Evaluating Stars Temperature Through the B-V Index Using a Virtual Real Experiment from Distance: A Case Scenario for Secondary Education.

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Abstract—In this paper we propose a scenario for secondary education at which students could estimate the temperature, the radius and the age of stars. To achieve this, we built a virtual real experiment which can be performed from distance on any portable device. Students can connect to a webpage and choose a star from a list. After applying B and V filters they obtain the B and V magnitude. Consequently, they calculate the B-V index of a star and using a simple formula they estimate the star's surface temperature. Furthermore, guided through a worksheet and with the use of Hertzsprung–Russell diagram they can estimate the radius and the age of the star.

Keywords—remote virtual experiments, astronomy, remote experiments, star surface temperature

1 Introduction

1.1 Astronomy in Education

Astronomy is a very interesting scientific subject and many students are highly motivated to study it. Studying the literature on astronomy education we found that most studies have been focused on Earth, day/night cycle, Earth-Sun-Moon system, seasons and Moon phases [1], [2] while fewer studies were referring to stars. More specifically, the great majority of studies which are focused on stars deal with the motion, the position and the origin of stars' light [3]-[6]. Furthermore, there are very few studies to approach stars temperature in secondary (or elementary) education. Beare [7] while analyzing the "The Faulkes Telescope Project" mentioned that a task for younger students is to "*identify hot young blue stars*" [3, p.6] and Agan [8, p.90] among other questions asks: "How do stars differ from one another?", providing as an answer the surface temperature.

Furthermore, exoplanets and their suns are issues that come up frequently on the web and the news [9]. What matters in these discussions, among other things, is the temperature of the parent star that the exoplanet is orbiting. The temperature of the

star and the exoplanet's orbit radius play an important role in determining what is called the habitable zone a notion which is at the center of discussions.

As a result we would like to introduce an educational approach which has to do with stars and more specific with their surface temperature, size and lifetime, a subject which has not been introduced as much as other astronomical issues in secondary education. To do so we utilize the internet and streaming video to control a distant virtual-real experiment. The analysis of data from the virtual-real experiment leads to the estimation of important star parameters. While all this enables the students to study some very crucial aspects of stars, in the same time introduces them to the actual workings of astronomers, and enhances many valuable competences for their future as active and knowledgeable citizens.

1.2 Star Spectrum

Star spectrum is what we obtain after passing star light through a prism. This is a way to demonstrate to students how a spectrum could be obtained and historically it was the method to find the spectrum of light sources.

In other words spectrum is all the frequencies (visible light) that a star emits. Astronomers, use the spectrum to obtain important information about stars, such as the temperature and the elements in star`s atmosphere. In figure 1 we see stellar spectra from stars with different surface temperatures. Two fast conclusions can be extracted from the spectra. Firstly, there are several black lines which are called absorption lines and are directly connected with elements that exist in a star's atmosphere. Secondly, the intensity is not evenly distributed among colors. For example the O type stars (which are the hottest) have a spectrum which has more intensity at the blue – violet region, while the M type stars (cold stars) have more intensity at the red – orange region.
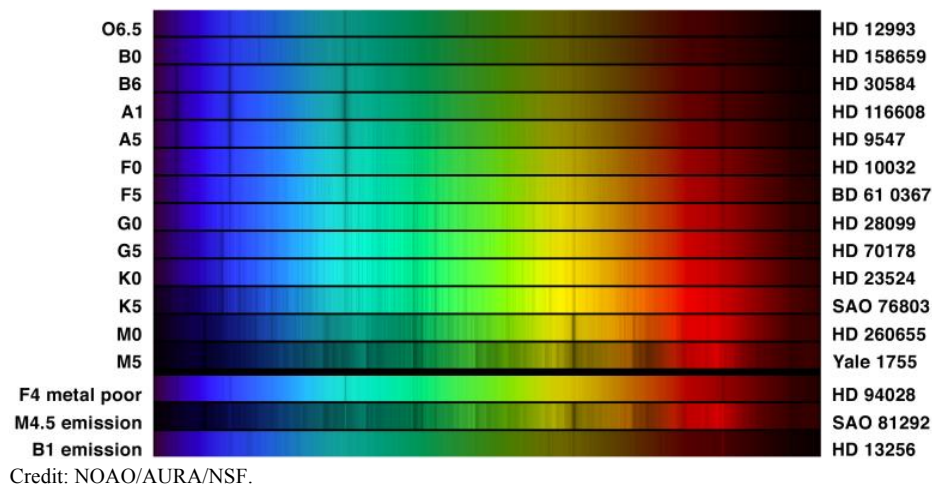

Credit: NOAO/AURA/NSF.

Fig. 1. Star spectral categories arranged in descending temperature going down.

1.3   Spectrograph

Researchers in their effort to obtain a spectrum use spectrographs, apparatuses which analyze the light into different wavelength components. Modern spectrographs utilize diffraction gratings, which provide higher detail of the spectrum (resolution).

Kaler [10] diagrammed the key components of a modern slit spectrograph (figure 2). As we can see several stages are required. Initially light from an object enters the telescope. On the focal plane of the telescope we place a slit so to turn the source into a point source. Then with the help of a collimating mirror light beams are made parallel. The parallel beam is then leaded to a diffraction grating and is analyzed to different wavelengths. Furthermore, light is captured by a detector (or CCD camera), through a mirror. The detector is connected to a computer which records the received data. By rotating the diffraction grating the intensity at different wavelengths can be determined. One must not neglect the importance of a reference arc lamp, which provides known wavelengths and thus known spectral lines that are essential in calibrating the spectrometer.

As it becomes obvious from figure 2 the whole process demands a rather sophisticated apparatus which is not available at school's science laboratory. Apart from the need of a spectrograph, one should possess also a telescope to collect start light.

Besides the two pre-mentioned obstacles there are several other issues such as

- possible damage of the equipment if not handled with care, an aspect of hands on experiments which raises the cost
- experienced stuff is needed to set up all the apparatuses, i.e. calibrate the spectrometer, use a comparison lamp of known spectra lines and perform the measurements
- stuff to maintain the experimental equipment
- space to settle all the apparatuses
- star observation takes place at night when schools are closed, the exception is the study of our own star, the sun.
- students with disabilities may be excluded

All the above reasons make it difficult for a secondary student to perform such an experiment in a hands on approach.

But even if we consider that all the apparatuses were available the only thing a student would do is wait for the computer to obtain the pertinent data, and afterwards he/she to proceed to the mathematical procedure leading to the surface temperature estimation. It is very common nowadays that several hands-on experiments are mediated through computers [11]-[13].
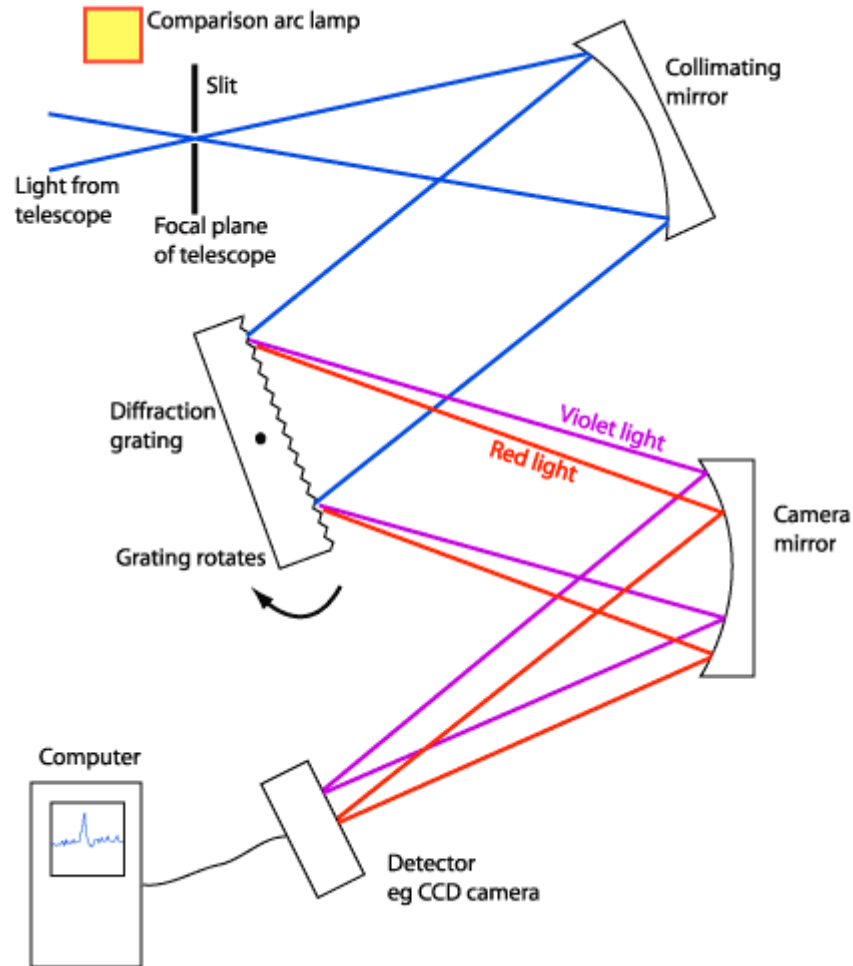
Fig. 2. Key components of a modern diffraction grating spectrograph.

2 Scientific approaches to estimate stars surface temperature

2.1 Finding the Surface Temperature from the Spectrum of a star

This method is based on the assumption that stars are blackbodies, which is quite reasonable. One feature of the blackbody radiation is that the spectral intensity peaks at a particular wavelength ($\lambda_{\max}$). Afterwards, using the Wien's displacement law (equation 1),

$$\lambda = \frac{b}{T} \tag{1}$$

one could come up with the star's surface temperature.

2.2   Finding the B-V index of a star

Another way to estimate the surface temperature of a star is by using filters. More specifically, in 1953 Johnson and Morgan [14] introduced a system of filters U (Ultraviolet, 364nm), B (Blue, 442nm) and V (Visible, 540nm) called the UBV photometric system. Letting the light of a star to pass through a filter we measure the flux of the passing light and we come up with three numbers F_U, F_B and F_V which correspond to the measured fluxes. By having the fluxes for Blue and Visual Filter we can calculate the B-V index using the equation 2:

$$B - V = -2,5\log(\frac{F_B}{F_V}) \tag{2}$$

As many researchers showed [15]-[17] there is a relation between the B-V index and the surface temperature of a star.

Furthermore, Ballesteros [18], provided a formula by which someone can estimate the surface temperature using flux data from any two filters of different wavelengths. But since the most common photometric system is the UBV photometric system, Ballesteros provided as an example a simple equation (3) from which someone can estimate a star's surface temperature by using the B-V index.

$$T = 4600(\frac{1}{0,92(B-V)+1,7} + \frac{1}{0,92(B-V)+0,62}) \tag{3}$$

3   Remote Experiments

Nowadays, there are three ways of conducting an experiment.

- Hands – on experiment
- Simulation
- Remote experiment

Hands-on experiments are real experiments with real laboratory equipment. The students have the opportunity to feel, hear, touch, and "play" with the apparatus. This is not true when the discussion refers to simulations. Software could represent reality in a very convincing way providing the observation of phenomena in high fidelity. Even though at simulations things are not real their educational value is unquestionable [19]-[21].

As computers and internet evolved a new way of experimentation was introduced, i.e. the remote experiments. Remote experiments are a type of laboratory activity which in a sense bridge the hands-on and simulation experimentation modes. More specifically, remotes use real equipment (just like hands-on) which are controlled through a computer (just like simulations or some hands-on experiments which are mediated through computers, as we have already stated).

Remote experiments are defined as real experiments involving real experimental instruments that can be controlled by a user through the internet. Therefore it becomes obvious that the user and the experimental setup do not share the same space [22]-[25]. The main idea of remote experiments is summarized in figure 3. A user through his/her personal computer, tablet or smart phone connects to a Server. Furthermore, the server communicates with a computer which sends data to the experimental set up. In our case the experimental set up is controlled by an Arduino.
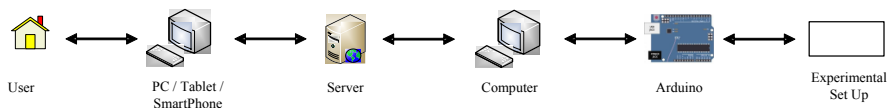

| User | PC / Tablet / SmartPhone | Server | Computer | Arduino | Experimental Set Up |

Fig. 3. The main idea of remote experiments (and virtual remote experiments)

Remote experiments have several advantages such as:

- Accessible 24/7
- Accessible for students with disabilities
- Low cost
- Enhance University – University and University – K-12 collaboration
- No risk of damaging the experimental equipment

Cost problems of a real laboratory setup are analyzed in [26]-[33] by getting data from several institutes. These studies mention the following aspects contributing to the total cost: the cost of laboratory establishment, maintenance of apparatuses and building problems.

On the other hand, the accessibility in hands-on experiments of students with different forms of disabilities is approached in [34]-[41].

Time restrictions are an issue in science teaching as well. As Faltin [29] mentioned, working students cannot attend laboratory courses since when the institute`s laboratory classrooms are available they may be at work. There must be an alternative way for those students to accomplish their lab work. That is possible through remote experiments which are available 24/7 thus giving students the opportunity to schedule their distant activity in sciences. Moreover, Lowe [33],[42] discussed matters related to the time restrictions inside the classroom when a laboratory exercise is being carried out.

4   Virtual Remote Experiment (VRE)

Establishing a remote experiment has many obstacles and limitations. One major limitation derives from the fact that remote experiments should use some real equipment, which in some cases, are unavailable or expensive.

One then faces a dilemma: Either to design a simulation experiment or to construct a remote experiment with real equipment which emulates some of the unavailable equipment. For the latter case we coin the term Virtual Remote Experiment (VRE).

Keeping in mind that students get more excited when they manipulate a real experimental set-up from a distance than a simulation [35], the purpose of the present work is to perform an essential astronomical procedure through a virtual remote experiment. As an example we choose the estimation of the stars' surface temperature. This VRE will enable the introduction of a key procedure of observational astronomy to students.

In our case, it is rather difficult to get access to equipment as described above (telescope, fluxes meter, slit spectrograph etc). Therefore, we decided to emulate all the above apparatuses with simpler but real equipment, which suit nicely educational purposes.

One possible choice is the use of a RGB LED. This versatile and inexpensive device has four terminals and comprises of three light emitting diodes. One terminal is used as a common connection to the three l diodes and the other three to supply current to each individual diode. By adjusting the current flow on can control the intensity of one of the three available colors (red, green and blue). Therefore, the intensity and color of the light produced by mixing the three colors can be chosen. This process is how a pixel in a LED screen works. The RGB LED is controlled using the PWM pins of Arduino. The above arrangement can help us emulate color and intensity of light coming from a star as could be seen through the telescope eyepiece lens. Also, we can emulate the effect of a filter by appropriately changing color and intensity. All in all, the combination of the RGB LED and Arduino can emulate the telescope and the filters.

At this point we must stress that this experiment even if it was a hands-on it would have been mediated through a computer and the images from the stars would be taken by a camera.

Introducing our VRE based scenario students get the excitement of manipulating a real telescope and filters. This immersion enhances students' attitudes towards astronomy and science in general. As Hanson stated [25, p.333], "…depending on the cognitive nature of the experiment, the degree of psychological immersion is not necessarily greater in either remote or hands-on labs…", which means that what it does matter is students' belief as it concerns the fidelity of the experiment. In the same vain Sheridan, [43] proposed that fidelity of display can enhance the sense of presence. Also, Slater and Wilbur [44] identify correlation between immersion and fidelity of a modality.

5   Software and hardware setup of a (virtual) remote experiment

5.1   Software

During the process of designing the software architecture of the VRE learning environment, we developed a website which contains

- A Home page (figure 5) that introduces users to the concept
- A star selection page (figure 6) to start the VRE (figure 7)
- A worksheet example (Appendix)
- General information and facts about each star and other info and simulation that could help users understand scientific terms of this field (such as color temperature etc.).
- A Hertzsprung–Russell diagram that users can use when conducting the experiment

To develop the above, and embed the VRE to the website, a Model View Controller (MVC) structure were needed. We used HTML, PHP, CSS and Javascript (JQuery). To connect user's actions through the website with Arduino's acts, C++ coding was necessary. And finally, to encode the Arduino itself, an Arduino code was also developed. The architecture is shown in figure 4.
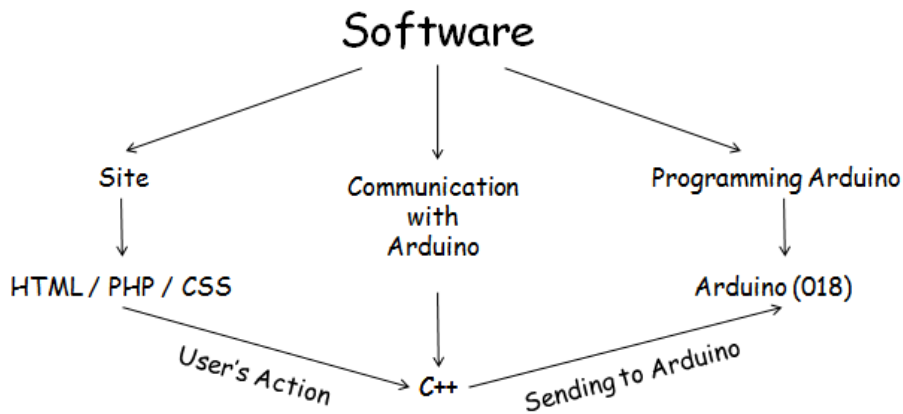

Fig. 4. Architecture of software set up.

5.2   Stars Selection Page

The present realization of the VRE proposes to the user to estimate the surface temperature of five stars which. These are

- Sirius
- Canopus

- Arcturus
- Rigil (Alpha Centauri A)
- Vega

These stars are the five brightest stars in the northern sky (although Rigil is a system of two stars consisting of Alpha Centauri A and B.)

The user can choose a star of his/her preference to perform the experiment from the corresponding page (figure 6).
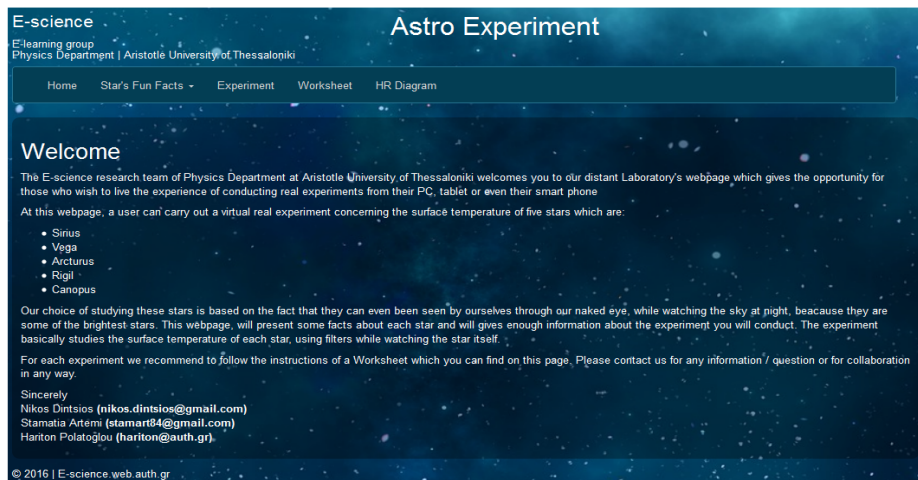

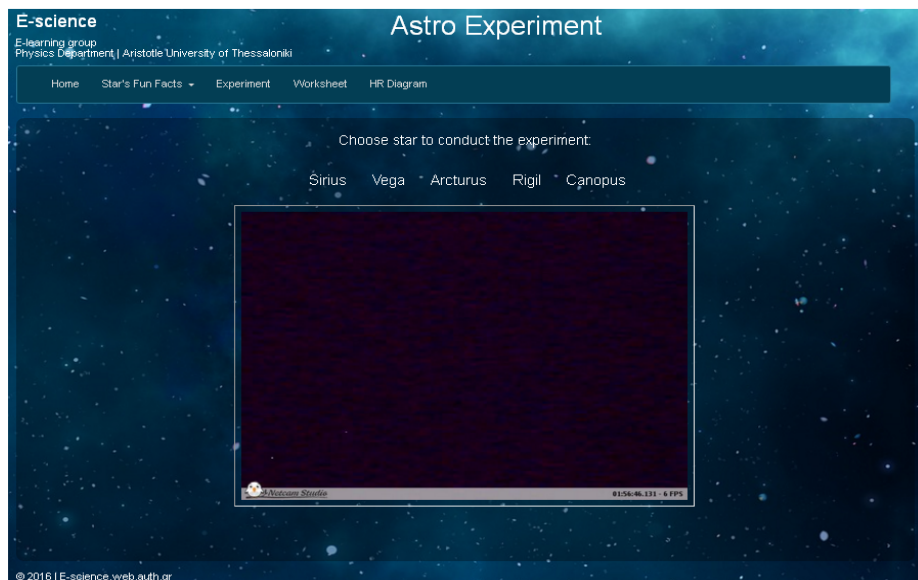**Fig. 5.** Home page of Astro Experiment.

Fig. 6. Star selection page of Astro Experiment.

5.3 Hardware

For constructing the specific experiment, we used a 10mm diffused RGB LED, an Arduino (Duemilanove), and a USB camera. A small box made of 10mm white mount board hosts the camera and the RGB LED. The wiring between LED and Arduino is shown at figure 7a, while at figure 7b someone can have a schematic view of the whole set up. One can notice the connection of three PWM pins to the RGB LED. All the above experimental equipment is located at Aristotle University of Thessaloniki.
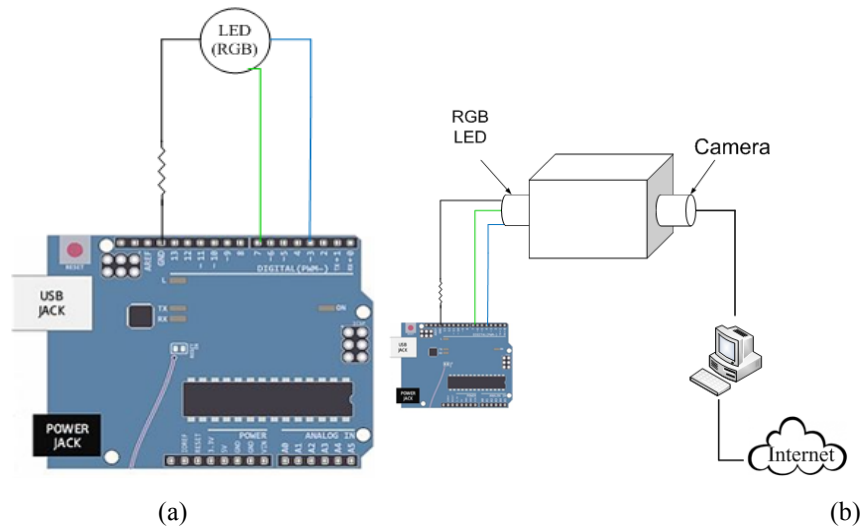
(a) (b)

Fig. 7. (a) LED and Arduino wiring, (b) The whole set up.

6 Scenario

The basic idea of our scenario is that students are looking through a telescope and observe the image after the application of a filter, either the Blue or the Visual. Furthermore, a special virtual instrument is measuring the light flux which passes through the filters, providing the B and V magnitudes (figure 8).

After subtracting V(magnitude) from B(magnitude) students come up with the B-V index and using equation 3 they estimate the star's surface temperature. From a H-R diagram they can also estimate the size, mass and lifetime of the star.

Summarizing the steps of our scenario

- Apply blue (and visual) filter
- "Look" through the telescope the light which passes through the filter
- Receive the B (and V) magnitude (from the flux meter equipment)
- Subtract and apply equation 3 to estimate star's surface temperature
- Place the star on the H-R diagram
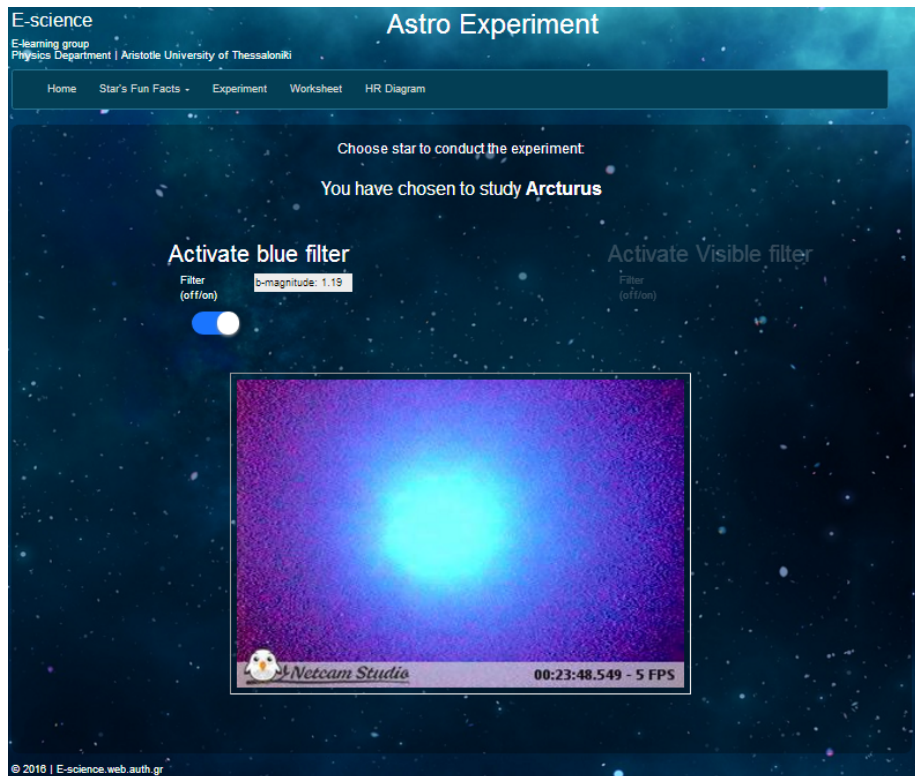- Estimate star's size, mass and lifetime

Fig. 8. Image after having applied the Blue filter.

The VRE can be conducted in two discrete ways: Firstly, as a demonstration experiment which will be performed, during a lesson, and secondly, the teacher can ask from his/her students to perform the lab exercise as homework (either every student on his/her own, or forming small groups of 2-3 students and work as a team). Our educational proposal includes a worksheet as a guide to the experiment, and provides feedback and assessment.

6.1 The VRE as demonstration experiment

Initially the teacher could ask the students to form small groups consisting of two-three persons and seat in front of a computer. Then, the teacher could provide each team with the worksheet and connects to the internet in order to perform the experiment, while all the students will watch the process through a video projector or their computers and fill in the worksheet paper.

Finally, the teacher could ask the students to estimate the surface temperature, size, mass and lifetime of another available star as homework, providing them the corresponding worksheets.

6.2 The VRE as homework

All remote experiments have a restriction. Only one user (or one team of users) can manipulate the apparatuses at a specific time window. This disadvantage is not very restrictive if we consider that a remote experiment is available 24/7 which means that a remote experiment is available even when the school laboratory is closed or even when school is closed. Taking under consideration this fact it is possible to perform these kinds of experiments (remotes or virtual remotes) even at weekends.

As homework, each student (or team) must complete a worksheet. After the homework is completed the worksheet must be returned to the teacher.

The benefits of giving the students the task to perform a remote experiment as homework from their own computers or mobile device (either as individual or as team), concern not only the field of astronomy but also key competences which every citizen of the 21st century should have.

Skills and competencies concerning remote experiments are addressed by Corter et al., [12]. The key competences as they are proposed from the European Parliament and of the Council of 18 December 2006 can be summarized in eight categories [45].

- Communication in the mother tongue;
- Communication in foreign languages;
- Mathematical competence and basic competences in science and technology;
- Digital competence;
- Learning to learn;
- Social and civic competences;
- Sense of initiative and entrepreneurship; and
- Cultural awareness and expression.

Performing a remote experiment (as a homework, either alone or as a team) meets the great majority of key competences mentioned above. Mathematical competence and basic competences in science and technology are fulfilled through remote experiments as well as digital competences. The latter refer to the use of Information Society Technology IST which is supported by the Information and Communications Technologies (ICT). The former, is fulfilled since basic mathematical processing is required and the use of experimental equipment such as "telescope" and "flux meter" or filters of different colors and camera, which are a part of the laboratory course.

Another aspect of key competences relates to the ability to manage his/her own learning, manage his/her time, decide what he/she wants to learn and to include all this effort to his/her pace. Along with the above one would ask him/herself several times how to proceed to complete the remote activity and he/she would ultimately make decisions, take risks and continue with the homework. All the skills described above, comprise the Learning how to Learn and the Sense of initiative and entrepreneurship competences.

After having performed the specific experiment (or another remote experiment) the student must return a lab report which in several cases he/she will present it in front of an audience, an effort which enhances a number of key competencies such as, communication in mother tongue and in foreign languages, sense of initiative and entre-

preneurship, development of social skills, plan and organize tasks and support personal plans.

7   Conclusion – discussion

Remote experiments are relatively new, powerful instruction tool for all educational levels. As every method of experimentation has its restrictions, remote experiments have their own restrictions. To overcome some of the obstacles that appear in designing a remote experiment, we introduced the "Virtual Remote Experiment" (VRE). VRE combine the setup of a remote experiment and real manipulation of instruments. What is missing are some unavailable or expensive equipment or cases where the real experiment can be performed at specific times. Those equipment are emulated through some simpler devices. In the present educational proposal, special effort is placed in developing a VRE that reflects as close as possible the real experiment. Since, the present VRE, has been utilized as a demonstration and as a homework by a small number of grade 9 students, reliable data (results) concerning its utility are yet unavailable. As a first impression, VRE seems to gain the acceptance of the Greek secondary education students, who felt enthusiastic controlling remotely a telescope. We strongly believe that we will face the same enthusiasm during the present school year when we include the present VRE in the curriculum of several Greek schools of secondary education.

Analogues efforts could provide solution to some other remote experiments in subject areas like particle physics, chemistry, geology and biology. The neutralization reaction of acid-base is a nice example as it is a straight forward process for a hands on laboratory session but very difficult to realize as a remote experiment. It would require for each repetition some elaborate mechanisms for removing the reaction products and replacing the reactants. Application of similar approaches to other disciplines or subjects and the consequent analysis of the results will prove the utility of the VREs.

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10 Appendix

Estimating Star's Surface Temperature
WORKSHEET

GOALS

- To estimate the surface temperature of several stars.
- To get familiar with filters
- To get familiar with the H-R diagram
- To identify the lifetime, the radius and the mass of a star through the H-R diagram
- To identify the lifetime, the radius and the surface temperature of the Sun

REMOTE ACTIVITY

- Connect with the site: http://e-science.web.auth.gr/astro
- Click on the tab "Experiment"
- Choose a star (e.g. Sirius)
- Activate the Blue and Visual filter and fill in Matrix I

Matrix I

STAR:			
Filter	*Color you see*	*Take down the values of magnitudes*	*Subtract V from B (B-V index)*
Blue		B Magnitude =	B-V index =
Visual		V Magnitude =	

DATA ANALYSIS
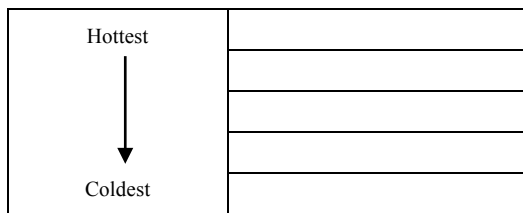
- Use the formula to estimate the surface temperature of the star that you have chosen

$$T = 4600(\frac{1}{0,92(B-V)+1,7} + \frac{1}{0,92(B-V)+0,62})$$

Matrix II

STAR:		
B, V magnitudes *(Matrix I)*	*B-V index* *(Matrix I)*	*Estimate Surface Temperature* *(Using the formula above)*
B Magnitude =	B-V index =	T =
V Magnitude =		

- Follow the same procedure for the other stars
- Classify the stars of the experiment from the hottest to the coldest

Hottest	
↓	
Coldest	

- Look at the H-R diagram (on http://e-science.web.auth.gr/astro) and estimate the lifetime the radius and the mass of the star(s).

THINK

a) When we use a red filter what color do we see behind the filter
- i   anything but red
- ii   red
- iii blue
- iv   none of the above

b) Looking at the H-R diagram the surface temperature of the hottest stars   on the diagram lies between (in Kelvin)
- i   1000 – 10000
- ii   10000 – 100000
- iii 100000 – 1000000

c) Which of the following categories would you classify Sun into?
- i   very hot and very big star
- ii   very small and relatively cold star
- iii a medium size star with an average surface temperature

d) Can you find the lifetime, the radius and the mass of
- i   iSpica
- ii   Procyon