3D-vision lab @ Open Labs Graz, an out-of-school learning environment

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Abstract. Vision and three-dimensional perception have always been an integral part of our everyday life. The commercial availability of 3D-technology makes it easy for everybody to perceive 2D-objects like photos and films three-dimensional. Consequently, 3D-vision is part of most students’ everyday life. As known from the PISA-study, Austrian students have a low value in motivation for science. The topic of 3D-vision is related to human body and therefore, as known from the ROSE study, it should be equally interesting for male and female students. Based on these assumptions, a first version of an out-of-school learning environment at the Open Labs Graz covering the topic of 3D-vision was designed and evaluated with two 11 year classes (n = 32). We found mediocre to rather high values of intrinsic motivation as well as differences between male and female students.

1 Introduction
Usually we perceive our environment three-dimensional, therefore vision and especially stereopsis are an integral part of our everyday life. Notwithstanding, the three-dimensional perception of two-dimensional objects (e.g. photos, videos) enabled via 3D-technology is a fascinating phenomenon. We are surrounded by 3D-technology: 3D-printers are printing different devices of everyday life, 3D-movies can be watched in the cinema or even at home. In the computer gaming world, the terms ‘augmented reality’ and ‘virtual reality’ belong to daily conversation. 3D-technology is taken for granted. Hence, 3D-images are part of students’ everyday life. This fact, as well as the connection to the world of entertainment and multimedia is supposed to make 3D-vision a motivating and stimulating topic for science teaching and learning.

Austrian students showed very low values and a significant gender-gap in the PISA-study concerning their motivation for science [1]. One reason seems to be that instruction does not meet students’ needs and expectations. According to research (e.g. ROSE-study) contexts related to the human body are considered to be of high interest equally for male and female students [2]. Therefore, we think the topic of 3D-vision has the potential to motivate students, generate interest and might counteract low motivation for science.

The aim of the presented project is the development and evaluation of an out-of-school learning environment on 3D-vision for upper secondary level students (aged 15-17) at the Open Labs of the University of Graz to foster students’ motivation for science as well as learning processes in optics. In this paper, we present the first version of the learning environment (chapters 2 and 3). Additionally, results of the accompanying evaluation of the first field implementation with two 11th grade classes are presented, mainly focusing on students’ motivation (chapter 4 and 5). Finally, we describe next steps in the development of our learning environment in the conclusion and outlook section (chapter 6).
2 Subject matter key ideas of the 3D-vision learning environment

Watching 3D-movies or using virtual reality glasses to generate a 3D-perception is currently part of human everyday life. As a result depth perception of two-dimensional objects (e.g. pictures, movies) is ordinary for everyone but techniques and physical concepts behind this process are hardly known. The basic concept behind most of these techniques is mainly the simultaneous generation of two different images on the left and right retina (binocular disparity). Differences of the images are processed in the visual cortex of the brain and binocular fusion leads to a 3D-perception.

Students’ knowledge about human visual perception is a prerequisite for understanding 3D-vision and related processes. First, students need to understand that light must enter their eyes for any visual perception. Second, it is important that light of one object point usually diverges and different light rays of the same object point reach our left and right eye. Third, straight light propagation has to be known as a basic concept behind.

The concept of light separation is crucial for developing a basic understanding of 3D-vision. In order to understand 3D-vision, students have to understand procedures about light separation. Through light separation, two different images are formed on the left and right retina (e.g. anaglyph method, polarization method). This two images are processed in our brain and binocular fusion takes place. Binocular fusion is a process where the two images of the left and right retina are unified into a single perceived image. This process is triggered when a great amount of points of the retinal image of one eye correspond with a big number of image points on the other retina, the so called Panum’s fusional area. Points outside the Panum’s area produce double vision (diplopia).

In physics class, optics and especially the topic of image formation can be challenging for students. Students frequently have difficulties in understanding image formation even at plane mirrors (see e.g. [3–5]). Within the learning environment the students should learn basic ideas about image formation, light and its properties as well as techniques to generate a 3D-perception of a 2D-image.

3 Description of the learning environment

This section provides an overview of the first design of the 3D-vision learning environment and the setting for which it was developed. Main focus of this section is the description of the core of the learning environment – the four quests and the basic ideas behind every quest.

3.1 General conditions of the 3D-vision learning environment

The 3D-vision learning environment is designed for upper secondary level students (grade 10-11) for an out-of-school learning environment – the Open Labs Graz of the University of Graz. The full intervention lasts 3 hours.

The learning environment consists of 3 main stages: An introduction and activation phase to reactivate prior knowledge and introduce main concepts of 3D-vision to the students. Additionally, students investigate phenomena of human binocular vision in simple experiments [6]. In the second stage, the students have to work in groups of 3–4 and complete four quests by following an inquiry based approach. There, the students have to investigate several 3D-vision phenomena. Each quest lasts about 30-35 minutes and is developed around a different facet of 3D-phenomena. Furthermore, the quests follow the bring-your-own-device (BYOD) philosophy and supplementary, aid cards are available for each quest. The idea is to enhance students’ conceptual understanding and digital skills at the same time. After these four quests, the last stage is to clarify unanswered questions and to consolidate the learning goals in a class discussion.

Several contents are addressed in the learning environment in order to foster a better understanding of vision, especially of 3D-vision. In addition to basic knowledge about image formation, real and virtual images and binocular disparity (respectively the generation of two different images on the left and right retina) are addressed. Furthermore, reflection and refraction as well as polarization, light colour and light filter methods are topics in the 3D-vision learning environment.

3.2 The quests of the learning environment

Core of the learning environment are the four quests. These quests follow a phenomenological as well as an inquiry-based approach. As 3D-vision is mainly based on binocular disparity and its processing
in the brain, binocular disparity is emphasized in the quests. Mechanisms like light separation via anaglyph glasses or polarizing glasses as well as enabling binocular fusion of two different images by means of a stereoscope are covered. The mentioned mechanisms result in the simultaneous generation of two slightly different images on the right and left retina. These different images form the basis of binocular disparity and the following processes in our brain. Monocular cues to depth, like motion parallax and accommodation are just mentioned shortly in the introduction but are not part of the learning environment. All in all, the concepts of image formation and disparity form central learning goals.

In the next sections every quest will be described in detail.

3.2.1 **Quest 1 – The Mirascope**

In this quest the students investigate a real 3D-image and its virtual image generated by a device called Mirascope. The Mirascope consists of two identical concave mirrors placed opposite to each other. A hole in the upper mirror allows light passing through. When a three-dimensional object is placed on the surface of the bottom mirror, a 3D-image and a virtual image of this real image are generated in the area of the hole of the upper mirror. This 3D-image resembles a real object (see Figure 1).

An approach to understand the formation of the real 3D-image is to follow the light paths. Several light rays diverge from the object. These light rays are reflected between the two mirrors and intersect above the hole of the upper mirror. So, the reflection mechanisms lead to light beams converging to an image point. After the intersection of the light rays at the image point, the light diverges in different directions and reaches our eyes. So we can perceive a clear image point. Likewise, as the bottom mirror is also mirrored, the real 3D-image of the object is reflected at the 3D-image of the bottom mirror. Hence, we even can perceive a virtual image of the 3D-image. A detailed explanation of the image formation process can be found in [7].

Image formation and the concepts of real and virtual image are focused in this quest. Several structured tasks should lead to a better understanding: First, the students have to make assumptions about the image formation in the Mirascope using laws of reflection. Second, the students have to investigate the types of images they are observing – real and/or virtual. This can be easily achieved with the help of self-luminous objects like LEDs and image points of the real image of the LEDs can be detected on a piece of white paper. This of course does not work for the virtual image. Third, the students have to investigate the image formation process using an applet created with GeoGebra1, a mathematical software. This applet provides an elaborated light ray model of the Mirascope. It helps the students to understand the phenomenon and the reflection mechanisms. Moreover, the students have to verify their own model created in the first step and reconsider their explanations.

Due to the fascinating phenomenon generated by the Mirascope, the first encounter with it and the 3D-images it forms causes usually a wow-effect and raises students’ interest and motivation to investigate the basic ideas and mechanisms behind.

![Figure 1. The Mirascope - Image formation of a small light bulb](https://www.geogebra.org/m/x3R2Ghbk)

1 The used online applet could be found here: [https://www.geogebra.org/m/x3R2Ghbk](https://www.geogebra.org/m/x3R2Ghbk) (November 12, 2018)
3.3 Quest 2 – Smartphone ‘Hologram’

A so called ‘hologram’ generated by a YouTube-video displayed on a smartphone screen and a truncated pyramid of overhead transparency is subject of this quest. The generation of the ‘hologram’ is very easy: First of all, one has to download a special video\(^2\) (available on YouTube) on a smartphone. The video shows four equal images arranged at the edges of a square (see Figure 2). Then a truncated pyramid made out of overhead transparency has to be placed upside down in the centre of the smartphone screen (see Figure 3). Looking through one side of the pyramid results in perceiving a floating object.

Each part of the video is reflected on each side of the pyramid. The reflection causes the impression of a three-dimensional moving object. What we are dealing with is just a reflection phenomenon and therefore, we perceive a virtual image. As the virtual image is generated by the means of reflection, we do not observe a real hologram – based on the principle of interference.

In this quest, the focus lies on the topics reflection and virtual image formation as well as on the clarification of the term hologram. Following these learning goals, first the students have to setup the experiment while tinkering a truncated pyramid and preparing their smartphone. Second, they have to investigate the image and the ‘source’ of the image while covering several areas of the screen with a piece of paper. They discover that just one of the four parts of the video is necessary to perceive the ‘hologram’. Third, the students have to find out which type of image is necessary for this illusion. Since the image just can be perceived when looking through the transparency and cannot be projected on a sheet of paper, it definitely has to be virtual. The name of the used YouTube video in this quest is ‘Hologram Project by Kiste’. So, the students have to find a proper definition for hologram and check whether the observed phenomenon matches this definition. The knowledge gained in the previous activities is essential to solve the final task, to explain the ‘Peppers ghost’ phenomenon used in theatres. The ‘Peppers ghost’ is a created illusion based on a similar effect as at the smartphone ‘hologram’, namely on reflection on a translucent and (for the audience) effectively invisible plate of glass. This causes the impression of a real object (e.g. a ghost) floating in the air.

\[\text{https://www.youtube.com/watch?v=Y60mfBvXCj8} \tag{November 12, 2018}\]
3.4 Quest 3 – Anaglyph method

Two dimensional anaglyph pictures observed through anaglyph glasses result in a visual 3D-perception. Main topic of this quest is 3D-vision caused by the anaglyph method – a light separation method due to different (mostly chromatically opposite) colour filters.

In this quest, first the students have to generate anaglyph pictures which can be observed and investigated with anaglyph glasses. For the generation of the anaglyph picture a smartphone app named ‘Make-it-3D’ is used. A photo of an object must be taken from one point of view and another photo of a slightly different point of view. Afterwards the two photos are overlapped and an anaglyph picture is generated by the app (see Figure 4). Looking at the picture with anaglyph glasses (in this case red-cyan glasses) generates a visual 3D-perception since light separation (based on light colour) takes place. The app creates two slightly shifted images – one of the light of red wavelength and the other one with all detected visible light except the light of red wavelength. Through the red glass just light of red wavelength pass and through the cyan filter light of the wavelength of cyan pass. Hence, two different images occur on the two retina and depth perception is enabled. More about the anaglyph method can be read in [8].

The investigation of light colour mixing and filtering processes is in the centre of this quest. In a first step the students become familiar with the app ‘Make-it 3D’. At the beginning they have to create their own anaglyph pictures. As a next step, the investigation of the generation process of the anaglyph picture has to be done. Therefore, differently coloured sheets of paper are imaged with the app. Left and right image are investigated with the separation function of the app, which allows to widely shift the two images (see Figure 5).

Using different coloured sheets of paper as objects for the generation of an anaglyph picture, the students learn about subtractive colour mixing rules. The investigation of the anaglyph glasses and their function is the last step. The influence of filters on colour perception is analysed. In addition, light separation processes caused by different colour filters are investigated.

![Figure 4. Picture made with the smartphone app 'Make-it 3D'](image1)

![Figure 5. Anaglyph picture of anaglyph glasses - wide shift between the two images](image2)
Figure 6. Double image used for the stereoscope/virtual reality glasses

3.5 Quest 4 – Stereoscopy & Polarizing glasses
This quest addresses two main topics: The functional principle of the stereoscope (or so-called ‘Virtual Reality glasses’) and polarizing glasses used in 3D-cinemas. With the stereoscope two separated side by side pictures are observed through convex lenses which further leads to a 3D-perception. Second topic are polarizing glasses which are currently responsible for most light separation mechanisms in 3D-cinemas which result in binocular disparity and further lead to 3D-perception.

The stereoscope enables binocular fusion of two slightly different side by side pictures (see Figure 6). When observing the two side by side images without any device, the difference between the two perceived images is too high to facilitate binocular fusion. Therefore, the two images have to be merged. This merging process is enabled through converging lenses. The lenses allow a perception of just two slightly different images on the left and right retina within the Panum’s area and binocular fusion is facilitated which leads to depth perception [9, 10].

Polarization is currently the most used concept in 3D-cinemas. Again the basic idea behind this concept is the method of light separation which enables disparity and further depth perception (see anaglyph method). Differently polarized light and polarizing glasses with different polarizing filters generate two different images on each eye’s retina and therefore, depth perception is facilitated.

The key learning goals for this quest are the understanding of the converging process of light by lenses of the stereoscope and the light separation process using polarizing filters.

The investigation of the stereoscope is in the centre of this quest. First, the students have to analyse the side by side images and video clips, which consist of two slightly shifted side by side images. The students are requested to observe the two images very precisely since there are just minor differences (see Figure 6). One huge motivation factor is that they have to watch a YouTube video with the stereoscope and it is up to them to select the video on YouTube on their own. In the next step, the investigation of the stereoscope itself is guided by several questions concerning the sort of lenses used in the stereoscope and the function of the two lenses in terms of 3D-perception. The students have to find out that the use of convex lenses leads to similar images on the retina of each eye and therefore binocular fusion is facilitated.

The investigation of polarizing glasses as used in cinemas is the second part of this quest. Students get polarizing glasses and several polarizing filters as well as a laser pointer. They have to investigate light passing through the filters in several overlapping and rotated positions. The students develop then hypothesis about the generation of 3D-vision caused by polarizing glasses.

To sum up, this quest follows the aim to foster students understanding behind 3D-vision techniques used in everyday life.

4 Evaluation of the 3D-learning environment
This chapter covers the explicit research questions as well as the design of the study.

4.1 Research questions
One main idea of the learning environment is to trigger boys’ and girls’ motivation for science. Additionally, we want to get first hints about students learning achievements and therefore we wanted to know if students’ explanations about 3D-vision differ after the intervention. So, main research questions are:
RQ1) How distinct is students’ intrinsic motivation concerning the 3D-vision learning environment?  
RQ2) How do students explanations of 3D-vision differ at the end of the intervention compared to their explanations at the beginning?

As already mentioned, due to the fact that 3D-vision is related to human body, according to the ROSE-study [2] we assume that 3D-vision is interesting for the students. Consequently, we assume that students’ intrinsic motivation concerning the learning environment is triggered. Furthermore, we expect an improvement of students’ explanations of 3D-vision after the intervention.

4.2 Design of the study
The first version of the learning environment was piloted with two classes of 11th grade (n = 32 (male = 20, female = 12)) at the Open Lab Graz in June 2018. The main focus was put on the investigation of its influence on students’ motivation since as mentioned above, Austrian students’ motivation for science is in general low [1]. Therefore, after the intervention 10 items of the intrinsic motivation inventory [3, 4], adapted to the setting of the learning environment, had to be filled in. A five-part Likert scale was used. In order to get insights into the students’ thoughts about 3D-vision at the beginning and at the end, an open questionnaire was administered. Furthermore, the students were asked to give written feedback on the learning environment for further improvement. This feedback was led by several questions as part of the survey: Their favorite quest, any open questions and what they think they learned within the 3 hours of intervention.

5 Results
In this chapter the results in terms of the intrinsic motivation will be reported as well as students’ explanations of human 3D-vision. Finally, the general student feedback on the learning environment will be described.

5.1 Intrinsic motivation
Addressing RQ1 our results show that the intrinsic motivation of the students concerning the 3D-vision learning environment was mediocre to rather high (μclass1 = 3.54 σ = 0.67 μclass2 = 3.05 σ = 0.62). Figure 7 presents the average intrinsic motivation of each class for each item. The separate analysis of each item shows that the topic of 3D-vision is regarded highly interesting for the students (μclass1 = 3.75 σ = 0.91 μclass2 = 3.92 σ = 1.00) and very exciting (μclass1 = 4.15 σ = 0.81 μclass2 = 4.00 σ = 0.74). The results of the items on the working attitude of the students show low to mediocre values. Lowest values were found for the item ‘I worked until I was satisfied with the results’ (μclass1 = 3.05 σ = 0.95 μclass2 = 2.33 σ = 0.89). One reason for this result may be that students’ feedback showed that the time slots were too short for some quests.

Several differences between the two classes could be found. The total scores of the two classes are not significantly different (t(29) = 2.016, p = 0.053), however, the analysis on item-level showed significant differences for three items (see Table 1). These results hint at different working attitudes in both classes. This goes along with information gathered about the classes in informal conversations with the class teachers. Furthermore, it has to be mentioned that the instruction took place at the end of the school year, where motivation of the students is generally lower. This is especially true for the last week of a semester after the final examinations, when there is no pressure to achieve good grades. Class 2 took part in the 3D-vision lab at exactly this period of the summer semester.

In terms of intrinsic motivation a significant gender difference was detected (t(29) = -2.862, p = .008). Female students showed higher values in intrinsic motivation than their male colleagues (μmale = 3.14 σ = 0.71 μfemale = 3.74 σ = 0.49). By analysing the items separately, three items showed significant differences in gender (see Table 2). The girls were more curious, would more likely do such quests in the Open Lab again and it was more important for them to do well at the quests. Overall, the learning environment seems to be an adequate trigger especially for girls’ motivation in science. On the one hand, these results are especially pleasing as in general Austrian girls show lower motivation for science than boys [1]. On the other hand, our initial assumption – that the biological context of this learning environment stimulates motivation – shows to be right.
Figure 7. Intrinsic motivation of the students after completing the 3D-vision learning environment.

Table 1: Significant differences of the two classes (T-test results)

| Item                                      | μ class1 | σ class1 | μ class2 | σ class2 | t       | df | p     |
|-------------------------------------------|----------|----------|----------|----------|---------|-----|-------|
| I tried to do the quests well.            | 3.45     | 0.945    | 2.67     | 0.985    | 2.236   | 30  | .033  |
| It was important for me to do well at the tasks of the quests. | 3.20     | 1.105    | 2.42     | 0.900    | 2.073   | 30  | .047  |
| I worked until I was satisfied with the results. | 3.05     | 0.945    | 2.33     | 0.888    | 2.124   | 30  | .042  |

Table 2: Significant differences concerning gender (T-test results)

| Item                                      | μ male  | σ male  | μ female | σ female | t       | df | p     |
|-------------------------------------------|---------|---------|----------|----------|---------|-----|-------|
| I was very curious about the results of the tasks. | 2.90    | 1.021   | 3.82     | 0.751    | -2.612  | 29  | .014  |
| I would be willing to do such quests in the Open Lab again. | 3.40    | 1.095   | 4.17     | 0.718    | -2.155  | 30  | .039  |
| It was important for me to do well at the tasks of the quests. | 2.60    | 1.095   | 3.42     | 0.900    | -2.175  | 30  | .038  |

5.2 Students’ explanations of 3D-vision
Addressing RQ2 the students were asked to describe how human 3D-vision works at the beginning and the end of the intervention. A first analysis and comparison of the pre- and post-explanations indicates, that most students’ explanations do not change a lot. At this point it has, however, to be
mentioned that 17 students already used a concept involving two eyes and/or two separate images before the intervention. A closer analysis of the explanations shows improvement in terms of the use of scientific terminology and technical vocabulary was used more frequently in an appropriate way and consequently, the giving explanations were in many cases (10 students) more precise.

Thirteen students have improved their explanations significantly on a subject matter level. Four of these students did not hand in any written explanation at the beginning of the intervention. After the intervention, they were able to explain the concept of vision with the help of the sender-receiver-model, but they were not able to account for 3D-vision. Seven of these 13 students added new correct aspects e.g. two different images on the retina of each eye, or the contribution of the eye muscles to three-dimensional perception.

Six students answered in the post questionnaire that they would not change anything in their initial explanation. For 13 students no improvement could be identified, they used the same or nearly the same phrases for their explanation after the intervention. Additionally, hints for (still existing) misconceptions were found. Although the duration of the intervention in the 3D-vision lab was short the students’ artefacts indicate that intended learning processes could be triggered for most of the students. This goes also along with the students’ self-report. Although the intervention was very short and the average knowledge gain was expected to be medium, the proportion of students who are able to explain 3D-vision in an appropriate way after the intervention could be higher. As mentioned above one reason for this low impact of the intervention on learning gains concerning 3D-vision could be the point in time of the intervention – the last week of the semester where students do not have any pressure concerning their grades.

5.3 Additional feedback of the students
The overall feedback of the students about the intervention was very positive. The students’ favorite quest\(^3\) was Stereoscopy & Polarizing glasses (16 students) followed by the Smartphone ‘Hologram’ (10 students) and the Mirascope (9 students). The Anaglyph Method was just mentioned by one student as favorite quest. According to students’ feedback, they liked the quest about Stereoscopy & Polarizing glasses because they liked using Virtual Reality glasses and they found it funny and interesting. Students who liked the Smartphone ‘Hologram’ and/or the Mirascope mentioned the perceived phenomenon as fascinating and spectacular. These answers go along with our initial assumptions. In terms of the content, it seems that the learning environment left little unanswered questions. 19 students stated that there were no substantial questions left, just three students had further questions. Besides, three students mentioned that they would like to know more about 3D-technique in cinemas.

Within the feedback section of the post-questionnaire we asked the students about their estimated individual knowledge-gain. Thereby, ten students mentioned several correct facts about 3D-vision. Nine students named virtual and/or real images and five students mentioned holograms. In addition, unspecific answers were given by five students, like that they had learned about the topics of the quests and/or something about optics. Just one student wrote that he had learned nothing. All in all, the students’ self-report on their knowledge gain is satisfying.

6 Conclusion & Outlook
Prior research has documented a lack of Austrian students’ motivation for science and a gender gap in disadvantage for the girls. Additionally, it is assumed that contexts related to the human body are equally interesting for male and female students [2]. 3D-vision is an integral part of human perception as well as a current topic in our everyday life. Therefore, we assumed that students’ motivation can be fostered. This paper reports an out-of-school 3D-vision learning environment and its evaluation with two 11\(^{th}\) grade classes. We found out that the students’ intrinsic motivation concerning the 3D-vision lab is mediocre to high which can be seen as a positive result compared to motivation values for physics in general. Low to mediocre values for the item ‘I worked until I was satisfied with the results’

\(^3\) Two students marked two and one student marked three favorite quests.
and students’ feedback indicate that students would have needed more time for some quests. Therefore, the learning environment will be adapted and tasks will be shortened.

Furthermore, significant differences between male and female students were found concerning their intrinsic motivation. Female students hold higher intrinsic motivation as their male colleagues. This results underpin the results of the ROSE-study [2]. So, the 3D-vision lab is obviously able to trigger students’ motivation.

In terms of students’ learning achievements, slight improvements of the students’ explanations on 3D-vision could be identified. However, the students’ explanations on 3D-vision after the intervention still showed room for improvement. This is a hint to deeper investigate students’ learning processes. So, within the next design-cycle emphasis must to be laid on the clarification of students’ learning processes within every quest. The knowledge about aspects which support or hinder students learning processes in the quests is essential to adapt the learning environment and especially the quests in order to enhance students’ conceptual learning processes. Therefore, currently teaching experiments with students are conducted to find out more about students learning processes.

Our results and conclusions are based on a small sample. So, all drawn conclusions are seen as first hints that help to improve the learning environment. Nonetheless, small improvements of students’ explanations concerning the concept of 3D-vision were detected. Furthermore, the 3D-vision learning environment seems to trigger students’ and especially girls’ intrinsic motivation.

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