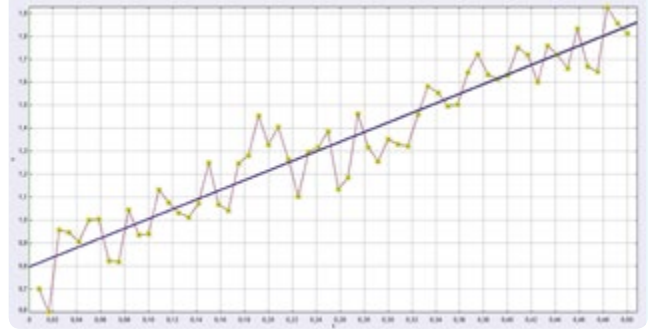
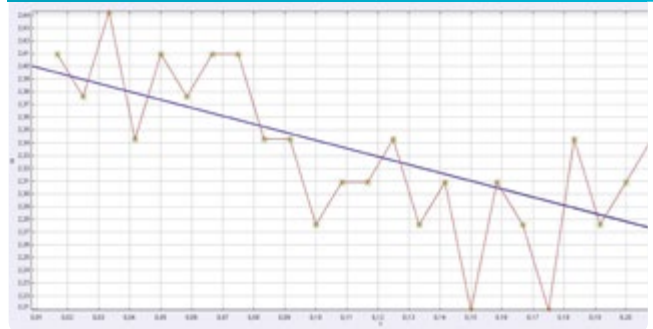
This is exactly what happens and, after a very rapid transition, the velocity of the ball assumes its final value, whereby the velocity \vec{v}_f is greater than the velocity \vec{v}_d , with which the ball meets the ground.

Students can see, even with the naked eye, that the ball travels faster on the ground. They can then analyse the motion and define the velocities \vec{v}_d and \vec{v}_f .

To do so, they must consider the rotational kinetic energy. Otherwise, there is no explanation in terms of energy conservation. Anyone who is aware of the fact that a solid body can have translational and rotational kinetic energy will understand that some of the rotational kinetic energy has been transformed into translational kinetic energy as a result of the friction between the ground and the ball.

2 | 5 Materials required

Two bars of 1 metre in length and the relevant stands and connectors; one small ball, preferably solid and made of hard rubber. A typical school laboratory is undoubtedly equipped with these materials.

FIG. 7 First part of the motion, $v_d = 1.85$ m/sFIG. 8 Second part of the motion, $v_f = 2.4$ m/s

3 | WHAT THE STUDENTS DO

3 | 1 First experiment: first set of activities

1. Set up the experiment.
2. Record a video [1].
3. Proceed with a video analysis tool, for example Tracker [2].
4. Define the velocities just before and just after impact with the horizontal plane [see FIGS. 6 and 7].
5. Measure the radius of the ball and define its angular velocity when it starts rolling along the ground (FIG. 9).
6. Measure the mass of the ball and define the translational kinetic energy just before ($E_{kin,tr(1)}$) and just after ($E_{kin,tr(2)}$) impact with the horizontal plane (FIG. 9).
7. Explain the change in kinetic energy.

FIG. 9 $\omega = 156 \text{ s}^{-1}$, $E_{kin,tr(1)} = 2.46 \cdot 10^{-2} \text{ J}$, $E_{kin,tr(2)} = 4.14 \cdot 10^{-2} \text{ J}$



FIG. 10 The set-up for the second experiment

3 | 2 Second experiment

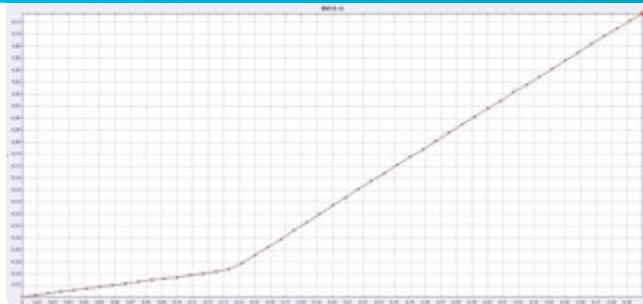
Students should set up an experiment similar to the first one. This time, however, the end of the ramp should be positioned about 0.6 metres above the horizontal plane.

Students should let the ball roll and fall on the surface below. They should record the motion and analyse it with a video-analysis tool, e.g. Tracker [2]. In this case the interesting aspect of the motion begins once the ball has left the ramp, when it assumes a remarkable spin. In this experiment, students will penetrate deeper into the fields of motion and energy.

Second set of activities

1. Set up the experiment
2. Let a ball roll downwards from the top of the ramp and record the motion with a camera [1].
3. Plot a graph of x vs. t and define the horizontal component of the velocity of the ball v_x as it falls and as it rises. Explain the change in v_x .

FIG. 11 Example of graph showing change of velocity



4. Measure the mass of the ball and calculate how much of the ball's $E_{kin,rot}$ is transformed into $E_{kin,tr}$. You should also define the velocity of the ball just before and just after it bounces.

$$v_{fall,fin} = 2.55 \frac{m}{s} \quad E_{kin,tr(1)} = 4.67 \cdot 10^{-2} J \text{ (FIG. 12) and}$$

$$v_{rise,init} = 2.76 \frac{m}{s} \quad E_{kin,tr(2)} = 5.47 \cdot 10^{-2} J \text{ (FIG. 13)}$$

$$\Delta E_{kin,tr} = 0.8 \cdot 10^{-2} J = -\Delta E_{kin,rot}$$

FIG. 12

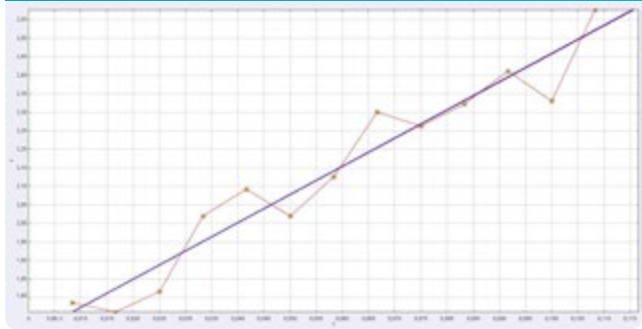
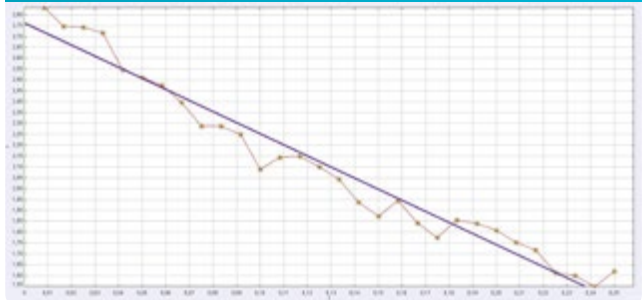


FIG. 13



5. Define the change $\Delta \vec{p}$ [$kg \cdot \frac{m}{s}$] in momentum of the ball during its contact with the ground.

$$\Delta \vec{p} = m \Delta \vec{v}$$

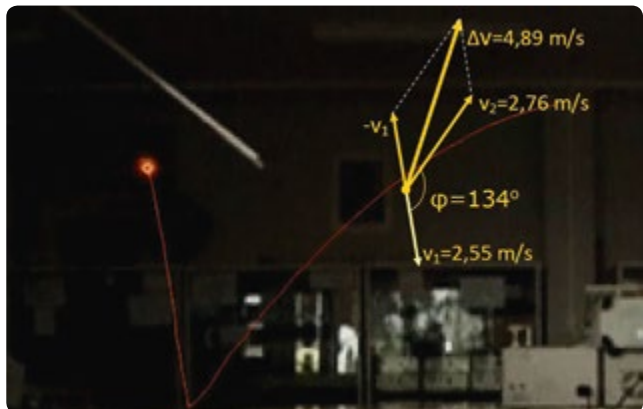


FIG. 14

\vec{v}_1 and \vec{v}_2 are the velocities just before and just after the bounce. Their absolute values in the specific experiment are $2.55 \frac{m}{s}$ and $2.76 \frac{m}{s}$ respectively with an angle of $\varphi = 134^\circ$ between them.

$\Delta \vec{v}$ is the change in velocity. Its absolute value is calculated to be $4.89 \frac{m}{s}$. The angle between \vec{v}_2 and $\Delta \vec{v}$ is calculated to be an angle of 24° .

The change in momentum results from the formula $\Delta \vec{p} = m \Delta \vec{v}$.

Its direction is the same as the direction of $\Delta \vec{v}$ and its absolute value is $7 \cdot 10^{-2} kg \cdot \frac{m}{s}$.

6. Consider the second part of the motion as if the ball were thrown from ground level. Define the initial magnitudes that characterise this throw and calculate the maximum height and the range of the throw. Compare the values you have determined with the respective values from Tracker. Explain any differences between the data analysis and the theoretical values.

4 | CONCLUSION

Students should observe the changes in motion and energy of a ball and relate these changes to the force, especially its horizontal component, acting between the ball and the ground, and to the torque of this force. At the same time they should conclude that the kinetic energy of a solid body consists of two quantities (translational and rotational kinetic energy). Finally, they might also overcome some preconceptions that perhaps derive from the fact that we usually work with the point-mass model while teaching mechanics.

5 | COOPERATION OPTIONS

Students of different schools, not necessarily from the same country, can communicate and exchange videos, primarily with respect to the first activity. It is assumed that they will reach the same conclusions, which they can then discuss via a teleconference.

Finally, they can meet up and conduct a set of activities, such as:

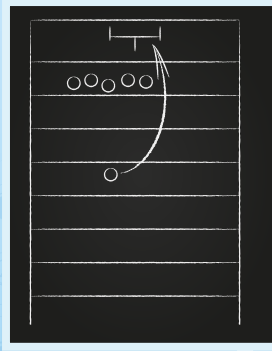
1. Go outside and set up a video camera. Record a video of a ball falling on the ground and look at the data for the motion of the ball during its impact with the ground.
2. Analyse this motion.
3. Draw conclusions about the characteristics of the friction during the impact of the ball with the ground.
4. Define the velocity of the ball before and after it hits the ground, measure the mass of the ball and calculate the translational kinetic energy.
5. Ask a skilled player from the class to kick a ball with varying techniques, record videos and describe the results when the ball hits the ground.
6. Produce a definitive answer to the crucial question as to why goalkeepers have greater difficulty when the ball bounces on the ground in front of them.
7. Once other activities have been completed, play a football game devoted to science. Naturally, such a game will produce a win-win situation for both sides, no matter the ultimate score!

RESOURCES

^[1] www.science-on-stage.de/iStage3_materials

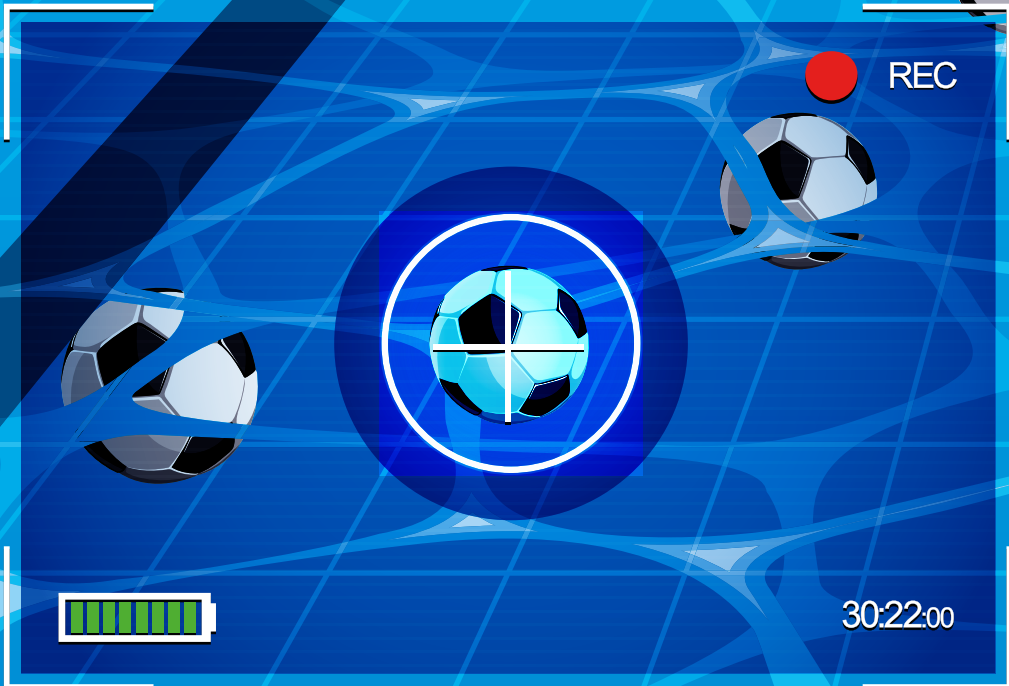
^[2] www.physlets.org/tracker

^[3] www.science-on-stage.de/iStage1-download





ANDERS FLORÉN · PHILIPPE JEANJACQUOT · DIONYSIS KONSTANTINOU · ANDREAS MEIER · CORINA TOMA · ZBIGNIEW TRZMIEL

SCREWBALL PHYSICS



 Magnus effect, fluid dynamics

 physics, mathematics

 16–19 years

1 | SUMMARY

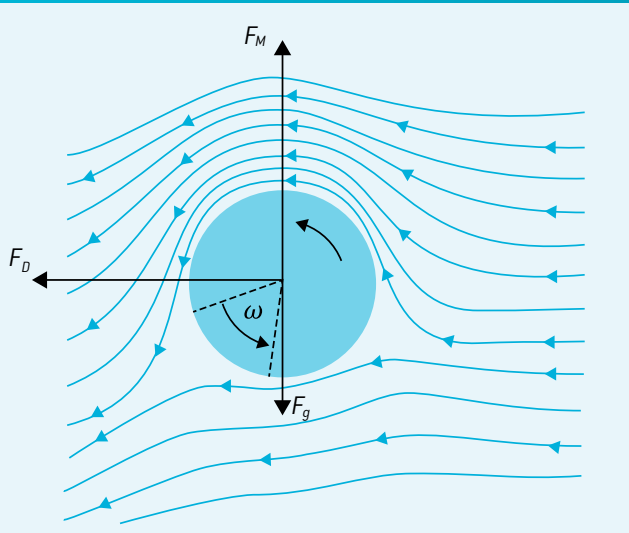
A rotating ball moving through the air will curl due to the Magnus effect, a force acting perpendicular to the direction and the rotational axis of the ball. Here we present some practical experiments, simulations and methods to calculate the trajectory.

2 | CONCEPTUAL INTRODUCTION

In June 1997, Roberto Carlos scored an infamous goal in a 35 m free kick that still baffles the viewer.^[1] How can the ball behave like this, going off in one direction and then magically curling toward the goal? The answer is that the ball is spinning in the air and is subjected to the Magnus force. If you would like to see a free introduction to free kicks from Master Roberto himself, we highly recommend his video from the UEFA Training Ground home page.^[2] If you want a free introduction to the Magnus force, continue reading.

To analyse the trajectory of a ball, we need to assess three forces acting on the ball: gravity F_g , the Magnus force F_M and the drag force F_D .

FIG. 1 Forces^[3]



The gravitational force is simply given by Newton's second law, $F_g = mg$, where m is the mass of the ball and g is the gravitational acceleration.

The Magnus force F_M occurs due to differences in pressure on opposing sides of the ball. The changes in pressure can be described via the Bernoulli principle. For a point on a surface moving through a medium with the velocity v , the total pressure p is equal to the surrounding static pressure p_0 plus the dynamic pressure q (EQ 1), where ρ is the density of the medium, in our case the density of air. But when a ball or cylinder with a radius

R is rotating (with an angular velocity of ω in radians per second), a point on the surface on one side of the ball is subjected to a higher flow of air ($v + \omega R$) than the opposing point on the other side ($v - \omega R$). Hence we can derive the difference in pressure $\Delta p = 2\rho\omega vR$ from EQ 1.

$$p = q + p_0 = \frac{\rho v^2}{2} + p_0 \quad (\text{EQ 1})$$

$$\begin{aligned} \Delta p &= \left(\frac{\rho v_2^2}{2} + p_0 \right) - \left(\frac{\rho v_1^2}{2} + p_0 \right) \\ &= \frac{\rho[(v + \omega R)^2 - (v - \omega R)^2]}{2} = 2\rho\omega vR \end{aligned}$$

$$F_M = \Delta p A = (2\rho\omega vR)A$$

$$\text{For a cylinder: } F_M = 4\rho\omega vR^2h. \quad (\text{EQ 2})$$

$$\text{For a sphere: } F_M = 2\rho\omega v\pi R^3. \quad (\text{EQ 3})$$

The pressure acting on the surface will constitute F_M . Without going too deeply into the maths behind it, we only need to address the forces acting perpendicular to the fluid flow. Any force acting in a direction other than perpendicular to the flow will be cancelled out by another opposing force due to symmetry. Hence, we only look at the effective cross area A of the object. For a ball, A will simply be a circle with the radius R (used in EQ 3); for a cylinder, A will be a rectangle with the height $2R$ and width h (used in EQ 2). In terms of vectors, \vec{F}_M is proportional to the cross product of the directional velocity and the angular velocity.

Finally, we have to assess the drag force F_D . Drag is complicated, as the airflow can be laminar or turbulent, depending to a large extent on the shape of the object and the nature of the fluid it is moving in. For our experiments it suffices to assume that the flow is laminar (as in FIG. 1) and use the standard drag equation where the force is directed in the opposite direction to v and proportional to the velocity: $F_D = \beta v$. β is a constant that depends on the properties of the fluid and the dimensions of the object; for a football in air it is $\beta = 0.142 \frac{\text{kg}}{\text{s}}$ ^[4].

3 | WHAT THE STUDENTS DO

Here we present three different options to demonstrate the Magnus effect. All of these experiments can be carried out as simple demonstrations, but you can also record the experiments and use our models to analyse the trajectories. In that case, make sure you record with a stationary camera at the same height as the objects and perpendicular to the trajectory, and at least a few metres away, in order to minimise angular distortion. The movie can then be analysed with a motion tracking program. We recommend Tracker^[5]. You can find detailed instructions on how to use Tracker in our first iStage book^[6]. There is an excellent app called VidAnalysis^[7] that will record the trajectory and carry out the analysis directly on an Android device (FIG. 2C). The data can also be exported for further analysis; here we use the free software GeoGebra^[8].



FIG 2 Slope cylinder

3|1 Cylinder experiments

Make different cylinders by using A4 or A3 sheets of paper and glue. Mount a tilted board and let the cylinders roll down the slope to obtain a free fall with rotation (FIG. 2A).

The students can examine what happens if they change the inclination of the slope, the radius or the height of the cylinder. The students can experimentally determine the parameters that will visibly give a greater effect and correlate this to EQ 2, or they can go further, extract the data, and proceed with data analysis (Model II) as described later on.

The Magnus effect in water (FIG. 3) is even more impressive because of the higher density of the medium. The cylinder must

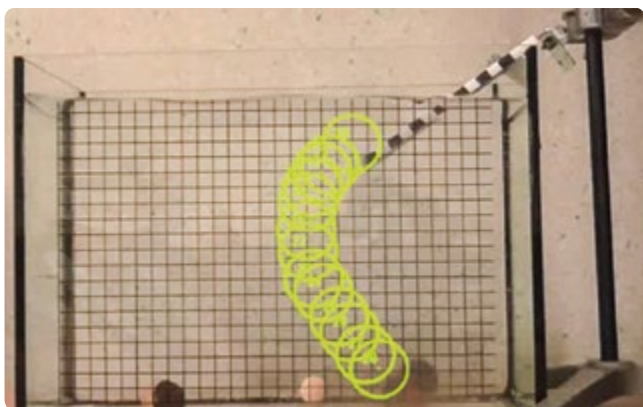


FIG. 3 The Magnus effect in water

have a higher density than water, and a rugged surface to increase the friction. We used a solid Teflon rod with Velcro glued to the surface. To adjust the weight of the cylinder you can glue coins to the ends of the cylinder.

An even more spectacular but trickier setup is to glue or tape the bases of two Styrofoam cups together so that you get a cylinder with a waist in the middle.^[9] Coil a string around the waist and release the cylinder into the air by jerking the string (FIG. 4; there is also a link to a movie on our GeoGebra page^[10]). This requires some practice, but the result is spectacular. The experiment is less reproducible compared to the other cylinder experiments, as the trajectory depends on the angle and how hard you jerk the string. Nevertheless, you can analyse the successful trajectories individually. In FIG. 4 the flying cups go into a circular movement. If the Magnus effect is substantially greater than the gravitational pull, F_M behaves like a centripetal force. This useful assumption will be used later during data analysis.

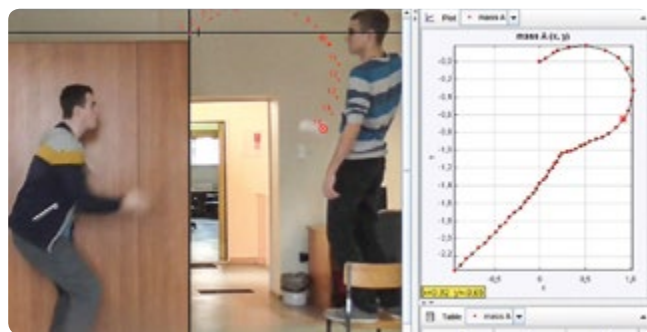


FIG. 4 Flying cups

3|2 Data analysis

We developed different mathematical models to analyse the trajectories. These models are directly accessible online from our iStage 3 GeoGebra page^[10]. We strongly recommend that you open them before continuing to read this text. They will run directly in your browser; just click on the link.

In all the calculations, we have assumed that the rotation is constant during flight. We then make two simplified models based on different assumptions:

Model I: As in the question-mark trajectory with the flying paper cups (FIG. 4), F_M will behave as a centripetal force, and the calculated trajectory of the object will be a circle with the radius r . This assumption is also reasonable in a penalty kick situation, where the total velocity of the ball stays roughly the same. Some of the energy is lost due to turbulence, so we need to introduce a constant C_s to describe this loss.

Then we have:

$$F_M = C_s 2\rho\omega vRA = \frac{mv^2}{r}.$$

$$\text{For a sphere: } r = \frac{mv}{2C_s \pi \rho \omega R^3}. \quad (\text{EQ 4})$$

$$\text{For a cylinder: } r = \frac{mv}{4C_s \rho \omega h R^2}. \quad (\text{EQ 5})$$

You can see the trace from **FIG. 4** in our GeoGebra model (flying cups) and change the centre of the circle and C_s . Play around with the parameters to get the best fit; the model will calculate r from **EQ 5**. For our data the best fit is $C_s = 0.86$.

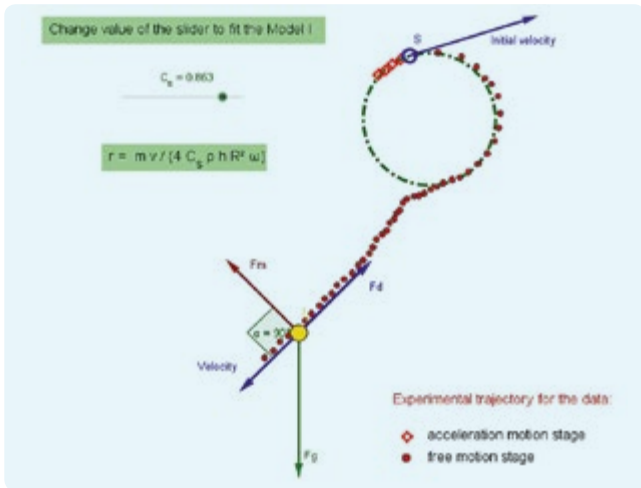


FIG. 5 Flying cups analysis

Model II: To simplify the calculations for the experiment with the paper cylinder (**FIG. 2**), the students can assume that the Magnus effect is pulling mainly perpendicular to the initial direction of motion, and that the cylinders have reached maximum velocity when they fall. With these assumptions, F_D and F_g cancel out, and the Magnus effect can be regarded as accelera-

tion a in the y -direction, so the calculated trajectory will be a parabolic curve:

$$y = \frac{a}{2v^2} x^2 \implies y = C_s \frac{\rho \omega R A}{mv} x^2.$$

$$\text{For a sphere: } y = C_s \frac{\pi \rho \omega R^3}{mv} x^2. \quad (\text{EQ 6})$$

$$\text{For a cylinder: } y = C_s \frac{2 \rho \omega h R^2}{mv} x^2. \quad (\text{EQ 7})$$

This is a simplification, but it will give us a similar C_s as in our other model.

On our GeoGebra page (**FIG. 6**), we have staged a recreation of Roberto Carlos' infamous free kick. You can play around with almost all the parameters to change the setup (distance, angle, the size of the goal, C_s , speed, rotation, position of the four-man wall, etc.). The analysis will show the calculated trajectory of both Models I and II, this time using **EQ 4** and **EQ 6** because we are looking at a ball instead of a cylinder. Challenge your students to find the best values for a given setup, or ask them to find the conditions where the models give different trajectories and ask them to explain why. (You will find out that the models differ when you give the ball very low velocity and high rotation).

3 | 3 Simulations

2D simulation: After some hands-on experiments the students can simulate the Magnus effect. Download the Java program ^[11]. In this simulation the students can modify the initial velocity, the angle, the drag coefficient and the angular frequency. The rotational direction and the forces acting on the ball are as shown in **FIG. 1**. In **FIG. 7** we show three examples of the trajectories at 30° with a frequency of 0, then 5 and $10 \frac{\text{rev}}{\text{s}}$. You can

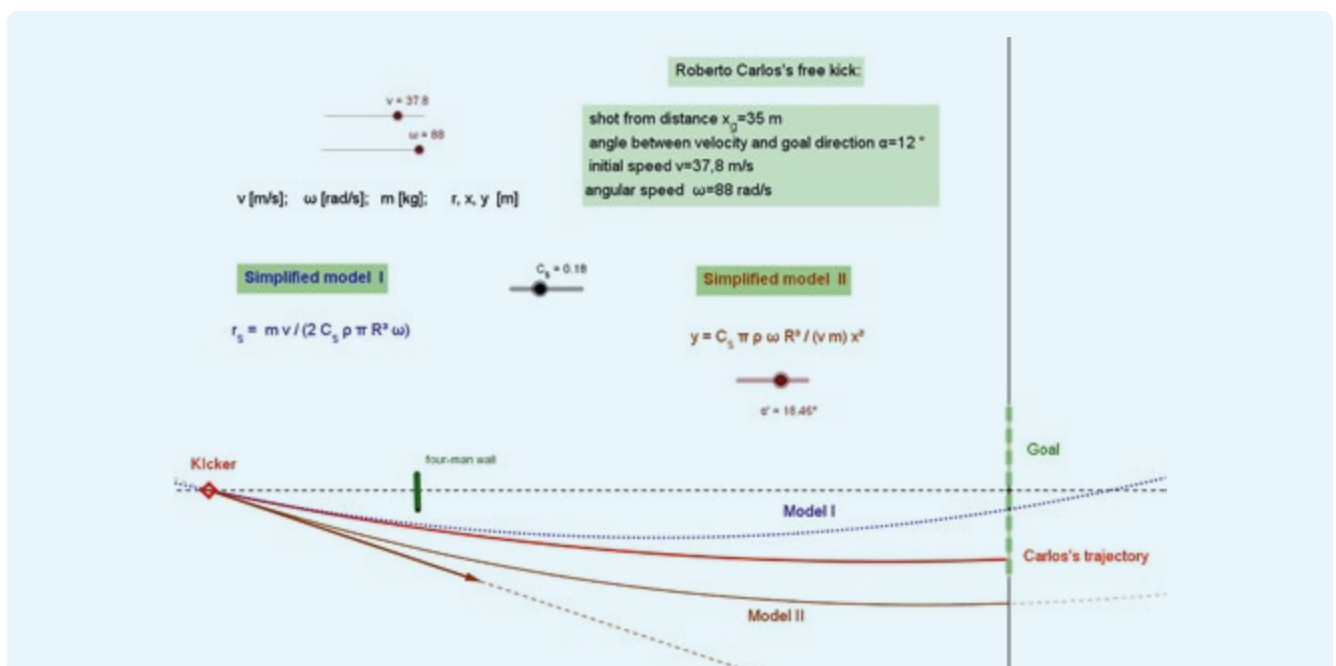


FIG. 6 Free kick analysis

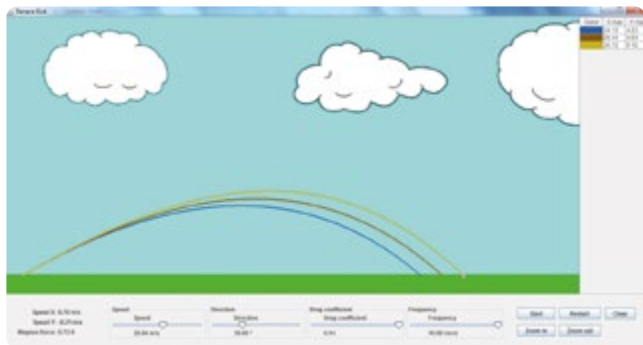


FIG. 7 2D simulation

see that the values of x_{max} and y_{max} are increasing if the frequency is increasing too.

3D simulation: Once again we have recreated the trajectory of Roberto Carlos' free kick (FIG. 8). Now you can try it out yourself by downloading the respective Java program [11]. Later, you can try a different version [11] without the kick, but you can change the parameters freely to see what influence they will have on the trajectory.

In 3D, things rapidly become more complex. In the two-dimensional model the ball can only have top spin or under spin, so the trajectory and the Magnus force will always act in the same plane. In the three-dimensional model the Magnus effect will curve the trajectory of the ball, but the angular momentum of the spin will always be conserved, as the ball behaves like a gyroscope. So the angle between v and ω will be different at dif-

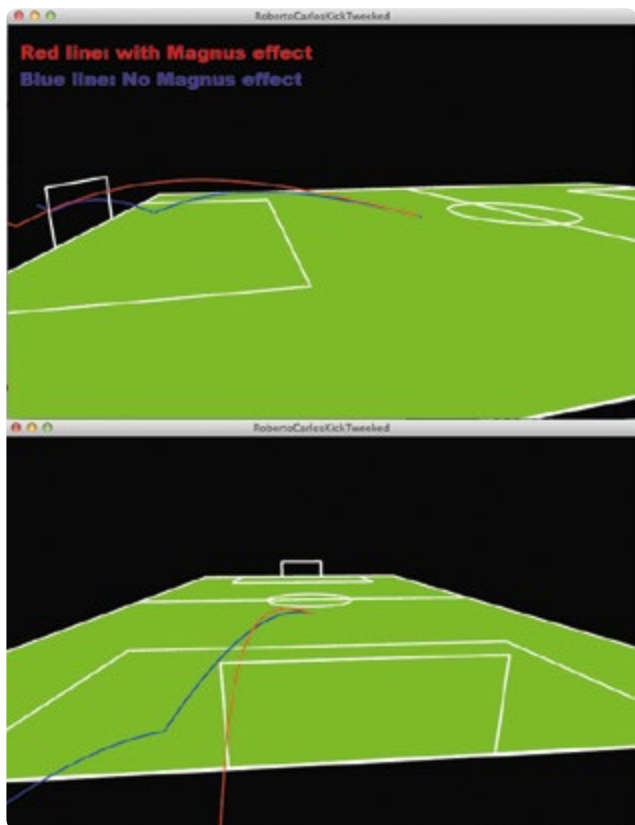


FIG. 8 3D simulation

ferent points of the trajectory, which will give the ball a more complex trajectory. Unlike the GeoGebra calculations, this program simply calculates all the forces numerically in each frame on the basis of the values in the previous frame. The program is written in Processing [12], a simplified version of Java.

4 | CONCLUSION

On the football field the trajectory of a football is complex and depends on a whole array of factors. In order to study this in the classroom the students have to break it down into manageable components using models and simplifications. These experiments, models and simulations give an insight into what we can conclude from working with a scientific method: If we assume that the game is played under water or that the football can be replaced by two paper cups we come very close to the explanation how Roberto Carlo manages to curve the ball.

5 | COOPERATION OPTIONS

On our iStage 3 GeoGebra platform [10] you can find information about how to obtain a copy of our GeoGebra files and how to use them. We propose a challenge: obtain the highest Magnus effect possible for the flying paper cups experiment. That corresponds to finding the highest value for C_s , as close to 1 as possible. You can share your analysis, results and models [11].

REFERENCES:

- [1] www.theguardian.com/football/2015/may/18/roberto-carloss-free-kick-against-france-recreated-sensible-soccer-style (08/03/2016)
- [2] www.uefa.com/trainingground/skills/video/videoId%3D761187.html (08/03/2016)
- [3] The original image for FIG. 1 was obtained from https://commons.wikimedia.org/wiki/File:Magnus_effect.svg (08/03/2016)
- [4] The Science of Soccer; John Wesson. CRC press, 2002. ISBN 978-0750308137
- [5] www.physlets.org/tracker
- [6] iStage: Teaching Materials for ICT in Natural Sciences, section "From Bicycle to Space", pp. 45-52; www.science-on-stage.de/iStage1_downloads
- [7] VidAnalysis app <https://play.google.com/store/apps/details?id=com.vidanalysis.free&hl=en> (08/03/2016)
- [8] www.geogebra.org/
- [9] A similar experiment is described by Laura Howes (Science in School, issue 35, 2016, www.scienceinschool.org/content/sports-spin).
- [10] www.geogebra.org/science+on+stage
- [11] www.science-on-stage.de/iStage3_materials
- [12] <https://processing.org>

BIG DATA

Over the past few years, the expression “big data” has become a household word in the world of computing. The concept of big data involves the analysis of extremely large quantities of data that can no longer be managed by traditional methods of evaluation. Large software companies offer management and solutions for the analysis of these large databases, most of which are automatically generated.

Even the area of football generates large amounts of data. All the games of the top leagues are recorded by numerous cameras from various angles and positions. Thus the play of individual athletes and their interaction with other players can now be automatically evaluated and rated. The use of many cameras and the data they provide enables TV reporters and commentators to provide and analyse the statistics regarding individual players’ time of possession, performance and endurance (for example, the distance they have run). However, we must admit that coaches are unwilling to offer outsiders any insights into their use of these data/this information for the purpose of developing strategy and tactics.

In “Data Match”, the students learn how to collect the data regarding the position of an individual player during a match. They do this with the assistance of a smartphone that can continuously transmit the player’s GPS information. They learn how to write such a program for their smartphones.

The teaching unit “Shoot to Thrill” created by the Big Data team deals with the round of penalty kicks that takes place after a match ends in a draw after regular time plus extra time. For example, does the order of the players taking the penalty kicks matter? Should the better players shoot first, or should the weaker ones precede them? We have developed a software program with which students can test various hypotheses and variations.

Hundreds of millions of euros are wagered on football. However, our authors of “Goal Stock Exchange” have come to the conclusion that predictions of game results that are based upon pre-



vious results are unreliable and unhelpful. On the other hand, we have observed that the wealth of information about football matches that is available on the Internet can provide excellent material for helping students learn to work with spreadsheets. By subjecting this information to the methods of probability calculus, they can examine the many questions that arise. However, students should be aware that they should under no circumstances enter the world of sports wagering for the purpose of financial gain.

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Werl, Germany
Coordinator

PERE COMPTE · STEPHEN KIMBROUGH · MAEVE LISTON · MARCO NICOLINI

DATA MATCH



🔧 technology (App Inventor; dweet.io; freeboard.io; programming, big data)

📡 Information and Communications Technology

👥 This project is recommended for students older than 15 years.

1 | SUMMARY

Since 2015, FIFA has authorised the use of tracking systems for official matches i.e. data-collection trackers for all players on the pitch. Off the pitch this data can be then examined and analysed to inform managers, trainers and players regarding players' performance.

These systems are also used during training sessions and for testing physical performance, providing data in real time. These wearable devices (for example watches or chips embedded in the player's clothes) collect significantly large amounts of data, such that these data sets, when collected, can be designated as Big Data.

This unit helps students to send big data in real time via mobile devices.

2 | CONCEPTUAL INTRODUCTION

The collection of real-time GPS data on the football pitch using memory technology is becoming increasingly important in the development of player performance, in the planning of training, in the prevention of injuries and in the development of tactics boards.

In any single football game approximately 1.5 million player positions can be captured by cameras and sensors. This GPS data can be used to measure and calculate a player's speed (pace),

acceleration and changes of direction.

Analysis of this data can also tell coaches when a player can return to the field after injury or when a player has a high risk of injury. Other examples of the type of data that can be gathered instantaneously using sensors in the players' shirts include body temperature (development of heat maps on the pitch), heart rate, percentage of oxygen, and the lactic acid concentration of blood.

Different software applications are needed to store, process, analyse and visualise such large amounts of data in a convenient and effective way.

3 | WHAT THE STUDENTS DO

This unit will enable students to send big data in real time using their smartphones. Students will become app developers, designing and making their own applications using the App Inventor^[1] program. The real-time data will be collected via this app and then sent to an online data-sharing website (dweet.io) which is linked to a screen-mapping website (freeboard.io). All aforementioned programs are free and can be used remotely in the cloud. Students will learn how to publish data they have collected and share it in the cloud.

3 | 1 App Inventor

MIT App Inventor is an innovative, easy-to-use program for app creation and development. It is highly suitable for first-time programmers and very student-friendly. Note: you have to create an account before using App Inventor.

Here is a step-by-step guide how to develop a football app to gather real-time GPS data from your students while on the football pitch (FIG. 1).

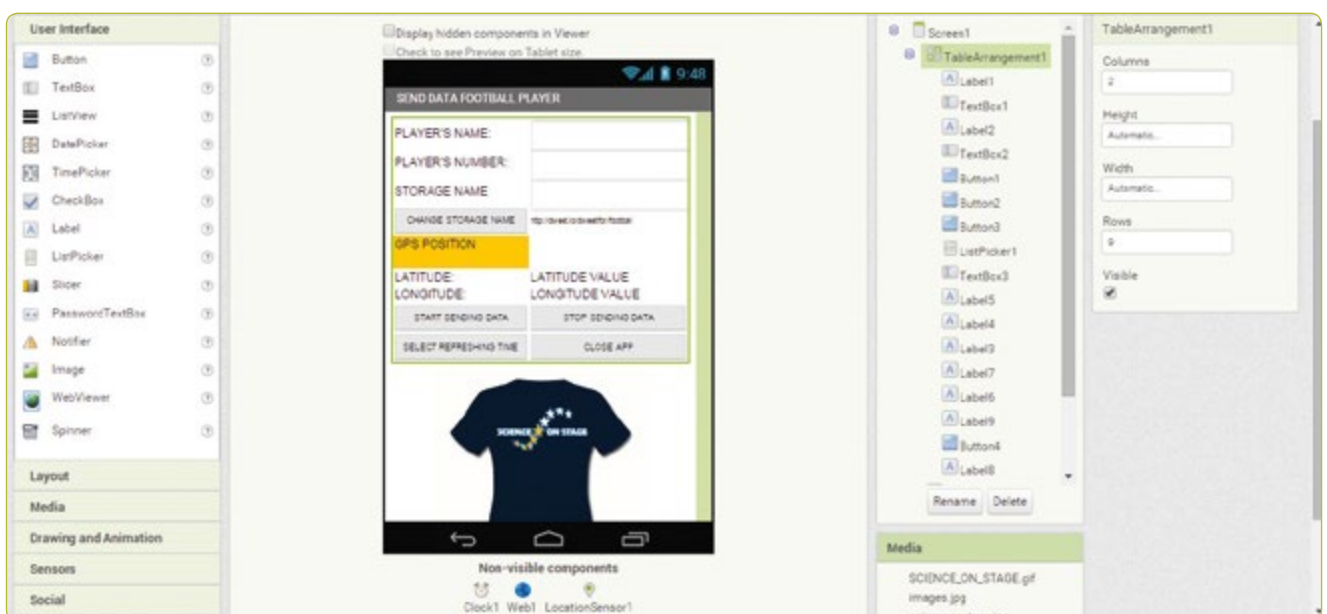


FIG. 1 Screenshot of App Inventor

3 | 1 | 1 **App Inventor screen design**

Open App Inventor, click *new project* and enter a name for your new project, e.g. *Send Data Player*. You will then be automatically directed to the designer section.

On the right-hand side of the screen you will find a list of screen properties you can choose in order to design screen content.

FIG. 1 was designed using the following steps:

- **Screen1.** AlignHorizontal: CENTER; AppName: SEND DATA PLAYER; Icon: SCIENCE_ON_STAGE.GIF; Title: SEND DATA FOOTBALL PLAYER
- **TableArrangement1.** Columns: 2; Rows: 9
- **Label1.**Text. PLAYER'S NAME:
- **Label2.**Text. PLAYER'S NUMBER:
- **TextBox1.** Hint: Introduce your name
- **TextBox2.** Hint: Introduce your number; NumbersOnly
- **TextBox3.** Hint: Introduce your storage name
- **Label3.**BackgroundColor: Orange; Text: GPS POSITION (see FIG. 2)
- **Label4.**Text. LATITUDE:
- **Label5.**Text. LONGITUDE:
- **Label6.**Text. LATITUDE VALUE:
- **Label7.**Text. LONGITUDE VALUE:
- **Label8.** FontSize:9; Text:http://dweet.io/dweet/for/football
- **Button1.** FontSize:11; Text: START SENDING DATA
- **Button2.** FontSize:11; Text: STOP SENDING DATA
- **Button3.** FontSize:11; Text: CLOSE APP
- **Button4.** FontSize:11; Text: STORAGE NAME
- **Label9.**Text. STORAGE NAME:

- **ListPicker1.** FontSize:11; Text: SELECT REFRESHING TIME (SECONDS)
- **Image1.** Picture: SCIENCE_ON_STAGE.GIF
- **Clock1.**TimerEnabled: NO; Timer Interval: 5000 (every 5 seconds)
- **Web1.** Url: http://dweet.io/dweet/for/thing (e.g. http://dweet.io/dweet/for/football; the "thing" is, in this case, "football", but you can choose any name your class would like)
- **LocationSensor1.** Time Interval: 1,000 (every 1 second)

3 | 1 | 2 **App Inventor blocks programming**

Click on the *Blocks* tab on the menu bar (FIG. 1).

Click *Button1* to activate the data-transmission clock and disable changes to the player's name and number.

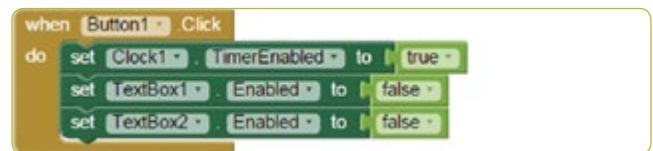


FIG. 3

Click *Button2* to disable the data-transmission clock and enable changes to the player's name and number.

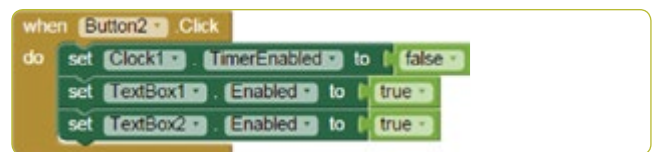


FIG. 4



FIG. 2 Components of TableArrangement1

Click *Button3* to close the application.

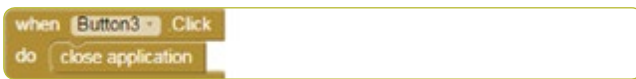


FIG. 5

Click *Button4* to change the URL of the file where you want to publish data at dweet.io.

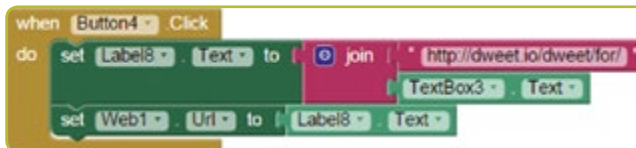


FIG. 6

When the GPS sensor detects a change in latitude or longitude, this data is recorded in *Labels 6 and 7*.

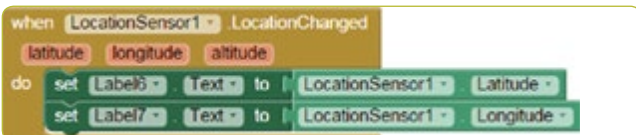


FIG. 7

The recorded data, along with the player's name and number, as well as the latitude and longitude of his or her position, are sent at regular intervals and every five seconds by default (FIG. 8).

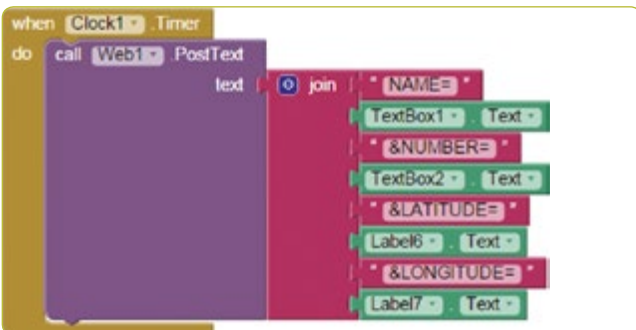


FIG. 8

The *ListPicker1* tab allows you to refresh time information in seconds; from 1 to 20 seconds (FIG. 9).

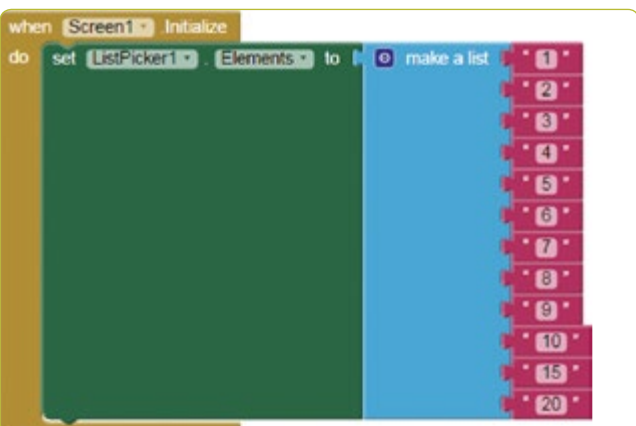


FIG. 9

The *Timer Interval* field is defined in milliseconds. (FIG. 10)

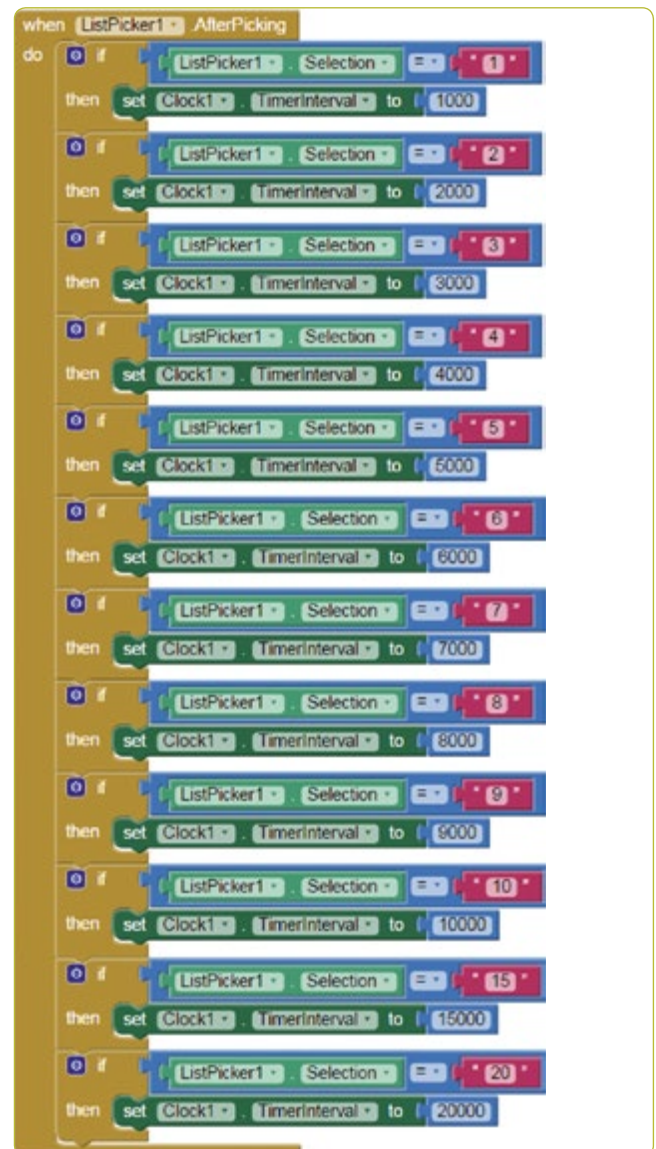


FIG. 10

3 | 2 Data storage on dweet.io

dweet.io is designed to publish data from sensors (FIGS. 11 and 12). This is more popularly known as the Internet of Things (IoT). dweet.io assigns a unique URL for every *thing*.

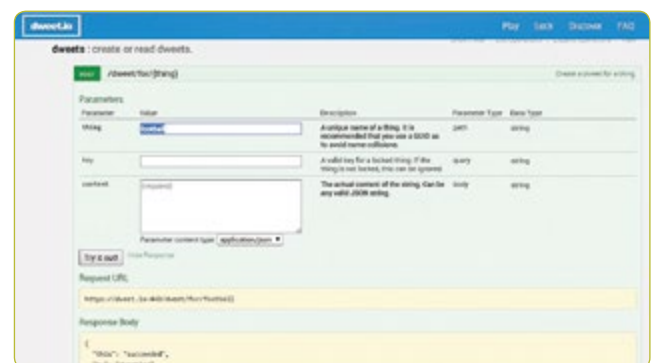


FIG. 11

- Select *PLAY*
- Click the *POST* tab.
- Write the storage name you want in the *thing* field. The storage name in the app has been set as *football* in the example shown in this resource. Therefore it must also be called *football* here in *dweet*.
- Click *Try it out!*

Using the *GET* tab.

To view the data stored, go to: `get/tweets/for/{thing}`, enter the *STORAGE NAME* chosen for you (by default *football*) and click *Try it out*.

3 | 3 Visualisation of data on freeboard.io

Freeboard is an open-source, real-time dashboard builder for the Internet of Things.

- Click on *Start Now*
- Enter a name and click *Create New*
- Click *Add Datasources* tab
- Click *Select a Type* and choose *Dweet.io*
- Enter a *Name: football*
- Enter *Thing Name: football*
- Press *Save*
- Click on *Add Pane* tab
- Click + symbol
- Click on *Select Type* and choose *Text*
- Title: *Player*
- Click on *+Datasource: Football and Name*
- Click *Save*
- Click on *Add Pane* tab and choose *Pointer*

- Click on *+Datasource: Football and Number*
- Click *Save*
- Click on *Add Pane* tab
- Click + symbol
- Click *Select Google Map*
- Click on *+Datasource: Football and Latitude*
- Click *Save*
- Click on *Add Pane* tab
- Click + symbol
- Click *Select Google Map*
- Click on *+Datasource: Football and Longitude*
- Click *Save* (FIG. 13)

4 | CONCLUSION

This teaching unit encourages students to develop their own application for sending data in real time. It provides an opportunity to gather “real data” on the pitch via smartphone—a tool that most students have in their pocket.

Students see that a smartphone is all that is needed to collect the data required and to increase the number of parameters to be studied at same time.

There are many options for data analysis. For example, students can plot and analyse the positions of the players of a complete team on a pitch by means of the following tools:

- Create an Excel file containing the latitude and longitude of all the players.
- Go to www.earthpoint.us and select *Excel to Google Earth*, select your Excel file, and click on *View on Google Earth*.

The screenshot shows the dweet.io interface. At the top, there are navigation links: Play, Lock, Discover, and FAQ. Below that, there are utility links: Show/Hide, List Operations, Expand Operations, and Raw. The main content area is titled "dweets : create or read dweets." and contains three API endpoints:

- POST** /dweet/for/{thing} - Create a dweet for a thing.
- GET** /get/latest/dweet/for/{thing} - Read the latest dweet for a thing.
- GET** /get/dweets/for/{thing} - Read all of the saved dweets (up to last 500) for a thing.

Below the endpoints is a "Parameters" table:

Parameter	Value	Description	Parameter Type	Data Type
thing	football	A unique name of a thing.	path	string
key		A valid key for a locked thing. If the thing is not locked, this can be ignored.	query	string

There is a "Try it out!" button and a "Hide Response" link. Below that is the "Request URL" field containing: `https://dweet.io:443/get/dweets/for/football`. At the bottom is the "Response Body" field containing a JSON object:

```
{
  "this": "succeeded",
  "by": "getting",
  "the": "dweets",
  "with": [
    {
      "thing": "football"
    }
  ]
}
```

FIG. 12

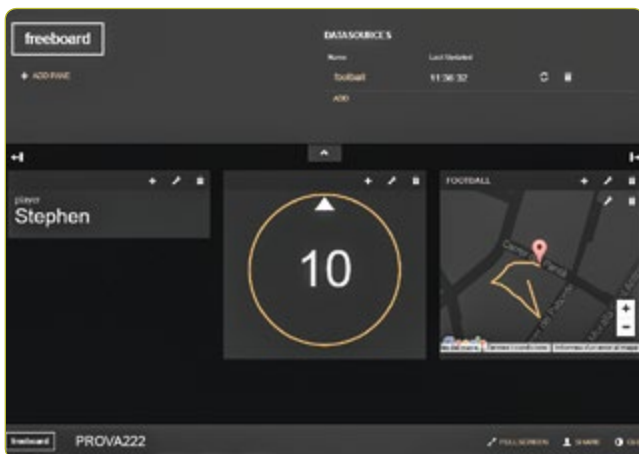


FIG. 13



FIG. 14 Student with bib to record data

- On Google Earth: check that the players' positions are being plotted on the location where they were playing football.

Further developments

- Match evolution: students can order these files chronologically, watching them like a film and analysing how the team moves and behaves during a specific period during a match.
- Area covered by a team: after producing a Google Earth view of the team's positions, students can use the *Polygon Area* utility, available from the same source. Following the easy instructions, students can calculate the area enclosed by the players' positions so as to determine whether they were playing as a scattered assembly or unified team.

5 | COOPERATION OPTIONS

Students can organise cooperative projects between different schools. For example, the students at one school might take measurements in real time, while students from another school analyse the data. This methodology can also be used to study other sports.

RESOURCES

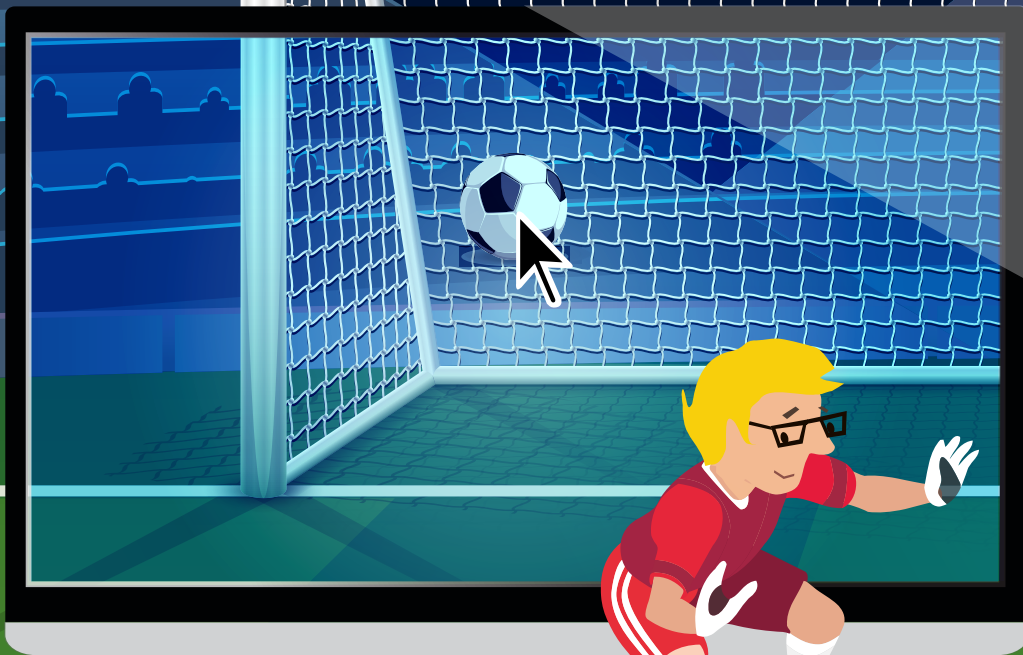
[1] MIT App inventor <http://ai2.appinventor.mit.edu/>


- <http://usuaris.tinet.cat/pcompte/football/> BIG DATA: Sending Data in Real Time
- www.realtracksystems.com/ WIMU Real track systems
- <http://go.sap.com/solution/industry/sports-entertainment/team-management/sports-one.html> SAP Sports One

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STEPHEN KIMBROUGH · DAMJAN ŠTRUS

SHOOT TO THRILL



 penalty shoot-out, combinatory, game theory

 mathematics, computer science, physics

 14–18 years

1 | SUMMARY

This project requires students to calculate the probability of a successful penalty shot, taking into account all of the internal and external influences [i.e. geometry, reaction time, choice of side].

The students must also find the perfect line-up for a penalty shoot-out as well as a “fair” alternative to it.

2 | CONCEPTUAL INTRODUCTION

The penalty shoot-out was introduced into the FIFA World Cup football rules in the 1970s.

It applies if a game is tied after extra time, i.e. the extra period of play added on to a game when the score is level after regular time. Before the introduction of this new rule, the winner was decided by the toss of a coin.

Penalty shoot-outs are among the most thrilling situations that can occur during a football match.

In this unit we will analyse how to maximise the outcome for a specific team.

The unit is divided into two parts. In the first part, the students calculate the probability of scoring a goal with a single shot. In the second part, they learn how the penalty shoot-out can be optimised.

3 | WHAT THE STUDENTS DO

3 | 1 Single penalty

To find out how high the probability of scoring is, we need to divide the penalty shot into two independent motions, those of the goalkeeper and those of the penalty taker.

First we assign probabilities to the goalkeeper on the basis of trigonometry.

The football goal is a rectangle with a width of 7.32 m and a height of 2.44 m. The height of the average goalkeeper is about 2 m and he has an arm span of about 2 m. The students can then compare the area covered by the goalkeeper with the area of the football goal. This yields the probability of the goalkeeper preventing a goal.

A second aspect is the goalkeeper’s reaction time and how long it takes him to reach the ball.

Students should begin by guessing where the best spots to aim the shot would be. The answer is: the upper corners of the goal. Then they have to use trigonometry to calculate the distance to that point. The time the ball travels can be calculated ($t = \frac{s}{v}$), with the assumption that the average velocity of the ball is 100 km/h.

The goalkeeper has that amount of time to react and jump into the right corner.

The students measure their own reaction time with a ruler that is dropped by one student and caught by a second student (see p. 30). Using the distance the ruler has travelled, the reaction time can be calculated as

$$t = \sqrt{\frac{2h}{g}}$$

g : gravitational acceleration; $g = 9.81 \frac{\text{m}}{\text{s}^2}$

t : time [s]

h : distance covered [m]

Subtracting this reaction time, the goalkeeper has the remaining time to cover the distance to the ball. The latter has already been calculated, such that he or she has to have an initial velocity of $v = \frac{x}{t}$ in order to reach the ball. An athlete’s average speed when jumping is approximately 16 km/h.

By comparing the two velocities, the students can see that the goalkeeper would never be able to reach the ball. This yields the conclusion that the goalkeeper cannot allow for any reaction time and must choose which corner to dive toward before the penalty has been taken.

Students divide the goal into two halves and calculate the probability of preventing the ball from going in one half of the goal, using the same method as above. This can also be calculated again, after dividing the goal into thirds.

It is hard for the penalty taker to estimate probabilities, but in general it can be said that a left-footed penalty taker will aim better at the right corner, and a right-footed penalty taker at the left corner.

The students can accumulate data by shooting 10, 20 or more times at an empty goal and calculate the accuracy of their shots.

The students should then write a program, or use the source code that can be found in the appendix ^[1], to simulate a penalty shot. The students first have to enter their probability figures. For both the goalkeeper and the penalty taker, the direction of the shot is altered by randomness. Bearing in mind the law of large numbers, the probability of scoring a goal in a penalty shoot-out can be determined by increasing the number of shots. On this basis, the students can explore the question of whether altering the strategies for shooting will lead to a higher or a lower



FIG. 1 Perspective of the penalty taker

accuracy. The students can compete against each other with their respective codes.

3 | 2 Penalty shoot-out

Penalty shoot-outs always take the same form. Five players from each team are nominated to take penalties in a fixed order. A coin is tossed to decide which team gets to choose which team should shoot first. The teams then take turns shooting a penalty.

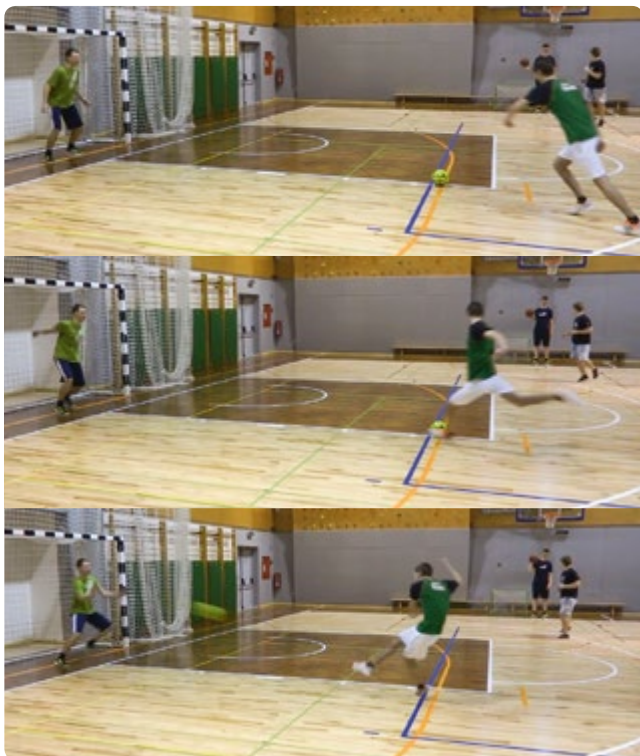


FIG. 3 Sequence of a penalty shot



FIG. 2 Perspective of the goalkeeper

The students are given a list of players with their average scoring probabilities. They choose five of these players and determine the line-up in which they will shoot. Two of the students compete against each other in a game that has been programmed in Scratch 2 [2]. Afterwards the students will have to prove that their line-up is the best possible one. Since the mean probability for scoring a goal is

$$p = \frac{(p_1 + p_2 + p_3 + p_4 + p_5)}{5} \text{ all of the line-ups are equal.}$$

The problem in real-life football compared to computer simulations is that the pressure on each penalty taker rises as the penalty shoot-out progresses. This value can be set at about 5%. This will lead to the following equation for the mean probability:

$$p = \frac{(p_1 + 0.95p_2 + 0.90p_3 + 0.85p_4 + 0.80p_5)}{5}.$$

Since we have $5! = 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1 = 120$ possible line-ups, the students must figure out a way to optimise the result. It should be up to the students to find a solution to the problem, although having the weakest penalty taker first and ascending to the strongest last is in fact the best solution.

With this in mind, the students can alter the Scratch 2 program to adapt it to their needs. [2]

The next variable that plays a role here is the psychological effect if the team that shoots first scores a goal. This situation puts even more pressure on the next penalty taker.

Next, the students can compare two teams of equal strength, changing the program and simulating it many times. This yields

the conclusion that the team that begins has a higher chance of winning the penalty shoot-out.

The students should finally have a debate to determine a fair rule for a penalty shoot-out. They should test the rule with the program mentioned above and find out whether five shots are enough to reach a satisfactory outcome.

The fairest sequence for Teams A and B, each one with eight players, would be AB BA BA AB. This is also known as the Thue-Morse sequence. The sequence of the teams shooting has to be altered, and the alteration itself also has to be altered.

4 | CONCLUSION

The students will learn how to model a real-world scenario and to analyse it mathematically. They will also learn how to use their programming skills to solve problems generated by complex situations and to write their own simulation of a penalty shoot-out.

5 | COOPERATION OPTIONS

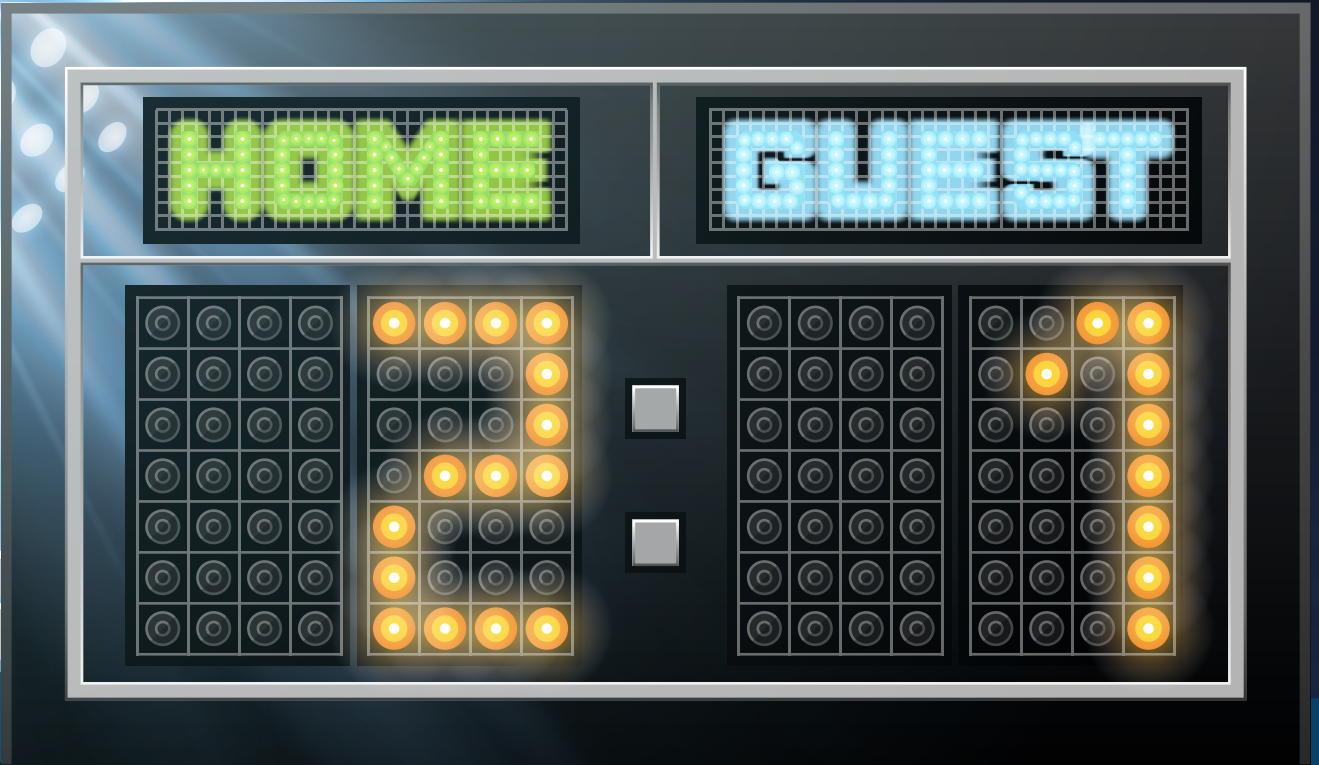
Students can organise a competition in class or against another school to see which penalty shoot-out strategy is the best (see 3.1).

Another idea could involve an attempt by the students to “improve” the rules of football by changing the size and shape of the goal. What would happen to the penalty shoot-out if the goal were round or triangular?

REFERENCES

^[1] www.science-on-stage.de/iStage3_materials

^[2] <https://scratch.mit.edu/scratch2download/>



GOAL
STOCK EXCHANGE

STEPHEN KIMBROUGH · MARCO NICOLINI · DAMJAN ŠTRUS



📊 spreadsheet, goals statistics, averages, graphs, relative frequencies, coincidence, probability, quota

🖥️ mathematics, statistics, ICT

👥 15–19 years

1 | SUMMARY

This teaching unit will give students the opportunity to work with, make sense of and ask questions about real-life football data that is freely accessible on the Internet^[1] or in daily newspapers.

2 | CONCEPTUAL INTRODUCTION

Football is the world's most popular sport with a global appeal that transcends national, cultural, gender and socioeconomic class boundaries. With an ever-expanding audience around the globe, football's appeal continues to grow, such that football has now become one of the most powerful businesses within the sport industry worldwide.

The European Football Market is valued at €19.4 billion^[2]. Many people around the world depend on this industry to make a living, including players, coaches, referees, marketing companies, the media and, last but not least, bookmakers. The sports betting industry is worth anywhere between €606 billion and €870 billion a year. Bookmakers' work involves predicting whether a team will win or lose and calculating betting odds on this basis. A successful bookmaker needs not only luck but also acute mathematical skills in order to analyse complex sets of data, taking into consideration a variety of combinatorial factors and complex variables.

3 | WHAT THE STUDENTS DO

The most important skill that students first need to develop is to become familiar with designing and building a database using spreadsheets. The type of football data available online includes a wide variety of variables, including dates of games,

home and away scores, full-time and half-time scores, number of shots, corners, fouls, off-sides, yellow and red cards, and, of course, betting odds. Students can take the desired data sets from these sources and import them into their own spreadsheets.

3 | 1 Data entry

First ask the students to make a spreadsheet with the results of games. An example of a spreadsheet is provided in **FIG. 1**. This spreadsheet is based on the German Bundesliga 1 in the season 2014/15.

The names of all the teams are listed in the left column (home team) and upper row (away team) in alphabetical order.

The results of each game are included in the two corresponding cells: the left cell indicates the number of goals scored by the home team, and the right cell indicates the number of goals scored by the away team. For example, when Bayern Munich played at home against Augsburg, the result was 0:1. When Augsburg were at home against Bayern Munich, the score was 0:4.

3 | 2 Calculations

Ask the students to:

1. Develop a formula to calculate the number of games that were played in the whole season in the Bundesliga 1 (Hint: 18 teams all playing against each other).

Solution: Each team has 17 opponents that have all played both home and away games, so each team plays $2 \cdot 17 = 34$ games (the Bundesliga 1 has 34 rounds). Since there are 18 teams, each round has nine matches. Therefore, in total, 306 matches were played in the season.

2. Calculate the goal statistics (goals scored and conceded) for each team for the whole season.

FIG. 1 Spreadsheet with results of games; German Bundesliga 1, season 2014/15

	away team home team	Augsburg	Bayern	Bremen	Dortmund	Frankfurt	Freiburg	Hamburger SV	Hannover	Hertha	Hoffenheim	Köln	Leverkusen	Mainz	Mönchengladbach	Paderborn	Schalke	Stuttgart	Wolfsburg
1	Augsburg		0 4	4 2	2 3	2 2	2 0	3 1	1 2	1 0	3 1	0 0	2 2	0 2	2 1	3 0	0 0	2 1	1 0
2	Bayern	0 1		6 0	2 1	3 0	2 0	8 0	4 0	1 0	4 0	4 1	1 0	2 0	0 2	4 0	1 1	2 0	2 1
3	Bremen	3 2	0 4		2 1	1 0	1 1	1 0	3 3	2 0	1 1	0 1	2 1	0 0	0 2	4 0	0 3	2 0	3 5
4	Dortmund	0 1	0 1	3 2		2 0	3 1	0 1	0 1	2 0	1 0	0 0	0 2	4 2	2 1	0 3	0 0	2 2	2 2
5	Frankfurt	0 1	0 4	5 2	2 0		1 0	2 1	2 2	4 4	3 1	3 2	2 1	2 2	0 0	4 0	1 0	4 5	1 1
6	Freiburg	2 0	2 1	0 1	0 3	4 1		0 0	2 2	2 2	1 1	1 0	0 0	2 3	0 0	1 2	2 0	1 4	1 2
7	Hamburger SV	3 2	0 0	2 0	0 0	1 2	1 1		2 1	0 1	1 1	0 2	1 0	2 1	1 1	0 3	2 0	0 1	0 2
8	Hannover	2 0	1 3	1 1	2 3	1 0	2 1	2 0		1 1	1 2	1 0	1 3	1 1	0 3	1 2	2 1	1 1	1 3
9	Hertha	1 0	0 1	2 2	1 0	0 0	0 2	3 0	0 2		0 5	0 0	0 1	1 3	1 2	2 0	2 2	3 2	1 0
10	Hoffenheim	2 0	0 2	1 2	1 1	3 2	3 3	3 0	4 3	2 1		3 4	0 1	2 0	1 4	1 0	2 1	2 1	1 1
11	Köln	1 2	0 2	1 1	2 1	4 2	0 1	0 0	1 1	1 2	3 2		1 1	0 0	0 0	0 0	2 0	0 0	2 2
12	Leverkusen	1 0	2 0	3 3	0 0	1 1	1 0	4 0	4 0	4 2	2 0	5 1		0 0	1 1	2 2	1 0	4 0	4 5
13	Mainz	2 1	1 2	1 2	2 0	3 1	2 2	1 2	0 0	0 2	0 0	2 0	2 3		2 2	5 0	2 0	1 1	1 1
14	Mönchengladbach	1 3	0 0	4 1	2 1	3 1	3 1	0 1	0 2	0 3	2 3	1 1	0 3	0 1	1 1		2 0	4 1	1 1
15	Paderborn	2 1	0 6	2 2	2 2	3 1	1 1	0 3	2 0	3 1	0 0	0 0	0 3	2 2	1 2		1 2	1 2	1 3
16	Schalke	1 0	1 1	1 1	2 1	2 2	0 0	0 0	1 0	2 0	3 1	1 2	0 1	4 1	1 0	1 0		3 2	3 2
17	Stuttgart	0 1	0 2	3 2	2 3	3 1	2 2	2 1	1 0	0 0	0 2	0 2	3 3	2 0	0 1	0 0	0 4		0 4
18	Wolfsburg	1 0	4 1	2 1	2 1	2 2	3 0	2 0	2 2	2 1	3 0	2 1	4 1	3 0	1 0	1 1	1 1	1 3	1

FIG. 2 Graph of scored goals (green) and conceded goals (red) for each team, German Bundesliga 1, season 2014/15

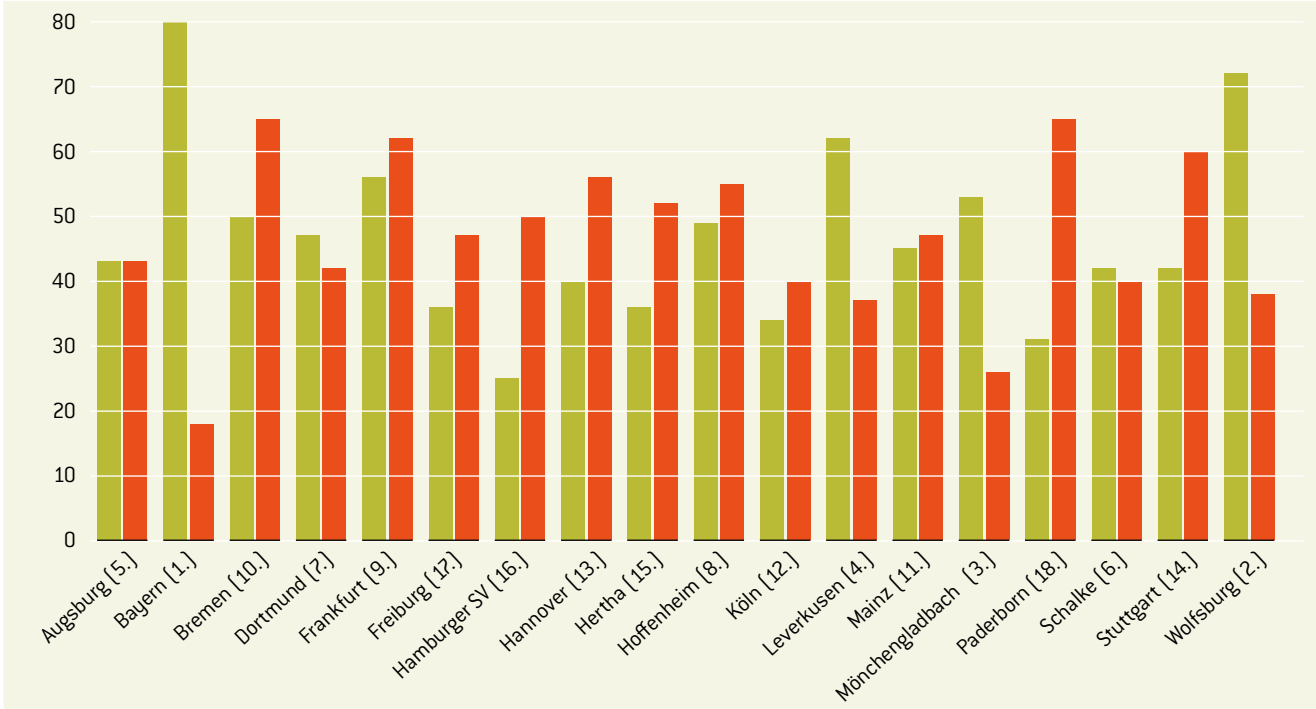


FIG. 2 shows all the goals that each team scored (highlighted in green) and all the goals that each team conceded (highlighted in red). Students can then compare the results from their spreadsheet with the real data from online databases in order to check their calculations.

3. Calculate the average number of goals per game in the whole season.

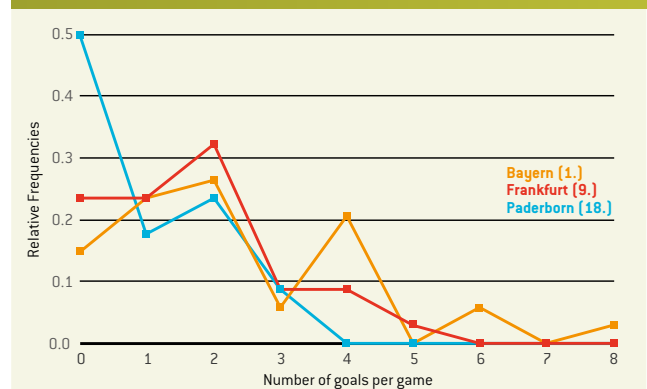
Solution: 2.75

4. Calculate the average number of goals per game that each single team scored and conceded. Students plot a graph of goals scored and conceded per game for each team. Ask the students to compare the graph with the position of each team in the final table, and allow them time to identify the connection between the shape of the graph and the ranking in the final table (in FIG. 2).
5. Calculate the relative frequency $p(n)$ of the number of goals per game. Students can count the number of games in which each team scored 0, 1, 2, 3 goals etc. They make a spreadsheet for each team and plot a graph with relative frequencies versus number of goals per game for all teams. FIG. 3 shows that Bayern played a total of 34 matches and did not score in five matches, scored one goal in eight matches, two goals in nine matches etc. Encourage students to use formulas that the spreadsheet program offers in order to design the suggested table in FIG. 3.

FIG. 3 Relative frequencies $p(n)$ for three teams

n	Relative Frequency					
	Bayern (1.)		Frankfurt (9.)		Paderborn (18.)	
	$N \cdot p(n)$	$p(n)$	$N \cdot p(n)$	$p(n)$	$N \cdot p(n)$	$p(n)$
0	5	0.15	8	0.24	17	0.50
1	8	0.24	8	0.24	6	0.18
2	9	0.26	11	0.32	8	0.24
3	2	0.06	3	0.09	3	0.09
4	7	0.21	3	0.09	0	0.00
5	0	0.00	1	0.03	0	0.00
6	2	0.06	0	0.00	0	0.00
7	0	0.00	0	0.00	0	0.00
8	1	0.03	0	0.00	0	0.00
	34	1	34	1	34	1

FIG. 4 Relative frequency versus number of goals per game for three teams



The sum of the second column is the number of games in the whole season played by one team, the sum of the third column is 1.

6. Find out what information (already calculated beforehand) students get if they multiply the number of goals n with corresponding relative frequency $p(n)$ on each row of the table. Then summarise all products:

$$\sum_{n=0}^{\infty} n \cdot p(n).$$

Solution: They discover the average number of goals \bar{n} each team scored per season.

7. Use the average number of goals to calculate so-called coincidence in the outcome of the games. Coincidence is a relatively effective deviation and according to the Poisson distribution, it equals $\sqrt{\frac{1}{\bar{n}}}$.

The outcome of each game is more difficult to predict as the coincidence value increases. This is only a rough estimation; however, it can be argued that football is based on coincidence. Coincidence in real gaming can often be as high as 100%. At the same time, coincidence is higher when the football team is lower in the table.

8. Plot a graph to show how the position of each team changes in the table during the season (for each of 34 rounds). Discuss with the students some possible reasons that may have caused this rise or fall in the table.

3 | 3 Probability

9. Students already calculated the average number of goals that each single team scored per match. Let r_1 be the average number of goals that the first team scores per match and r_2 the average number of goals that the second team scores per match. We define R as the quotient: $R = \frac{r_1}{r_2}$.

The probability that the first team will score the next goal is calculated using $p_1 = \frac{R}{R+1}$ and the probability that the second team will score the next goal is calculated using $p_2 = 1 - p_1 = \frac{1}{R+1}$.

Obviously, the averages change with each goal scored. However, we shall not consider this but rather use the previous averages for the whole match. Ask the students to calculate probabilities p_1 and p_2 for each team using the data obtained in 33 rounds so as to compare the theoretical calculations with the actual football results in the 34th round of the Bundesliga 1, 2014/15.

10. If, at a particular moment in the match, both teams have together scored n goals, the probability that all of the goals have been scored by the first team is p_1^n , and the probability that all of the goals have been scored by the second team is p_2^n . The probability that the first team has scored k of n goals is $\binom{n}{k} p_1^k p_2^{n-k}$.

11. The probability that the team which scores r goals per match will score n goals in time t (between 0 = start and 1 = end of the match) equals $p = \frac{(rt)^n}{n!} e^{-rt}$.

Ask students to plot the graph of the probability of scoring n (0, 1, 2, 3 or 4) goals during 90 minutes of a football game for each team. Use the data obtained in 33 rounds to compare the theoretical calculations with the actual football results in the 34th round of the Bundesliga 1, 2014/15.

12. Students can also be asked to check the probability of result $n:m$. The theory states that this probability produces the equation

$$p_{n,m} = \frac{(r_1 t)^n (r_2 t)^m}{n! m!} e^{-(r_1+r_2)t}.$$

This equation presumes that the number of goals for each team is independent of each other, which is obviously not true, but it can be used for a first approximation. Students should compare the theoretical calculations with the actual football results in the 34th round of the Bundesliga 1, 2014/15 (FIG. 5).

FIG. 5 Football results of the 34th round of the Bundesliga 1 in the season 2014/15 [3]

Bayern	Mainz	2 : 0
Dortmund	Bremen	3 : 2
Frankfurt	Leverkusen	2 : 1
Hamburger SV	Schalke	2 : 0
Hannover	Freiburg	2 : 1
Hoffenheim	Hertha	2 : 1
Köln	Wolfsburg	2 : 2
Mönchengladbach	Augsburg	1 : 3
Paderborn	Stuttgart	1 : 2

4 | CONCLUSION

Continuous examination and analysis of data sets can most certainly help to predict the results of football games. However, to predict the correct score for certain games, many other parameters, apart from goals, must be taken into consideration (i.e. injuries, players' form, condition of the pitch, weather conditions etc.). If there was a magic formula there would be a lot more betting millionaires. Similarly, the work for odds compilers could be considered more art than science.

However, the aim of this teaching unit has not been to talk about football betting, so let us conclude here.

5 | COOPERATION OPTIONS

Students from different countries can collect the results of all games of their top national football league. They should then calculate the goal statistics (score and conceded) for each team for the whole season, calculate the average number of goals per game in the whole season and calculate the average number of goals per game that each single team scored and conceded.

Finally, they should compare the results of their calculations and analyse their national league. Are all the teams more or less equal, or are there a few very strong teams, a few very weak teams and a larger number of average teams? Maybe students will even discover a third, fourth or fifth option ...

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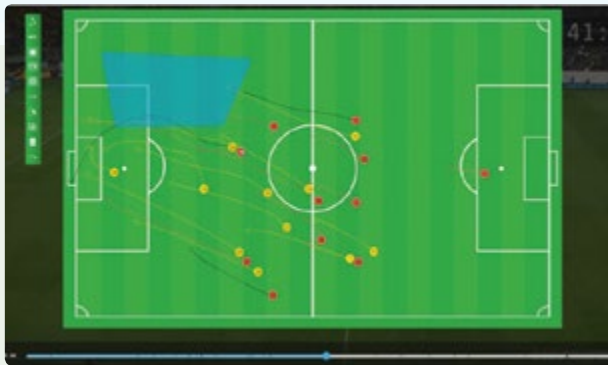
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IT HELPS SCORE GOALS

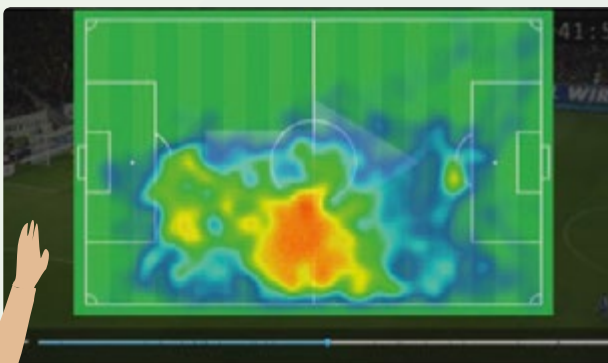
IT has become a crucial tool in football, helping teams train for a game and enabling analysis during half-time. Thanks to the targeted clustering and analysis of big data, coaches can perfectly attune the movements of individual players and the team as a whole to those of the opposition and make these responses automatic. In the case of analytic tools such as *Match Insights*, the focus is on the analysis of video material. During training, sensors attached to the players' bodies provide information not only about their positions and movements but also about their pulse rate. Statistics about individual players and teams make it possible to draw up profiles of their performance and to make comparisons. Coaches use this information to design an ideal training plan and the tactics to use in a forthcoming match.

VIDEO ANALYSIS (MATCH INSIGHTS)



TACTIC BOARDS

These show the players' movement patterns, such as back lines, runs and the distances the players cover. The patterns provide the coach with information, for example in which situations the opposing team changes from man marking to zonal marking in order to gain goal-scoring opportunities.



HEAT MAPS

These map the performance of individual players, showing their movement paths and the area of the pitch they cover. This tells the coach whether they are better in defence or attack. That way the coach can fully exploit his players' potential and assign them suitable roles within the game.

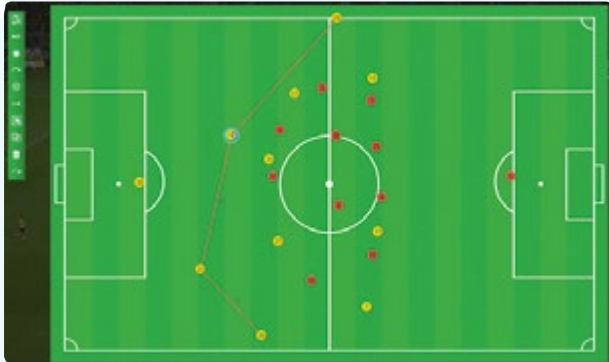


PLAYERS' STATISTICS

A player's performance is recorded throughout the entire game. This provides the coach with information at a glance — for example, shots at the goal, distance covered, number of passes and individual performance in relation to the performance of the team as a whole. The record also indicates the player's risk of injury.

RECOMMENDED USE FOR THE DEPLOYMENT AND TRAINING OF PLAYERS

MOVE ANALYSIS AND TEAM COMPARISON



The coach compares the last ten matches of two teams, for example in actual or potential goal-scoring situations. The comparison might show that the opposing team has a weakness in standard situations or scores most of its goals toward the end of a game. In such a case, the coach can instruct his team to generate standard situations and to slow down the game as it approaches its end.

RECOMMENDED USE FOR TEAM TACTICS

PERCEPTION AND SHOT TECHNIQUE

Major clubs already use IT applications in specialised training sessions.



THE FOOTBONAUT

This is a three-dimensional square, cage-like coaching facility that fires balls at players. It is used to train technique and coordination in first touch, ball control and shot accuracy.

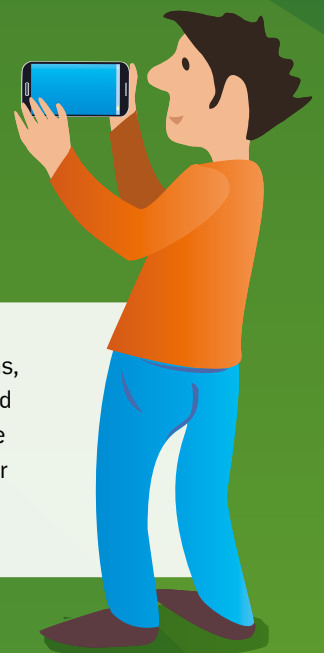
THE HELIX

This is an on-the-pitch simulation tool for mental training to improve a player's understanding of the game at a distance and during fast play.

PERSONALISED BEHAVIOURAL TRAINING



Outside of official training sessions, players also talk with coaches and video analysts in order to improve their performance and prepare for the next game.



FURTHER RESOURCES AND MATERIAL



The authors have created further resources and material for the teaching units. You can find them as free downloads at: www.science-on-stage.de/iStage3_materials

PROJECT EVENTS WITHIN iSTAGE 3 – FOOTBALL IN SCIENCE TEACHING

Brainstorming for topics within the final meeting of the project *iStage 2 – Smartphones in Science Teaching* in Berlin, Germany
 ▼ 5 December 2014

First workshop in Berlin, Germany
 ▼ 24 – 26 April 2015

Presentation of the publication in Brussels at the Representation of the State of Hessen to the European Union
 ▼ 2 June 2016

▲ 3 February 2015
 Coordinators' meeting in Dortmund, Germany

▲ 6 – 8 November 2015
 Second workshop in Berlin, Germany

▲ Follow-ups throughout 2016 and 2017
 Teacher training courses in various European countries

PAIRS CARDS

See teaching unit "Stamping on the Carbon Footprint", p. 12.
 Download at www.science-on-stage.de/iStage3_materials





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FURTHER MATERIAL



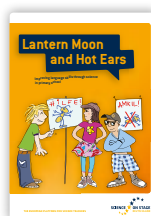
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