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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

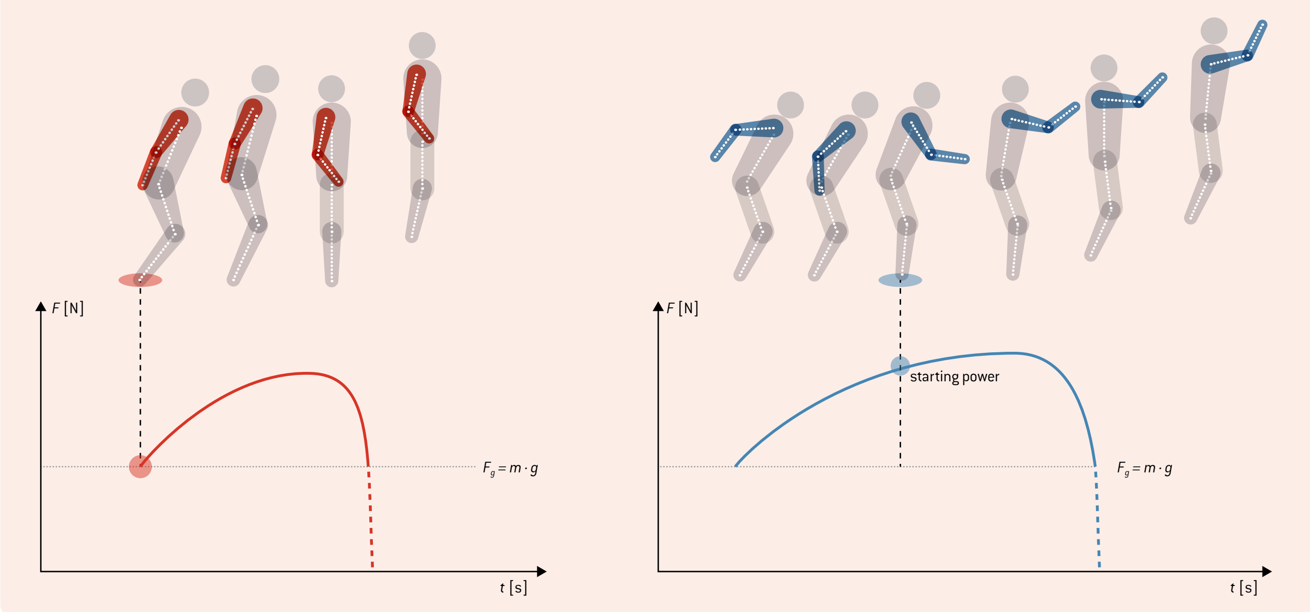
The biomechanical concept of "starting power" explains why you can jump higher if you gain additional momentum by swinging your arms. By measuring and comparing the height of jumps of different kinds (arms close to the body, arms behind the back, swinging arms), the students can investigate the effect 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; $g = 9.81\,\frac{\text{m}}{\text{s}^2}$
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:

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

$\overline{P}$: average power [W]
W: work by the increase of potential energy [J]
m: mass of the jumping student [kg]
g: gravitational acceleration; $g = 9.81 \frac{\text{m}}{\text{s}^2}$
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)

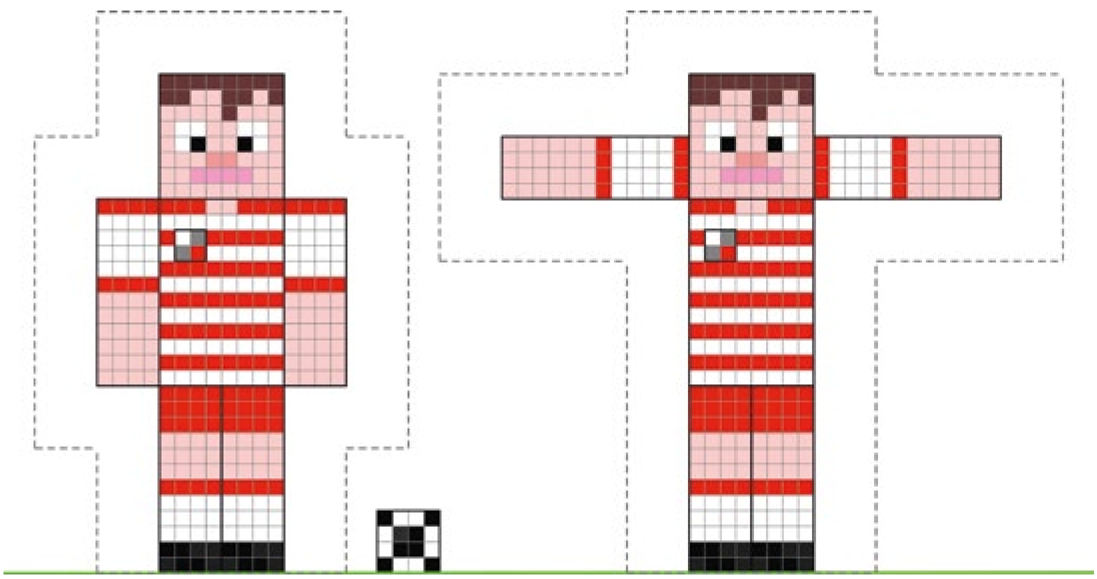
2 | 2 Surface area of the player's body

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.

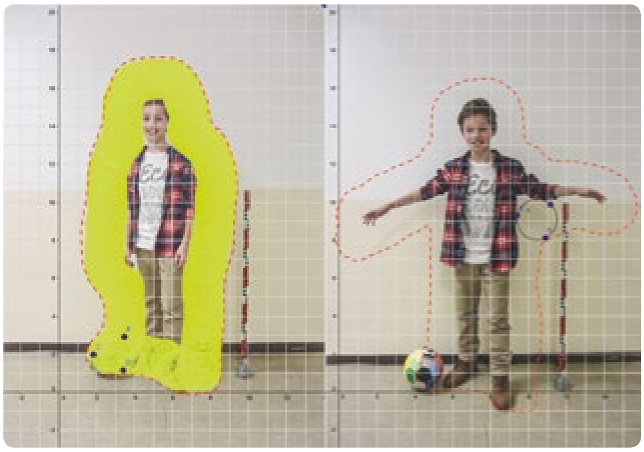


FIG. 4 Estimating the body's surface area with GeoGebra

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

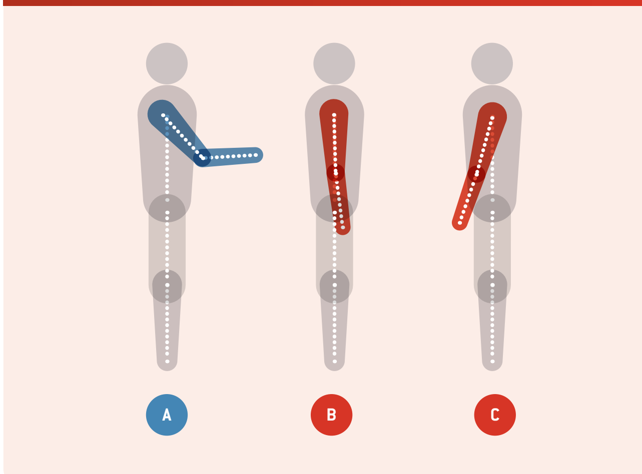
3 | 1 | 1 How to run fast

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.

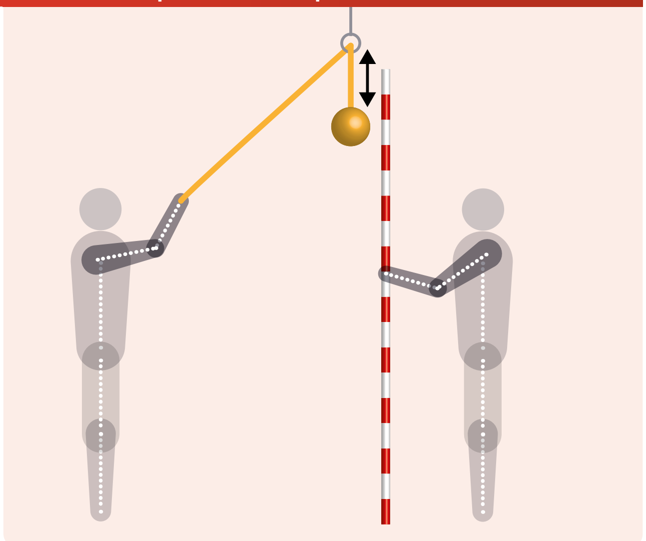
3 | 1 | 2 How to jump high

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])

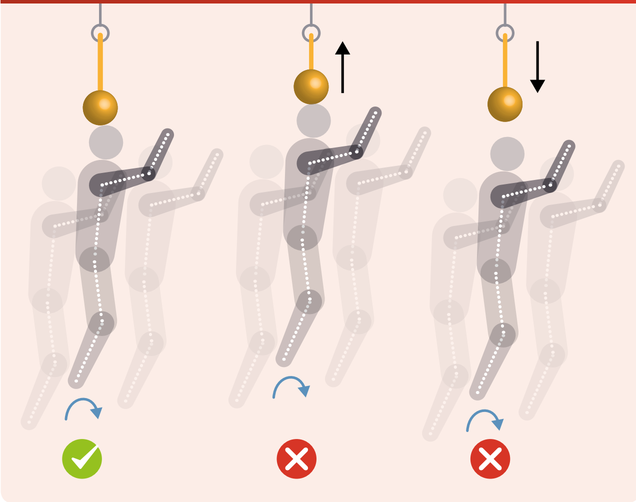
- Build a simple header pendulum (string, soft ball) (see **FIG. 6**). Be sure that you can vary the height of the pendulum easily.

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.
  1. Stand directly under the ball.
  2. Jump and try to hit the ball with your head.
  3. 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.

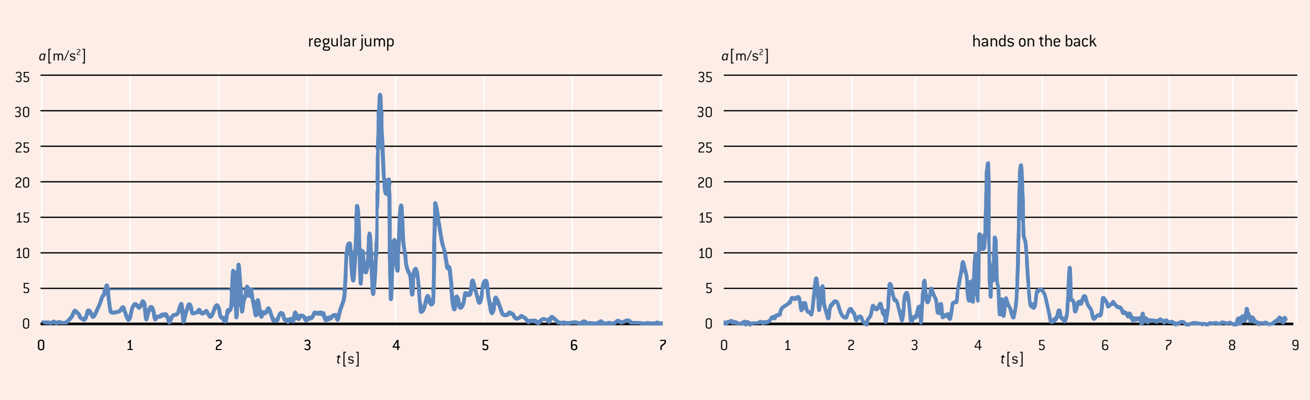
3 | 2 Surface area of the player's body

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 at 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

h [cm]	*t* [s]	*h* [cm]	*t* [s]	*h* [cm]	*t* [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.

REFERENCES

[1] FIFA: Laws of the Game 2015/2016 www.fifa.com/mm/Document/FootballDevelopment/Refereeing/02/36/01/11/LawsofthegamewebEN_Neutral.pdf (p. 121)

[2] Argentina vs. England (1986 FIFA World Cup) https://en.wikipedia.org/wiki/Argentina_v_England_%281986_FIFA_World_Cup%29 (08/03/2016)

[3] 2009 Republic of Ireland vs. France football matches https://en.wikipedia.org/wiki/2009_Republic_of_Ireland_v_France_football_matches (08/03/2016)

[4] Eamon Dunphy: The FIFA payment to the FAI was like something from The Sopranos www.independent.ie/sport/soccer/international-soccer/eamon-dunphy-the-fifa-payment-to-the-fai-was-like-something-from-the-sopranos-31279282.html; published 04/06/2015

[5] Christopher J. Arellano, Rodger Kram: "The metabolic cost of human running: Is swinging the arms worth it?" http://jeb.biologists.org/content/217/14/2456.abstract

[6] At www.science-on-stage.de/iStage3_materials you find some videos for these activities and ways to share your results.

[7] http://minecraft.novaskin.me/

[8] www.geogebra.org

[9] iStage 2 – Smartphones in Science Teaching; www.science-on-stage.de/iStage2_publication_EN

[10] www.physlets.org/tracker

[11] https://play.google.com/store/apps/details?id=com.lul.accelerometer (27/04/2016)

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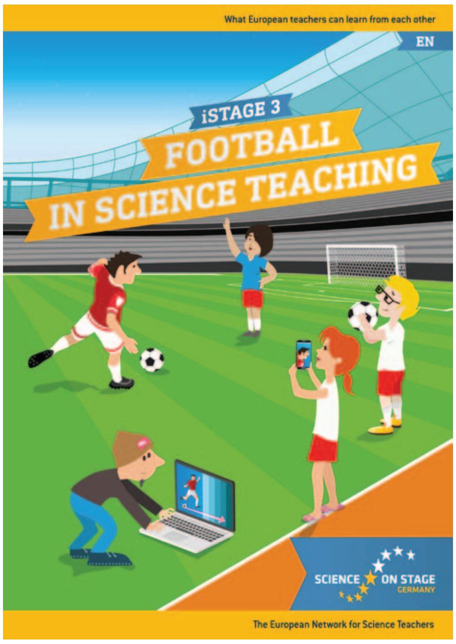

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