Project description for participation in the European Science on Stage festival from 29 June – 2 July 2017 in Debrecen

Colours, light and shadow

Abstract
In this project, students plan and carry out experiments in which they investigate the rules for additive colour mixing and the position of colours on the colour circle, to explain coloured shadows and complementary colours.
One of the goals in the Danish curriculum is to present and use scientific methods, As part of the basic science course, hypotheses must be easy to verify or falsify, using simple and cheap experimental equipment.
The results from the experiments with colours are used to motivate the learning of more difficult subjects in physics and biology, e.g. colour vision, colour blindness, the Bohr model of the atom, photosynthesis.

Involved disciplines
Physics and biology

Age group (of the students)
16-18

Materials used in this project
White and coloured LED-spots (Red, Green, Blue)

What is innovative about your project?

The project is an example of an open problem in which the students have to plan and carry out the experimental study on their own.
Instead of a traditional final written report the students use their gained knowledge to help younger students (14-16 years old), visiting our school in the Science Festival week, to help them make hypotheses and experimental verification or falsification.

Project description

In this project, students plan and carry out experiments in which they investigate the rules for additive colour mixing and the position of colours on the colour circle, to find explanations for coloured shadows and complementary colours.
One of the goals in the Danish curriculum is to present and use scientific methods, This project is part of the basic science course, and therefore hypotheses must be easy to verify or falsify, using simple and cheap experimental equipment.
The results from the experiments with colours are used to motivate the learning of more difficult subjects in physics and biology, e.g. colour vision, colour blindness, the Bohr model of the atom, photosynthesis.
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Content of the course

The course includes several elements central to physics and biology, and methodological elements that are common to biology, physics and the basic science course.
Interdisciplinary dimensions are in focus, and collaboration between biology, physics and the basic science course is supporting the project.
The methodological elements includes data collection and systematisation, processing and interpretation of biological and physical data, controlled experiments, development of hypotheses with the corresponding experiments for verification or falsification, setting up models and experiments, as well as oral communication of results, using relevant scientific concepts.

Subjects in the course

Shadows in white and coloured light

To make the students wonder, they are presented to a dramatic setup of white spotlights, coloured spotlights and a combination of white and green light. Moving in the area between the spots and the background, their shadows make dramatic pictures on the background wall. The white spots give shadows in different shades of grey, the coloured spots give shadows in primary colours or colours produced by additive colour mixing. White and green light produces green and magenta shadows. The effect of the white spots seems quite obvious, the coloured shadows hopefully make them wonder: how does this happen? What makes you see a magenta shadow produced by white and green light?

Additive colour mixing and the colour circle

The students experiment with simple red, green and blue LED-spots, mixing red and green, green and blue, blue and red, to see the colours that appear: yellow, cyan, magenta. Using this knowledge, they can establish a colour circle with 6 colours.
Another way to do the same is to use colour mixing on a computer. When you make drawings you can pick the colour from a palette, or you can choose the mixing of the three components red, green and blue. In this way, it is easy to see, that e.g. magenta is a mixture of red and blue.
Besides this, the students can see that white is a mixture of the three primary colours red, green and blue.

Complementary colours and afterimages

Looking at the colour circle, and knowing the result of the mixing of two primary colours, e.g. red and green is yellow, the students can get the idea of complementary colours. Using their homemade colour circle, they can see that the colour opposite yellow is blue, and blue was the only primary colour not used in yellow. Therefore: blue is the complementary colour to yellow!
Afterimages are seen when you look at a coloured object for a long time, and switch to a white background. As an example: look at the Swiss flag, a red square with a white cross. The afterimage will be a cyan square with a black cross, because cyan is the complementary colour to red, and black is complementary to white.

Colour vision

Colour vision is possible because of the three different types of cone cells in our retina. A specific wavelength is detected because the different cone cells detect different amounts of photons. The cone cells are named L, M and S (for Long, Medium and Short), depending on the wavelength of their peak sensitivity.
How can we see that a lemon is yellow? Because the reflected light from the lemon hits M and L cone cells sensitive to medium and long wavelengths. Our brain understands this information as seeing the colour yellow.
Why do afterimages appear? When you have looked at a coloured object for a long time, e.g. a lemon or a yellow wall, the M and L cone cells "get tired", temporarily losing sensitivity. When you switch to a white background, the S cone cells are (relatively) more sensitive than the M and L cone cells, and therefore the afterimage appears blue. After a while, the M and S cone cells gain their normal sensitivity, which makes the afterimage disappear.

Colour blindness

If your cone cells doesn't respond in "the normal way", your colour vision might be disturbed, giving red-green or other types of colour blindness.
Colour blindness is tested using the famous Ishihara Colour-Blindness Test, using printed books with coloured test plates. Using computers, it is now possible to find the test (or something like it) on the internet. However, the results depend on the quality of your computer monitor, and therefore, the results must be taken with a pinch of salt.

Bohr atomic model, light sources

Continuous spectra are seen from e.g. halogen lamps or white LEDs. Line spectra are seen from lasers and from gas-discharge tubes, e.g. the ones used in neon signs.
The wavelengths in line spectrum of hydrogen can be calculated by rules first derived by Danish physicist Niels Bohr (1913). The agreement between calculated and measured wavelengths is excellent.
The wavelengths can be measured by a very simple technique using cheap rulers and gratings, basically to measure angles and calculate wavelengths.

Photosynthesis

To understand photosynthesis, you have to know that chlorophyll in leaves absorb red and blue light.
The chlorophyll pigments absorb light with wavelengths in the range of 420 - 480 nm (blue light), and light with wavelengths in the range of 610 - 690 nm (red light). The green light (520 - 600 nm) is reflected. This is the main reason for leaves to look green!
It is easy to make controlled experiments using different colours to see the production of CO_2 in the photosynthesis reaction in leaves. All you have to do is to measure the rate of photosynthesis by counting the number of bubbles rising from the cut end of a piece of *Elodea* or *Cabomba*.

Didactic considerations

In contrast to the traditional "cook book experiments" often used in basic science courses, we have found a number of experiments that can be carried out with simple equipment and in a relatively short time.
The introduction is a short presentation of some of the subjects involved, presented without any explanation, hopefully making the students wonder. How did this happen? Can we find an explanation for the phenomenon seen?
After this introduction, the students get the experimental equipment, and try for themselves. They have to plan the experiments, making hypotheses and experimental verification or falsification, a simplified version of Inquiry Based Education. In a way, they are writing their own physics and biology textbook, based on visual observations and controlled experiments.
During the Science Festival week, our students act as coaches for the visiting younger students. Working with another form of communication than the usual presentation/reporting gives them a great opportunity to see, that repeating an explanation (to a new group of visiting students) is a way to learn more for yourself. Trying to help the visiting students to understand makes our students understand even better!

Evaluation

Some of the subjects were known to the visiting younger students, but on a more basic level. Other subjects were new, and here they really needed help to explain their visual observations. Most of visiting younger students said that they had got an increased interest in science and also that the course had been relevant for them.
Our students were satisfied with the different approach, the experimental work in a simple IBSE way, planning and conducting experiments on your own, and the oral communication when helping the visiting younger students. Helping and explaining the same subject six times made some of our students conclude “Helping and explaining was much easier after having tried a couple of times!”

The teachers’ evaluation was positive and we experienced that the students worked well, alone and in groups. This was the case for the initial experimental work, as well as during the final visit. The students participated actively and were committed. Despite the limited number of lessons available the students have learned scientific methods; to formulate hypotheses, design controlled experiments, evaluate the results in relation to the hypotheses, communicate the results verbally by explaining how the experiments are conducted and what the experiments show. It is our impression that altogether the students have come further in understanding the scientific method than they would have in traditional education.