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Geometrical optics and video calls: A cool path to Physics, CV and ML in high schools

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Summary. — In this article we discuss an experience developed with high school students during Covid-forced distance learning. Students tried to make actual video calls in perfect Star Wars style using phones and 3D-Holo Pyramids. To achieve some results they were forced to rethink Geometrical Optics, Periodic Phenomena and had to understand some basic tools from Computer Vision (CV) and Machine Learning (ML).

1. – Introduction

This work originates from some considerations: high school students learning takes place more effectively when they are engaged [1, 2]; often STEM disciplines (Science, Technology, Engineering and Mathematics) are abandoned or neglected because they are not understood or misjudged as difficult (especially by girls as they get older); in this period of distance learning due to COVID-19 many students show lack of motivation to learn.

We thought that with a proposal of a "cool" project, the subsequent Project-Based Learning would have been successful as a strategy to catch attention and commitment. The results confirm that challenging learning methods as Project-Based Learning improve comprehension and interest.

Ingredients in this educational path are: the building of the simple fake-holo-projector, the comprehension of the Physics underneath, the use of the library of Computer Vision (OpenCV: `https://opencv.org`) with Python computer (`https://python.org`), the didactic use of ML and the way to simplify its comprehension.

Various authors and experiments show how Constructivism is a way to engage high school students in Science [2-4].

Learning by doing accompanies the construction of a personal knowledge framework [1], fostering cognitive engagement with other teaching methods [5].

Technology achievements exponentially grow (see https://www.kurzweilai.net/the-law-of-accelerating-returns) and young people start from their present, not teachers' one, thus we must use up-to-date technology to better engage our students.

Technology and Physics are strictly bonded, present digital technology allows simulations and experiments. One of the teaching strategies to reproduce phenomena (simulate) and to control (measure) them is Physical Computing [6]; it could be thought of as Constructionism [7] that is a natural extension of constructivism and emphasizes the hands-on aspect [7, 8].

We experimented three effective constructivistic learning methods with engagement during past years [9-11]. They are: Problem-Based Learning, Project-Based Learning and Challenge-Based Learning (CBL). In Problem-Based Learning students are individually engaged in studying and trying to solve a problem, they group only if specifically guided. In the case of Project-Based Learning students have to create their knowledge artifact to reach their purpose and moreover they try to work together to improve their performance regarding quality and time spent. Challenge-Based Learning introduces challenging elements highly effective in enhancing learning will for students such as challenges between groups, and/or time defined-goals, like Hackathons.

In this article we discuss an example of Project-Based Learning.

2. – Methods: A Project-Based Learning

One of the five key features of Project-Based learning environments is their start with a *driving question*, that is a problem to be solved [1, 5].

We proposed this educational path to a group of students of 3rd class in an Italian High School. The idea about the problem to be solved (chosen by the group) was driven by the pandemic context with videocalls: improving experience in both privacy and interaction. So the driving question was: *Is it possible to create a Holographic Video Call experience for real?*

The analysis was: deceiving eye and mind is easy with simple optics, creating "fake holograms" is simple using real images generated by reflection (*e.g.*, with the illusion technique known as *Pepper's ghost* https://www.instructables.com/DIY-Pyramid-Hologram/), videocall in realtime is everyday experience and algorythms and software for single-person background subtraction already exist.

Geometrical optics and Holograms: Studying the HoloPyramid. – First of all every student built a 3D-Pyramid (truncated square pyramid) with plexiglass. Every face of the pyramid is positioned in such a way that the observer's eye sees reflections inside the pyramid itself (with the correct angle). The size of the pyramid had to be calculated to reflect images from mobile-phone or tablet screen.

Points of view and Periodic Phenomena: Analysing correct projections. – The second step was thinking that each face should show a different point of view creating as example a video with all the four points of view as in fig. 1. The simplest idea was to use a "periodic" video such as a rotating object around a main axis.

Background subtraction: Computer Vision, Machine Learning with Python and BodyPix. – The third element of the learning path was the use of up-to-date technology to achieve the expected behaviour of the "product". The scheme of the data workflow was built with the teacher, using every piece as a black-box and then investigating its actual meaning and behaviour (actual workflow used: fig. 2).

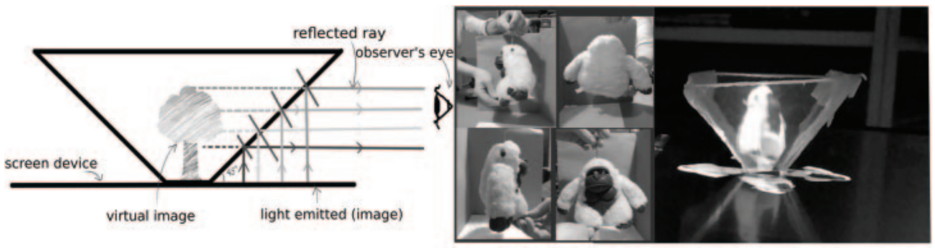

Fig. 1. – Reflection in a pyramid drawn by a student, projections, result.

Elements needed were: simple Python programs using specific Computer Vision library; choosing or not standard background subtraction algorithms in OpenCV; understanding fake webcam interface, using Machine Learning BodyPix library as effective solution in eliminating background.

3. – Results and discussion

In a Project-Based Learning the result is successful whether the project has reached an end or not. If the artifact answers the driving question according to the objective then the project has reached its goal. This fact implies the learning path has been successful.

The distance working caused less responsibility in performing personal tasks, the continuous reorganization and uncertainty caused a delay of one month (in five months).

Students did not make any effort in using their acquired theoretical knowledge in optics, they preferred to "understand" what the phenomenon was and to rebuild knowledge from scratch. Their theoretical scaffolding anyway was built immediately and revisited after practical-working activities.

Personal engagement and interest towards STEM disciplines in our students was improved and is still growing. Students recognized "weirdness" of real images produced, not holographic as they expected because they are not stereoscopic. They found the simple quarter-period phase difference between views, then they simulated the correct behaviour both by creating images and videos (like the gorilla puppet in fig. 1), and found out that not-ML-background-subtraction algorithms created artifacts which appeared as in fig. 2 (not-ML algorithms used: Gaussian Mixture-based Background/Foreground Segmentation: MOG, MOG2, GMG with Bayesian or k-nearest-neighbourhood: KNN).

They understood that ML [12, 13] is composed by training a neural network that produces a model, and the use of this model to detect something. (Model used:

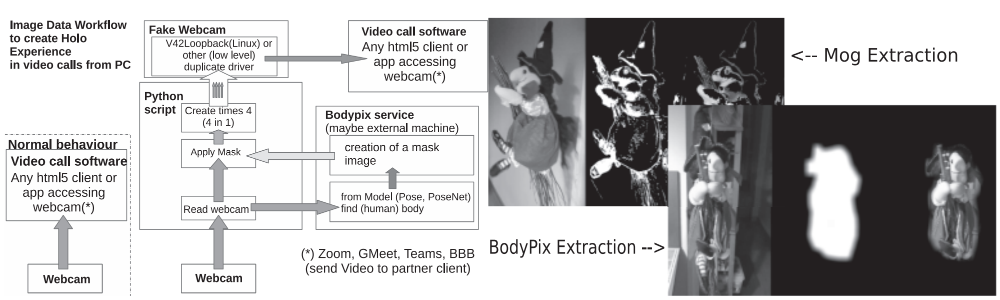

Fig. 2. – The workflow of data processing, differences in extraction results.

Bodypix, `https://blog.tensorflow.org/2019/11/updated-bodypix-2.html`), model library built on Tensorflow.js (`https://tensorflow.org`) NN-library by Google (see fig. 2).

4. – Conclusions

The use of technology is not an innovation so far. Project-Based Learning confirms its appealing and committing role to students.

We still think that innovation in learning paths must be coherent with contemporary *new* technologies and that Physical Computing is a “game changer” [6]. Since we use modern microprocessors in the learning paths for experiments, students are more engaged.

Future developments, in “Problem- or Project-Based Science (PBS) Learning” [5], are projects involving Physical Computing (simulation and experiments) again, using CV, ML and probably TinyML (Tiny Machine Learning, the use of the small devices with ML capability) without hiding their complexity.

These projects should be decided with students, they are the real engine of innovation and future.

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