DISCUSSION OF PV LAB EQUIPMENT AND PHOTOVOLTAIC SYSTEMS FOR TEACHING THE SCIENCE OF PHOTOVOLTAICS

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ABSTRACT

A comprehensive education not only requires instruction by qualified teachers, but is enhanced if students can gain hands on experience. Solar energy technologies provide simple experiments where students can learn about science and technology while at the time giving concrete examples that are a growing part of every day life experience. In this paper two approaches to hands on experiments are discussed. The first is a series of lab equipment and experiments that were developed at the UNESCO - MSUAE Chair "Renewable Energy and Electrification of Agriculture" at the All Russian Research Institute for Electrification of Agriculture (VIESH) to help teach the principles of photovoltaics, particularly to students of the Moscow Power and Engineering Institute (Technical University). The second is the use of actual photovoltaic systems installed at schools and monitored to demonstrate the system performance. These two experimental methods are examined and compared and contrasted.

1. INTRODUCTION

The public wants to know more about the renewable energy options, the solar industry is looking for people with a good background in renewable energy, and students are demanding to learn more about clean renewable energy. With the lesson plans that are now being developed for renewable energy, there is a pressing need for corresponding hands on experience either through the use of lab equipment to augment and enhance the educational experience or photovoltaic systems installed on the school building. This article is about lab equipment developed at the All Russian Research Institute for Electrification of Agriculture (VIESH) to help teach the principles of photovoltaics (PV) and the of PV systems installed on Oregon high schools used to help teach science to high school students.

Both properly designed PV lab experiments and installed and monitored PV systems can be used to teach science. Each option has its strengths and weaknesses. This article discusses, compares, and contrasts the usefulness of PV lab equipment and monitored PV systems in teaching renewable energy to students.

The article is organized as follows: Solar Laboratory equipment and experiments developed at VIESH is described followed by a discussion of how experiments are used to teach the principles behind solar electricity [Figs. 1-13]. Next the use of monitored PV systems on high schools in Oregon [Figs. 14-15] are discussed along with how the teachers can use information from these systems in their science lessons. Then the two methods are compared and contrasted.

2. SOLAR LABORATORY EQUIPMENT & EXPERIMENTS

For a real extension and implementation of renewable energy resources engineers, technicians, scientific experts and project workers are needed. Moreover a broad understanding of the subject among all planers, technicians and experts (and even among politicians and decision makers) who is linked to the subject is necessary. In this context the UNESCO - MSUAE Chair "Renewable energy and electrification of agriculture" in the All-Russian Research Institute for Electrification of Agriculture (VIESH) and jointly with the MSUAE (Moscow V.P. Goryachkin State University of Agricultural Engineers) are

Fig. 1: Test field at the VIESH roof

developing strategies concerning the educational resources including laboratory equipment (lab kits) on renewable energy. The UNESCO - MSUAE Chair is guided by principle connecting education to research. Education programs inspire students to explore sustainable energy solutions to meet our future needs.

2.1. Previous experience

Teaching Physics at the Moscow Power Engineering Institute (MPEI) one of the authors started to develop special topics and demonstrations of solar energy principles in the General Physics courses (some papers were published in English [1-5]). Some work was done on solar education during JFDP program [4, 5] and other in the framework of the Fulbright program [6].

The research institute VIESH has experimental workshops for production solar cells and solar modules. It has also a number of labs for developing PV systems, solar concentrators, and quite busy test field on the roof of one building (Fig.1), that is used during the practical and project activity of students.

Renewable energy education is important topic in XXI century. The quality of renewable energy education

Fig. 2: Lab kit for studying solar cells

depends on quality of fundamental and applied courses, teaching resources, and laboratory equipment. Lab equipment should incorporate modern information technologies (including Internet, geographical information systems (GIS) and satellite technology) and pedagogical methods and tools [7] into educational activity.

Lab equipment should add specific useful skills to the basic theoretical knowledge of the principals and fundamentals. Some of the lab installations created in the 1980's are still in use. One piece of equipment is used for measuring of absolute spectral sensitivity and diffusion length in solar cells (SC) at the MPEI. Lab equipment includes monochromator UM-2, source of linear spectra, source of continuing spectra, standard receiver, reference SC, and solar cell to be evaluated. Over the last 10 years more than 2000 students have used this equipment to understand the principles of working SC and have measured some of the important characteristics of SC.

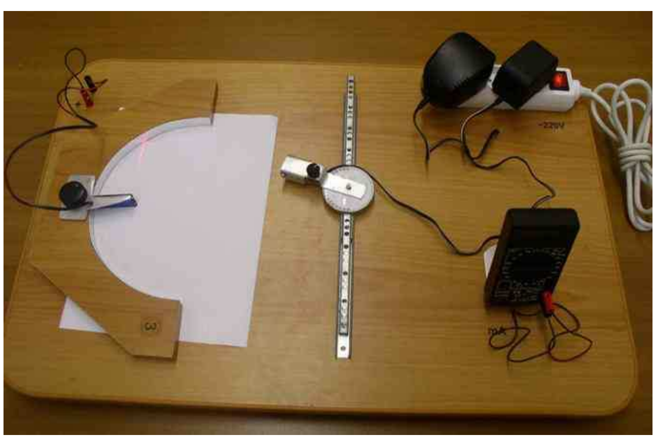

Fig 3: Lab kit for studying concentrating collectors

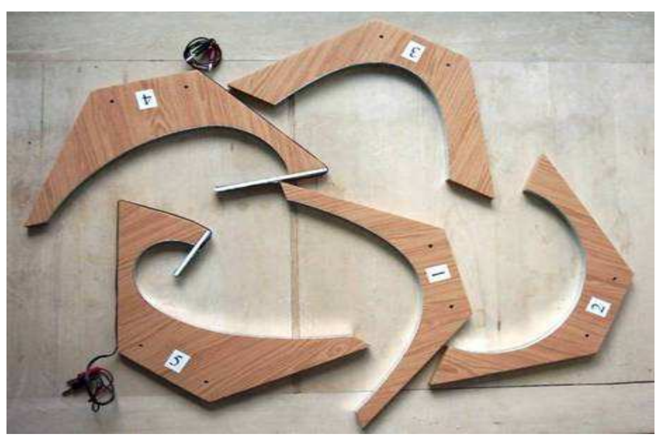

Fig. 4: Set of concentrator profiles

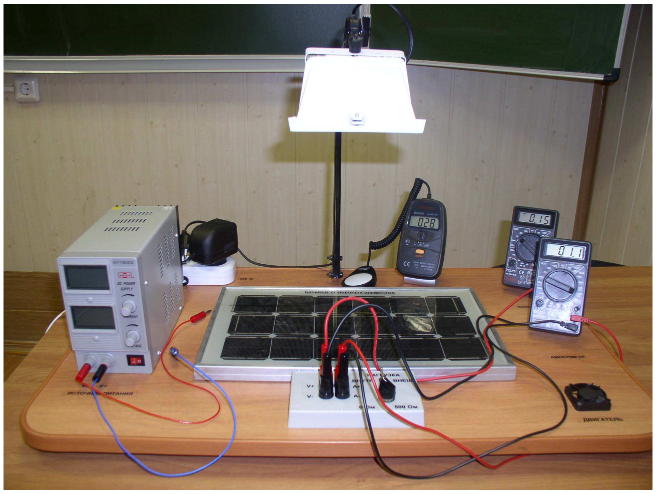

Fig. 5: Lab set for solar module study

Modification of this lab allows also to measure I-V curve of SC.

2.2 The UNESCO - MSUAE Chair educational activity

The systematic development of lab equipment for teaching renewable energy and scientific research skills has started at the Chair from 2004. One of the main tasks of the Chair is integrating educational and research activity of students during the practical work with lab equipment and preparing a research project. The VIESH' test field is very suitable for research and teaching activity. Unfortunately sometimes bad or just not sunny weather does not allow proper experiments the limitation of students' time schedule.

To avoid the dependence of weather some of lab equipment was created at recent years. Lab equipment demonstrates principles behind renewable energy technologies and is very suitable for using at universities, colleges, technical schools, and high schools. The equipment is useful for understanding solar energy, nontraditional and renewable energy, some aspects of physics, solid state physics and semiconductors, applied optics.

A number of sets were made to fill orders by a number university in Russia. The most typical lab sets are shown in Figs. 2, 3. Lab equipment for studying of SCs parameters and characteristics (Fig.2) has SCs, light source, power supply unit, measuring devices, adjustable load. Three SCs is enough to demonstrate all main features of separate SCs (sometimes we use different types of SC), their connections in the modules (series and parallel), different levels of illumination, effects of shading and so on. Dependence of short circuit current on open voltage characteristic uses for deriving internal properties of the p-n-junctions. The energy supply unit allows measurement of the dark IV curve.

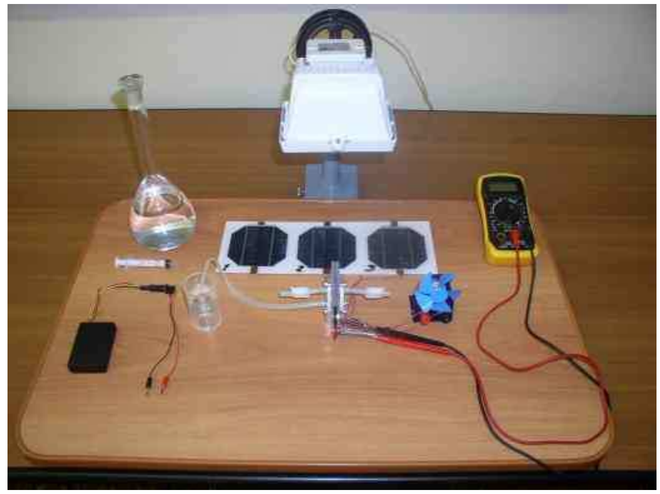

Fig. 6: Lab equipment for study of solar-hydrogen system

Lab set for study solar concentrators (Fig.3) has light source – semiconductor laser with cylindrical lens, set of different type concentrators (some of them with bifacial SC), micro ammeter, protractor, movable strip for laser. A variety of solar concentrators can be examined using this lab equipment. Students can study classical and non-imaging optics (classical parabolic concentrator, Baranov and Winston concentrators), principles of light reflection, and ray tracing (Fig. 4).

Lab equipment for studying of solar module parameters and characteristics is illustrated in Fig. 5. In comparison with the lab set for studying of SCs it has additionally a device for measuring of illumination level and a demonstration load (the electric fan).

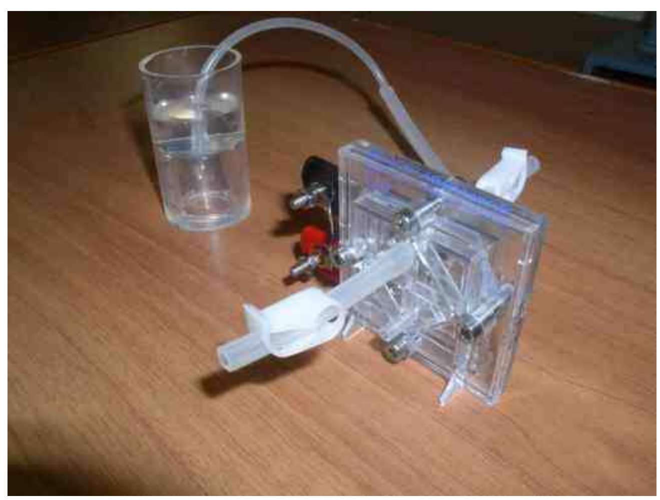

Fig. 7: Reversible proton exchange membrane fuel cell with hydrogen storage (Fuel cell store)

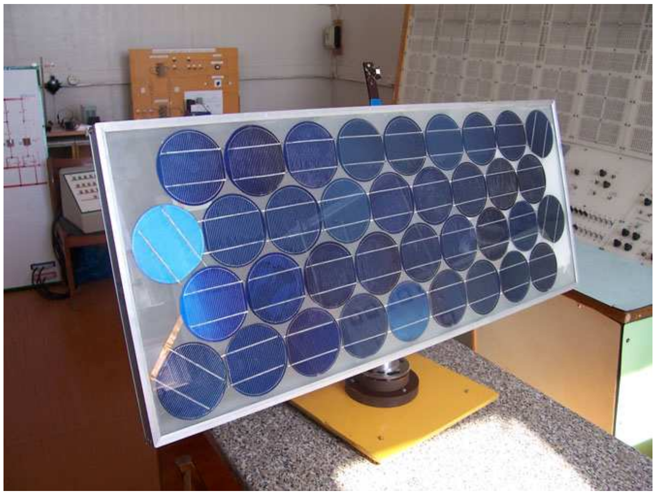

Fig. 8: Lab kit for study tracking solar module (front)

Fig. 9: Lab kit for study tracking solar module (back)

Lab set for realistic simulating the operation of a solar-hydrogen energy system (with reversible proton exchange membrane fuel cell) is shown at the Fig.6. Lab equipment has source of light, set of SCs, reversible fuel cell (RFC) and tank for storage of hydrogen (oxygen is also possible to store). The RFC is shown in Fig.7. It can operate in either direction, to produce hydrogen from SCs electricity or to produce electricity from storage hydrogen. Students can study current–voltage relationship of system for different operational conditions, efficiency of system.

Lab system for the study of a tracking solar module was built for the base solar module of VIESH. The equipment, developed at Mari El State University (MARSU) in the framework of a diploma project, allows comparison of output characteristics for double axes tracking system with standard fixed array when the tracker is turned off(Fig.8, 9).

Simple and non-expensive version of a helio-simulator for the sun's path was built for lab simulations of solar radiation arriving depending on time of the day, season and latitude (Fig. 7). Before the practical class students study Internet sites for calculating of sun's path diagrams (for example see http://solardata.uoregon.edu/SunChartProgram.html.)

According to John Perlin the Royal Institute of British Architects developed a device called the heliodon in the early 1930's to help architects determine the effects of the sun on buildings before they were constructed. By mounting a model of a proposed structure on a rotating drawing board with a fixed light source simulating the sun, designers could easily ascertain the solar exposure of the proposed building. Some of the versions of heliodons were built recently by Prof. N. M. Lechner in the USA. (These system are too expensive for mass production.)

The developed version of helio-simulator has source of light, frame for moving it, models of the houses with the integrated SCs for estimation of solar exposure of the proposed solar systems in buildings. The principal of work is shown in Fig.10 (the 3 D Max pictures). Helio-simulator demonstrates the motion of the sun relative to a building

Fig. 10: The principal of work of helio-simulator (3 D Max picture)

Fig. 11: Arial of satellite receiver on VIESH roof

Fig. 12: Lab complex for receiving and process satellite images

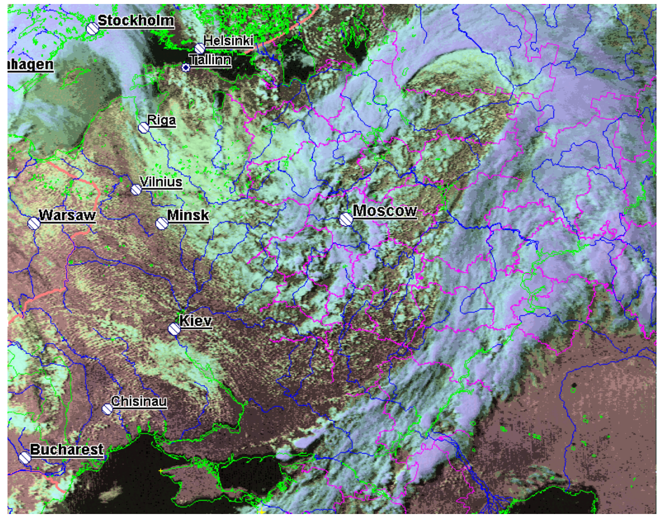

Fig. 13: Example of space image with geographical map putting on it.

(obstacle) for the purpose of designing solar responsive architecture.

Lab equipment «Receiving and processing of satellite images of the Earth in real time operation mode» (Prof. Schakhramanyan M. A., [8]) is a new stage of using modern space technology (Figs.11-13). The system consists of satellite antenna, receiver of satellite signal, software of processing aerospace image of the Earth. Software of the receiving complex «Kosmos – M2» is able to determine the temperature of underlying surface at any point of the image obtained; to measure distance from one point to another with regards the Earth's geometry; to determine surface area; selection of map layer and so on, to have real time images within an interval of 2-4 hours.

2.3 Value and advantages of developing lab equipment

Lab equipment clearly demonstrates various operational modes of SCs, solar modules, fuel cells, and solar concentrators. It produces data for evaluation of system elements, defining component parameters, and studying how the systems work, including modern GIS systems.

Lab equipment

- enables ray tracing for different concentrating configurations.
- is versatile: usable for laboratory work for a variety of courses at the different levels.
- is simple to use and capable of a wide variety of re-search activities of student and postgraduate students.
- is easy to modify lab equipment for a variety of applications.

The authors have had a positive experience of teaching students of Oregon Institute of Technology using small scale real photo-thermal stationary concentrator created at University of Oregon [6]. At the same time it should be remarked that teaching during a research project is time consuming activity and can be used in framework of special projects. It is better to involve students in such research projects after training them on the developed lab equipment.

The lab projects described are continuing to develop and new ideas are being implemented. The main result of the using and developing elaborated equipment is the knowledge and experience students acquire while participating and stimulous student receive thinking about and developing new ideas. The students with different background (from different universities) gain experience in several major areas. For example, students with strong chemical background from the Moscow State University of Engineering Ecology get a much better understanding of electrical engineering principles. Students from the MPEI (TU) have acquired knowledge on chemical processes in fuel cells. We have plans to develop lab equipment for studying single wire transmission electric line (based on Tesla ideas and new developments of Prof. Strebkov D. S.), lab equipment for evaluation high voltage photovoltaic modules (based on multiple vertical p-n junctions) and others. Students like practical classes and actively participate in developing new equipment and generating new ideas.

3. USE OF PV SYSTEMS ON SCHOOLS

Over the last several years, schools have been installing photovoltaic systems on their roofs and monitoring the

Fig. 14: Dedication of PV bus stop shelter at Pleasant Hill High School and students who helped in the construction.

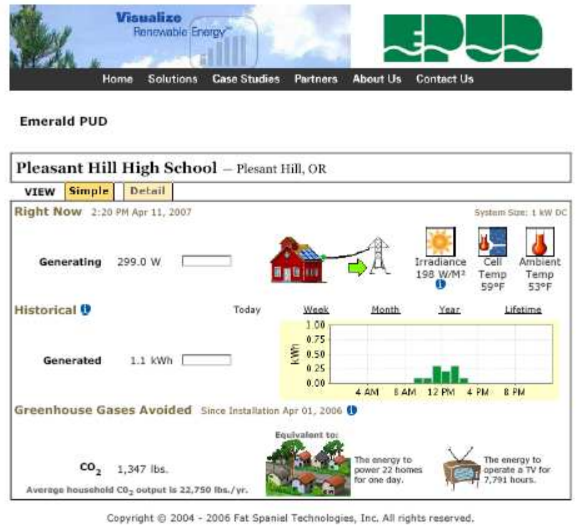

Fig. 15: Example of Fat Spaniel Webpage for Pleasant Hill High School System.

system performance. Data from these systems along with solar lesson plans have been used to teach chemistry and physics along with renewable energy. In this section, use of PV systems as educational tools is discussed. In particular, Emerald People's Utility District in Lane County Oregon installed photovoltaic systems on all four high schools in their service territory. The goal of the project was to gain experience with grid tied photovoltaic systems and to provide educational information to teachers and students on solar electric systems. The first system install was discussed in an earlier article [9].

As funds became available, three 1 kW PV systems were install at the remaining three high schools (Fig. 14). These systems used Sunny Boy inverters and Sharp PV panels. In addition to the PV system, monitoring equipment was installed. The monitoring equipment included a Fat Spaniel meteorological system measuring the horizontal solar radiation, ambient temperature, and cell temperature. The Fat Spaniel monitoring also included the output of the Sunny Boy inverter (see Fig. 15). The inverter outputs measured were the DC current and voltage and the AC power output.

3.1 <u>Using Monitored PV Data</u>

Emerald PUD contracted with a teacher at each of the high schools to develop a lesson plan that could be used in conjunction with the PV system. To date only one lesson plan has been completed. That lesson plan is designed to teach the magnitude and relationship between different common concepts of energy. The lesson plan will be posted on the UO SRML Website along with other lesson plans developed for teaching about solar electricity. As the other lesson plans are developed they will also be posted on the Website.

There are many ways in which to solar electric system performance data can be used. In the Emerald PUD service territory, the performance of one system against another can be compared. Since the Fat Spaniel Website is updated regularly over the day, students can compare system performance with the outside weather. Historical data can also be downloaded from Fat Spaniel and then several interesting plots can be created. One of the simplest just plotting the current, voltage, or power against total horizontal irradiance. Ideally incident solar radiation on the array should be utilized, but that information is not as easy to calculate. The solar angle calculator available on the UO SRML Website at http://solardata.uoregon.edu/DownloadExcelAddin.html has the ability to calculate tilted irradiance from total irradiance on a horizontal surface, but requires a little more time to learn that is typically available in a high school classroom.

The inverter efficiency of turning input DC power into the AC power output is an important parameter that often can be calculated. The input DC power can be calculated by multiplying the DC current and voltage and the efficiency can be calculated by dividing the output AC power by the input DC power. The efficiency can then be plotted against AC output power, total solar radiation or even ambient or cell temperature.

4. ADVANTAGES & COMPARISON OF CLASS EXPERIMENTS AND PV SYSTEM BASED LESSONS

4.1 Advantages of hands on experiments

Advantages of class room experiments are independence of weather conditions in comparison of studying real scale systems on test fields, and provides opportunity to concentrate studying on basic principles. Class room experiments can be cost effective and can be more easily organized with more predictable results in accordance with teaching plans. This is necessary step for forming initial research skills.

The main disadvantage of class room experiments is non impressive small scale studying values. At the same time teacher can ask students to calculate real system' parameters based on small scale results.

Our experience showed that class room experiments are more suitable at the first steps of studying special subjects and should be extended by work with real scale equipment.

4.2 Advantages of school installed PV systems

Solar systems installed in schools provide several educational benefits. Solar electric systems show that the systems work. Students, teachers, parents, building administrators, along with utility personnel see solar electric systems working. They see that photovoltaic systems are real and not a futuristic fantasy of scientists.

PV systems can become part of student pride, especially if students are involved in the design, construction, or monitoring the system. At Pleasant Hill High School, students helped clear the area and lay the foundation for the solar covered bus stop. Students in the metal shop helped design and weld together a bike rack for the bus shelter (Fig. 14). In addition, panels were purchased that had transparent backing so that students could see the solar cells while they were waiting for the bus. Not all installations can be so well planned and executed, but thoughtful design and implementation can greatly add to the value of the PV installation.

Monitoring of the solar electric system is also very beneficial. Not only can one check that the system is working as expected, but one can demonstrate how the system performs at different times of year and in different weather conditions. The more extensive the monitoring, the more information can be extracted out of the system.

It is particularly useful if system performance can be monitored or displayed over the Internet. Some inverters come with software that enables a cleaver student to create a Webpage that displays the data. However, there are other alternatives that can be used to put the data on the internet. Often utilities would like to see the data displayed on the internet and will help cover the cost of such a display (see Fig. 15).

Lesson plans using solar electric systems to teach chemistry and/or physics benefit from having an actual system that students can see and if monitored, evaluate. Such systems are complimentary to lab experiments if they are available.

Photovoltaic systems are easy to maintain and operate. Except for keeping an eye on the inverter to make sure that the system is working and occasional cleaning of the array (maybe once a year) there is really little maintenance that photovoltaic systems require.

Photovoltaic systems produce green energy and, depending on how the system is financed, this electricity can be sold on the green market.

The main drawback to a photovoltaic system is the cost. There are many ways to finance a photovoltaic system. Often photovoltaic systems at schools are installed through some utility program. An alternative way is to make the project a community project and get local businesses involved to utilize some the tax credits available. This is how the PV systems installed by Emerald PUD were partially financed.

Someday in the future, whether it is twenty year or a hundred years, every school in the country will have a solar electric system. This starts with one school, then one school district. With an increasing need to provide quality education about renewable energy as we move into the XXI Century and with the start of the Solar Age, a technical component to education is essential. Installed PV systems and hands on solar lab experiments complement each other in teaching about solar electricity and provide a very useful technical base.

4.3 Complementary experience

Lesson plans, lab experiments, and on site photovoltaic systems provide a complimentary learning experience. There is an old idea in teaching a subject matter should be taught in three different ways to make sure that the students grasp the idea. Lesson plans, lab experiments, and actual solar systems fit neatly into this concept. Lesson plans give the student the ideas and concepts. Experiments give a feel for rational behind the concepts and provide concrete examples. Real systems show the students that these concepts and facts apply to the real world.

5. ACKNOWLEDGEMENTS

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Students are working at UNECO MSUAE Chair

Students enjoying their work