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Citizen science project *Nuclear e-cology* − Modern physics education at the high school level

Tadeusz Wibig, [a*]**,** University of Lodz, ul. Prez. Gabriela Narutowicza 68, 90-136 Lodz, Polonya.
Punsiri Dam-O [b]**,** School of Science, Walailak University, 222 Thai Buri, Tha Sala District, Nakhon Si Thammarat 80161, Tayland.

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Abstract

We present the citizen science project called "Nuclear e-cology". It is a proposition for teachers to expand and enrich opportunities of the afterhours school activities, but its main purpose is, eventually, to introduce the modern physics and science in general to the school curricula. We put a special attention to the teamwork and the general scientific methods. Groups of students initially started the serious scientific work and some of them finished the study in the 2014/15 school year and we found results of their activity of the real physical value. We shortly present some of them here and based on interviews and opinions of teacher involved in the project, we discuss some educational aspects of the project. We believe that the further work could be fruitful and successful from the point of view of students and teachers.

Keywords: citizen science; physics education; e-lab project; distance learning;

*ADDRESS FOR CORRESPONDENCE: **Tadeusz Wibig,** University of Lodz, Poland.
E-Mail Address: t.wibig@gmail.com / Tel.: 635-56-57

1. Introduction

Grazing fields, vegetable farms and residential areas are the common things that we usually see along the roadside, while traveling on a highway away from the city limits. They have been located there for a very long time. There are really important questions: If there are animals grazing in the fields? People who are living in those areas eating vegetables from those farms, are they, are we safe from highway pollution?

Searching for answers, we can conclude that in regards to human health and the environment that we live in, some experiments to measure the concentrations of heavy metals deposited in dust, soil, plant and animals have been performed. Results indicated that the heavy metals emitted by the automobiles are spread to the roadside and accumulated. Furthermore, at some sites the concentrations of some heavy metals were higher than recommended safety limits and potentially caused health problems in both humans and animals. However, the actual distribution with respect to the distance from the roadside had never been precisely determined.

The "Nuclear e-cology" project was established with cooperation of three research teams: The general physics team from University of Łódź, the biology and environmental science team from University of Wrocław and the group of X-ray laboratory from Jan Kochanowski University in Kielce. The project involves the modern physics in the studies of the ecological system. As the first research subject we decided to examine some heavy metal pollution in the roadside plants using the X-ray spectroscopy.

The importance of this research concerns two points of view: Physical and educational.

1.1. Physical point of view

Road transportation activity, a primal component of economic development and human welfare, is increasing around the world as the economies grow. Road traffic has been highlighted as a major source of heavy metal emission (e.g. cadmium, copper, iron, lead, zinc and nickel). Consequently, the rise of the road transportation activity causes the higher levels of emitted metals, which impacts the ecological environment on the roadside and the surrounding areas such as farmlands, pastures, rivers and residences. The heavy metals may enter the food chain as a result of contaminating edible plants or their intake by people. If these levels are excessive, the metals can cause serious health risks. For example:

- Zinc, in fact, is an essential trace element and serves a number of roles and functions in the human body (e.g. being a component of enzymes involved in the synthesis and metabolism of carbohydrates, lipids, proteins, nucleic acids and other micro-nutrients; involving in DNA synthesis and the process of genetic expression; stabilizing cellular components and membrane). However, the prolonged intake of more than 300 mg per day of zinc (Fosmire, 1990) can lead to disturbance of copper metabolism, causing low copper status, reduced iron function, impaired immune function; can cause abdominal pain, nausea, vomiting, diarrhea, epigastric pain, lethargy and fatigue.

- Lead is a cumulative toxicant. However there is no known level of lead exposure that is considered safe for humans. Once it enters the body, it is distributed to the brain, kidneys, liver and bones. The body stores lead in the teeth and bones where it accumulates over time. Lead affects the development of the brain and nervous system in young children and causes high blood pressure and kidney damage in adults. Moreover, the exposure of pregnant women to high levels of lead can cause miscarriage, stillbirth, premature birth, low birth weight and minor malformations.

- Bromine would cause different effects depending on the chemical compounds. In case of 1, 2-dibromoethane (Gift et al., 2004), which was used as an antiknock additive in lead fuels, potentially causes adverse reproductive and fertility effects.

In the early works, some research groups conducted the experiments to examine the concentration of heavy metal elements in roadside samples within different distances from the road. For example, Schuck and Locke (1970) from the Air Pollution Research Center, California, USA examined lead in cauliflower collected from the distances of 15 – 360 m from a highway. They found the presence of detectable amount of lead when the cauliflower was grown up to 135 m away from the highway. In the end of 20th century, Othman et al. (1997) from the Department of Radiation Protection and Nuclear Safety, Atomic Energy Commission of Syria studied lead levels in roadside soils, vegetables and plants in the city of Damascus, Syria within 80 m from road edge. Alov et al. (2001) from Department of Analytical Chemistry, Lomonosov Moscow State University, Moscow, Russia in the early 21st century investigated the iron, manganese, titanium and lead content distribution in soil in vicinity of the Moscow highway. Later Viard et al. (2004) from the Laboratoire BFE, Metz, France measured the concentrations of lead, zinc and cadmium in soil, grass and snails within 320 m from a highway. They found that the highway induces a contamination up to all the distances they studied. Detailed analysis presents that different research groups obtained different results, even with regards to the same heavy metal element such as lead. The question "How the heavy metal elements can really be deposited aside the roadside?" is still an open one.

1.2. Educational point of view

The importance of the research in general is also important for the education of the next generations. Nations address, in principle, the high priority in physics through science, technology and education policies by providing infrastructure and funding. People trained in physics are essential for continuing research in a particular field, and for maintaining a technically sophisticated workforce. Physics worldwide has a long tradition of producing scientists in different fields and ranges of education.

On the level of graduate education, students dealing with experimental and theoretical physics have an opportunity to experience and solve complex problems. Their trainings involve design, building, and testing of instrumentation. Additionally, they learn teamwork, management, and communication skills in addition to gain new technical knowledge and expertise. Their skills are readily applied to a wide range of technological problems in their homelands; in medicine, industry, environment, business, management and government. Future physical knowledge and technology will be directed by these people. Undergraduate degree in physics provides a foundation for graduate studies in physics. The undergraduate students should have an opportunity to acquire deep conceptual understanding of fundamental physics and gain important skills for experimentation in physics.

Young students are usually fascinated by natural phenomena. A way to attract them to the educational path in physics is to reinforce them early and maintain their interest. Healthy curiosity has power of inspiring students in the educational process. On the other hand people wish to have a good quality of life. Physical health and emotional well-being connect people to the environment in which they live. People can create a good environment by the assistance of efficient technologies. The technologies could not be developed without the knowledge of science (physics). We understand the significance of physics and education linked to environmental science. We therefore established the project which dedicates school students of worldwide countries with the experimental lessons in physics on environmental investigation. We wish to prepare the young people to become the next generation of scientists (physicists).

2. Non-professional scientists in a real scientific research

The physical problem - the accurate analysis of the distribution and average density of the heavy metal elements in the plants growing in the vicinity of the roads, a large collection of data is required. It would be impossible to sample so extensively using traditional field research models due to the limitations of time and resources. One of the ways to accomplish the objective of the study is to involve the non-professional scientists in the research.

In fact, the involvement of non-professional scientists in a "real" scientific research, known as crowd science, is not a new method of conducting the research. This method was developed before 20th century and known as amateur self-funded researcher. It has become increasingly important in conservation science since the beginning of the 21st century. In the field of physics, most of the crowd science projects are related to astronomy (Franzoni & Sauermann, 2014). The exact physical citizen science experiment has never been created. Proposed research project of the examination of heavy metal pollution on roadside by using X-ray spectroscopy is developed in the citizen science method for worldwide secondary school students through the internet project entitled "Nuclear e-cology". The knowledge which students gain from this study can be a supplement of learning modern physics at schools but also a foundation for learning physics on higher educational levels.

The objectives of our project research are to study the distribution of heavy metal pollution on roadside taking into consideration the following aspects:

1) Characteristic distance of the spread of deposited heavy metal elements.

2) Average relative density of the heavy metal elements on the studied sites.

The heavy metal elements of interest are iron, nickel, zinc, lead, bromine, rubidium and strontium. We presented here results of first run of the project based on plant species growing in the vicinity of the roads:

- In Poland: Leaves of *Taraxacum officinale F. H. Wigg*. (dandelion) or *Achillea millefolium L*. (yarrow).

- In Thailand: Leaves of *Chromolaena odorata (L.) King & Robinson* (Siam weed) or *Tridax procumbens L.* (tridax daisy).

Selection of sample types to be used in the present study was based on the role of samples in ecological system, availability of the samples in the vicinity of the roads, the feature of the samples of being a bio-indicator and the safety of the experimenters - school students. The 18 individual samples are expected to be collected at the distance 0 (road edge), 25 and 50 m on both sides of the road. A perfect studied site is considered to be far from, for example, roundabouts, crossroads, farmlands, residential areas and industrial areas and without any barrier between the road and roadside. The particular sites were chosen by the school students. Each individual sample consisted of leaves of the plant species collected 'uniformly' over a whole single sample area of about 1 m^2. The information about studied sites such as address, road name/number, GPS coordinates, photos and topology was recorded in the "Nuclear e-cology" project database.

Leaves of the plant samples were rinsed with tap water, dried in ventilated room for two weeks and then grinded into powder form with a ceramic mortar. All this was done by the students at their schools. Then the specimen was packed and sent to our laboratory for further preparations needed for the spectroscopy measurements at the X-ray Laboratory at Jan Kochanowski University in Kielce, Poland. We used the total reflection X-ray fluorescence (TXRF) technique which requires the dry residuum of liquid sample. Thus the amount of the powder sample of 0.1 g was digested in 4 ml of high purity nitric acid (65%) and the mixture was left for 1 – 2 days until the sample decomposed and dissolved. Next, 2 µl of solution was pipetted into a quartz sample carrier, and this drop was dried in infrared. The dry residuum was next analyzed using PICOFOX spectrometer with analyzing time of 15 min.

2.1 X-ray spectrum analysis software

The most important part of the measurement, from the educational point of view, is the spectrum analysis.

There are many specialized programs with large libraries which automatically or semi-automatically fit the peak intensities. These programs are used by the scientists in laboratories. In the work here, the users of the program were school students. In order to understand the idea of the spectrum deconvolution, the spectrum analysis software with manual fit ability was developed and introduced to the school students.

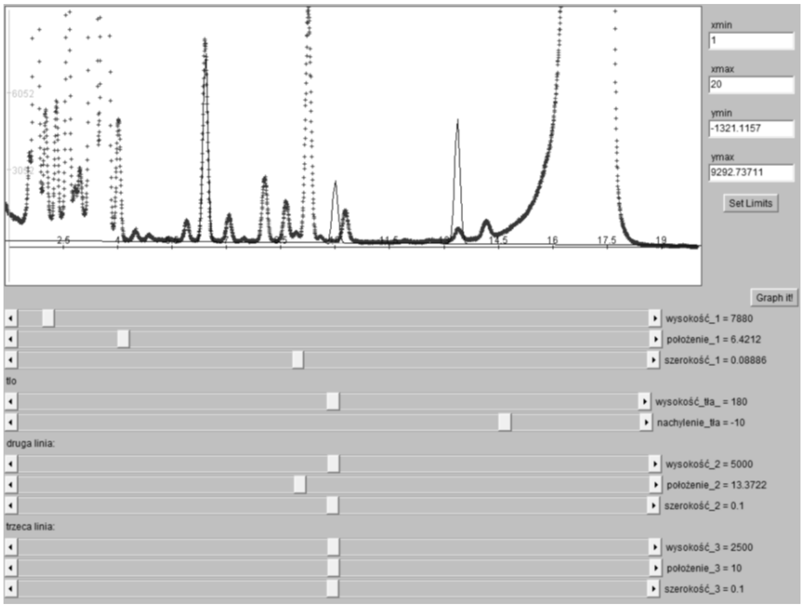

Figure 1. Our spectrum analyzer, the Java application to analyze X-ray spectrum file on a web browser.

Before introducing the program to the users, a test of using the program was conducted among 37 people, who had not experienced in X-ray spectrum analysis, in order to observe the way they obtain the 'best fit'. Their results were compared to those obtained by us, who worked in X-ray field and gathered some experience already, and with the results obtained from the SPECTRA program, the software package used with the S2 PICOFOX spectrometer in the X-ray Spectrometry Laboratory, Jan Kochanowski University in Kielce. The information obtained from these studies helped us prepare more detailed instructions for the school students, participants of the "Nuclear e-cology" project.

The whole student activities in the proposed project can be summarized in nine steps shown in Fig.2 below:

Step 1: Register

Step 2: Complete survey

Step 3: Study instruction of the experimental lesson

Step 4: Survey research sites and availability of the roadside plants and the first teleconference

Step 5: Collect the samples from the selected research site

Step 6: Prepare the sample and *send the samples to the laboratory*

Step 7: Learn to analyze spectrum using our software and the second teleconference

Measurement

X-ray spectrum data files

Step 8: Analyze spectrum data and write lab report

Step 9: Submit the final report and the third (final) teleconference

Figure 2. A scheme of activities in the experimental lesson for the participants

2.2 The "Nuclear e-cology" website

The almost obligatory element of any citizen science project is the project webpage. The first step of the project mentioned in Figure. 3 was to go to the project page and registration for individuals and for the group. The "Nuclear e–cology" webpage can be found at http://wfis.uni.lodz.pl/edu. It is the main resource of all pieces of information related to the experimental lesson such as lab instruction, exercises, the software, learning materials, activities of particular groups and calendar of the activities. All webpages were prepared in four different languages: Polish, Thai, Russian, and English, according to the languages of the participants from different countries. In addition, the Facebook application on the "Nuclear e-cology" community page was also used as another option for the participants to follow the news from the laboratory. It enables the participants to reach the news easily and fast.

2.3 Participants of the project

Initially, there were 29 groups registered consisting of 108 students and 10 teachers participating in the project. At the end of the year 2014, 7 groups of 26 school students completed all activities in the program, while 6 groups were still continuing the study and 17 groups quitted the project (see Table 1).

Table 1 Groups of Participants Registered to the "Nuclear e-cology" Project of 2013/2014

Countries	Poland			Thailand			Russia		
Educational levels	Secondary school	High school	University	Secondary school	High school	University	Secondary school	High school	University
Number of groups registration	12	10	-	2	2	1	-	2	-
Number of groups quite the project	6	7	-	2	-	1	-	-	-
Number of groups not yet finish the lesson in 2014	2	2	-	-	-	-	-	2	-
Number of groups completed the lesson in 2013/2014	4	1	-	-	2	-	-	-	-

2.4 Opinions from school teachers

The teachers gave us their opinions and comments about the experimental lesson and these can be summarized as follows:

1) The activities meet students' need, especially ones who love studying science.

2) The experimental lesson is rather advanced for the first year of secondary school students. Actually, it suits for high school students of the last year. But those high school students are focusing on their admission/examination to university instead of doing scientific project.

3) The teachers consider the study of the experimental lesson of their students as a part of studying physics at school. They scored their students by this experiment.

4) The laboratory scientists should conduct the experimental instruction including knowledge relating to X-rays and X-ray spectroscopy to the school teachers before starting work with their students.

5) The spectrum analysis process takes very long time. The students should be given longer time to work on this part.

6) Every teacher recommended/suggested other students to participate the activity of the Nuclear e-cology laboratory.

7) The physics teachers from some schools invited biology teachers to participate with the project.

Certainly, school teachers were not only observers, but they played important role on assisting their students for example took care of the young students during field work, provided them with laboratory equipment for sample preparation, arranged computer with internet connection for working on the lesson and attaining the teleconference, gave suggestion to their students, and encouraged their students when the students were declining their enthusiasm and effort. Without their active role project probably would not have finished successfully.

3. Example of physical results

The participants produced their 'final reports' in a standard form using prepared automatic spreadsheet consisting of three parts: Part I – data from fitting X-ray spectra, Part II – data containing analysis results on distribution of heavy metal elements in roadside plants (with respective graphs) and Part III – conclusions. It takes one-two months for analysis of eighteen X-ray spectra containing of all together 144 peaks to be fitted. The participants in each group usually managed to complete this part by sharing the work. In Parts II and III, the participants analyzed data, interpreted graphs (automatically presented in the spreadsheets), discussed on the results and worked out their final conclusions. All this took about 2 – 4 weeks time.

As an example of physical results obtained by the 'Nuclear e-cology' project students we would like to show here findings related to the lead (Pb). All other measured elements: Iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), bromine (Br), rubidium (Rb), and strontium (Sr) behave accordingly, (Dam-o, 2015; Wibig and Dam-o 2016).

The average relative density of lead was measured by each group, and results are shown in Figure. 3. Quite surprising effect is seen there: The first three bars are by a factor of ~10 lower than the other four. With the help of additional information obtained with the help of school students we were able to propose the explanation of the systematics seen in Figure. 3. The relative density of lead is related to the age of the road.

Second main point of the 'Nuclear e-cology' project studies was to establish the distribution of the heavy metal relative density with respect to the distance from the road edge. The individual results from all groups analyzed together showed that the relative density of lead in the samples at most of the studied sites was decreasing in the perpendicular direction to the road edge.

The effect of this compilation is shown in Figure.4 in the comparison with other experiment results. Some of them are based on different techniques and used different samplings, and different species. However, as it is seen, our measurement agrees with the 'professional' scientists' results, and even we can even say that the estimated uncertainty of our points seems to be slightly smaller than the others.

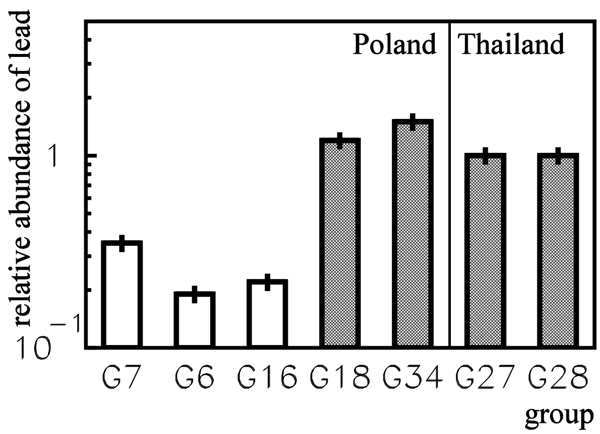

Figure 3. The average relative density of lead in roadside plants of different studied sites in Poland and in Thailand; three empty bars represent roads of the age less than 10 years, while dashed four are for the roads older than 10 years

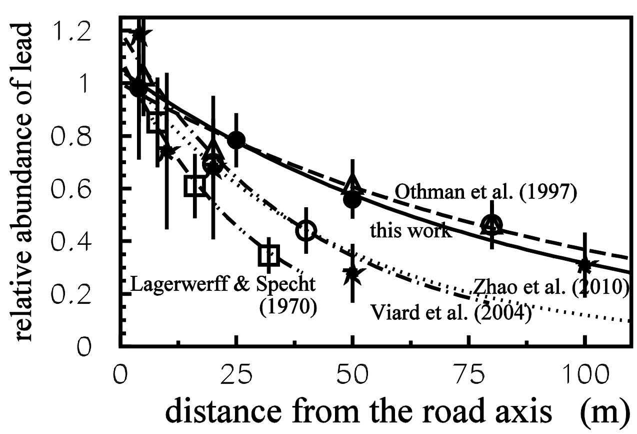

Figure 4. Relative density of iron from our study (black circles) compared with other experiment results (Lagerwerff and Specht, 1970) - squares, (Othman et al.,1997) – empty circles, (Viard et al., 2004) – triangles and (Zhao et al., 2010) stars. The lines shows exponential decreases adjusted to each data set. According to small statistics they should be taken with care

4. Continuation of the project

The groups from the 2013/2014 project, which have not finished the study, could continue their study in 2015. For the next edition, the 2014/2015 project was opened for new registration starting from January to April 2015. In the new edition, there were two experimental lessons offered the participants to choose from. The first one was still on the examination of heavy metal elements in roadside plants. The second one follow the same idea but instead of pollution along the roads, participants will conduct that study on water resources e.g., rivers, lakes and reservoirs to examine some heavy metal elements in lesser duckweed (*Lemna minor L.*) – aquatic plant.

One of us (P.D.) would like to establish another center of the Educational Nuclear e-Laboratory in Thailand. We already have the lab center established in Poland. The laboratory in Thailand could provide the participants within country and from neighbouring countries with convenience on delivery of the samples. We have a plan to use the X−ray spectrometer and lab facilities at the Synchrotron Light Research Institute in Nakhon Ratchasima, which is a province in the North East of Thailand. We expect to involve scientists who can be the specialists in biology, environmental science, and physics education in Thailand and Asian context.

Especially, in 2015, the association of Southeast Asia Nations (ASEAN) had strategic schedule for the ASEAN Economic Community. In a strategic approach for the freer flow of capital, every country in ASEAN Economic Community had to take action on an arrangement for the cross recognition of qualifications, education and experienced market professionals. Thailand aims at becoming the Education Hub of the ASEAN Economic Community. Various government policies will facilitate the active research collaboration in education, science and technology amongst many universities and institutes of science, in order to educate and prepare people to be able to work in ASEAN.

Due to the character of the "Nuclear e-cology" project (as the one project of remote laboratories in different fields of physics), it enables us to work with students, and researchers in ASEAN and worldwide countries. The collaborative research activities can enhance growth and productivity in science and education. Moreover; this project can result in providing the young people not only with scientific knowledge, but also with public awareness of the environment. Having taken all the facts and data from the extensive research in putting this ongoing project together, it is recommended that this project is sufficiently valuable to justify the investment of time, interest, and finance, so it can be continued in Thailand.

5. Conclusion

Summarizing the physical side of the "Nuclear e-cology" project we examined the relative densities of iron, nickel, zinc, lead, bromine, rubidium and strontium in roadside plants along different study sites in Poland and Thailand with the X-ray fluorescence spectrometry method. Two general findings are reported (Dam-o, 2015):

- Some heavy metal pollution observed in the analyzed samples depends on the age of the road.
- Relative densities of iron, nickel, zinc, lead and bromine decreased with the increase of the distance from the road.

From the educational point of view the summary could be made in one sentence: We have created the citizen science project "Nuclear e-cology" which involved school students to do research on the important region on the edge of physics, ecology, biology, environmental and nature monitoring/conservation science and, what is more important, we have shown that it works in practice.

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