Tutoring Gifted High School Students by Design of Experimental Setup in Nuclear Physics

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Abstract

Working with gifted high school students and creating a culture of excellence becomes an important part of education, especially of education of topics in natural sciences. By engagement of gifted students in relevant scientific research activities and tutoring them through all phases of activities, students achieve various high-level learning outcomes. Nuclear physics is a relevant topic for analysis of natural processes in the environment, and thus it can be very attractive research topic for gifted high school students. Analysis of some of nuclear physics processes in the environment and preparation of related experiments need the collaboration with academic staff at universities and research institutes, which brings additional potentials for students. Thus, tutoring gifted high school students through research projects in nuclear physics could enable students to understand key concepts and phases even in any research projects, bringing new students to universities in STEM fields.

This paper presents the concept of tutoring gifted high school students from preparation and design of simple but relevant experimental setup, theoretical analysis of concepts in nuclear physics, up to the use of experimental setup in simple, but relevant experiments in the environment. The experimental setup has been designed, as a low-cost spectrometer on information technology platform to measure ionising radiation in the environment, such as alpha- and beta-particles of various energies. In the preparation of the research activities with students we have used the Manual for optional teaching in physics and relevant research papers in nuclear physics for education purposes.

Keywords: *gifted students, tutoring, design of experimental setup, optional physics education*

1. Introduction

Attracting gifted young students to science and technology and transforming them to future gifted researchers should be a societal task for all countries, especially countries that need further development of economy. Gifted students excel in creative thinking, abstract reasoning, and possess a wide range of interests and quality of work. They stand out with their intellectual abilities, particularly ‘general intelligence, desire for knowledge, perseverance, common sense as well as critical observation’ ([1], [2]). By analysing the characteristics of gifted students and aspects that allow gifted to evolve, the scientists came up with the ‘Three-Ring Conception of Giftedness’ [3]. In this model, Renzulli lists three factors important for the development of gifted behaviour: above average ability, creativity, and task commitment. Only if characteristics from all three rings work together can high achievement of gifted be witnessed.

If we are to offer the education which would encourage motivation and creativity of gifted students to develop and realise their potentials, it is crucial to provide additional well-organised work with teams of gifted students. Through teamwork, all students autonomously contribute with their work, ideas and interests. This type of scientific projects with students can be tailored to their specific abilities, strengths, needs, learning styles and interests. Challenging task encourages their creativity, flair for research, critical thinking, and metacognitive and practical skills.

Examples of such teamwork would be the preparation for international scientific competitions, preparation of a relevant experimental research, and conduction and analysis of scientific research.

Such extracurricular project activities with gifted students in the III. Gymnasium (Split, Croatia) we started several years ago, while preparing students for international competitions in Physics of elementary particles [4]. In 2021, a relevant success was achieved by the team of students with interests in different areas, from science and technology to arts. At that international competition (CERN, Beamline for Schools, BL4S) there were 289 well organised groups from all over the world. Our team has been selected as one of 26 groups with best and interesting research ideas.

This work includes presentation of research activities of gifted students from preparation of a relevant experimental research, and conduction and analysis of scientific research in nuclear physics.

2. Methodology and high school enrichment project

Since the existing educational systems and high school curricula are not able to fulfil the needs of gifted students appropriately, many high school students are hardly able to decide about their future studies and professional orientations. By regular lessons in science gifted high school students often are underchallenged. Their potentials are not stimulated appropriately, which causes their loose of interests and motivation. In order to attract gifted high school students to science and modern technology, various extracurricular challenging projects need to be systematically established.

As an example, two types of experimental setups have been organised as student research projects. One experimental setup consists of simple mechanical materials, and another a low-cost spectrometer based on information technology platform that measures ionising radiation in the environment (such as alpha- and beta-particles).

2.1 Experimental project with cloud chamber

Claud chambers are detectors that make tracks of high energy particles coming from various sources, including the Universe, and resulting from the natural radioactivity. Several decades ago, detectors based on the same principles were used as the first particle detectors, leading to important discoveries (for example, positrons, muons, and kaons).

The material provided for students to build the cloud chamber is: a black box, sponge and magnets to fix it at the bottom of the black box, sheets of plexiglass for the walls of the cloud chambers, iron blocks, polystyrene base of the detector, and scotch tape to fix and to reinforce the plexiglass to the black box. For the operation the cloud chamber, isopropanol, hot water and freezer are needed, and flashlight to illuminate the inside of the chamber and to observe the traces of energetic particles.

The components for the cloud chambers are presented in the Figure 1.

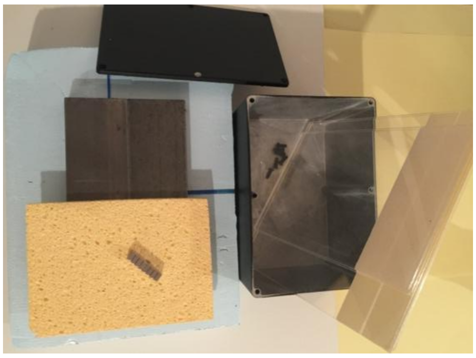

Fig. 1. Components of the cloud chamber.

The particles, which tracks can be visible in the cloud chamber, are muons and anti-muons, electrons and positrons, alpha-particles, including muon transformation, electron-muon scattering, and photoelectrons.

The physical processes that can be tested by analysing experimental results obtained by the cloud chamber are related to special relativity, natural radioactivity in the environment (cosmic and solar rays, and radon), and radioactivity occurred by technological elements (welding rods).

2.2 Experimental project with particle spectrometer

A low-cost particle spectrometer for measuring ionising radiation from alpha-particles and electrons, with energies up to 10 MeV is an excellent experimental educational tool for exploring natural and artificial radiation, such as radon, potassium-rich food and some every-day objects (old watches, ceramics, some glasses, etc.) [5].

The components (resistors, capacitors, silicon PIN diode, amplifier, cablers. etc.) for the particle spectrometer are presented in the Figure 2.

Fig. 2. Components of the particle spectrometer.

The mechanism for the operation of the particle spectrometer is based on electrical charge that is generated on photodiodes. The charges form electrical currents which are amplified and converted into compatible pulses with audio signal inputs. The values of the pulse are proportional to the energy deposited. For the relevant values of the energy, the calibration with sources and is detector is needed. The measured spectrum of energies and open-source software enables real time display and attractive analyses. The spectrometer is relevant for measuring alpha-particles and electrons with energies from 30 keV up to 8 MeV. the components are made for exploring natural and synthetic radioactive sources.

3. Student activities and achieved outcomes

In preparation for conducting the research with gifted students, it has been necessary to introduce them basic concepts in nuclear and particle physics, such as different types of subatomic particles (electron, proton, neutron, photon, muon, positron, alpha, etc.) and their key properties. Also, they have needed explanation on different states of matter and basic processes (evaporation, condensation, and ionisation).
Students have been prepared to build the above presented particle detectors, and to use them to make cosmic particles and other natural radiation visible and measurable. Students have been able to study some of particle properties, particle tracks and discuss their observations. They have realised that we are not able to see the cosmic and natural radiation particles, but they are part of our everyday life. The students found that it is possible to measure some of their properties (energy, momentum, etc.) by using relatively simple, but technologically relevant equipment.
By analysing some of research articles in the past, the students were able to find that nearly hundred years ago, by using cloud chambers new particles were discovered, while today by using them for education purposes, still they make motivating and challenging and relevant research experiments. Of course, modern particle detectors in relevant experiments use different techniques for particle detectors but using similar principles to study properties of particles.
Experimental activities with the particle spectrometer and presentations of findings gives opportunities for the team of gifted students to achieve various competences: to select relevant literature and

guidelines; to assemble given particle spectrometer and cloud chamber; to draft and present project research reports; to discuss with other students and experts; to understand principles of detectors; and achievement of practical experimental skills.
Student achievements has been assessed by using a set of questions, and after the project activities, the students were asked about their motivation and abilities regarding the experiments. About 80 % of them expressed that they were very motivated for such activities; 70 % that they would be able to work autonomously by using relevant literature; 80 % stated that a good supervisor and enough time for the project are the key success components. The interests of students for further work with the available particle detectors are: impact of ionised radiation to the environment; energy distribution of radiated particles; second radiation of a substance that has been exposed to primary radiation. Only 20 % of students were not able to express their further scientific interests related to experiments.

4. Conclusions

The key factor for success of extracurricular science activities is the individual autonomous and responsible teamwork by using relevant and attractive experimental devices. The extracurricular activities with gifted students show that the acceleration and enrichment of gifted students requires the cooperation of schools with universities and research groups. The universities should develop trainings for teachers working with gifted students, which should support the independence, motivation and creativity of students. The experiences and the feedback from students show that the trainings at universities should include: the relevant scientific background of individual experiments including possible problems and questions of students; possible combination of different experiments and technologies; the didactical background to accelerate experiments, making them feasible and interesting for gifted students.
The current success of our examples is confirmed by evaluation of students. Our interests on further research of giftedness includes development of new relevant experiments and analysis of transition from gifted students to relevant researchers.
While developing and testing extracurricular activities we went through several phases, from theoretical research and competition for the first generation of gifted students, practical experimental setup, up to the competition in experimental physics projects for the next generation. The general assessment of such extracurricular activities with gifted students needs further follow up of students, analysing their interests and success in their further study and currier development.

Acknowledgements

This research was partially supported under the project STIM – REI, Contract Number: KK.01.1.1.01.0003, a project funded by the European Union through the European Regional Development Fund – the Operational Programme Competitiveness and Cohesion 2014-2020 (KK.01.1.1.01).

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