Enhancing Student Engagement in High School by Designing Research in High Energy Physics

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Abstract

Creating a culture of excellence and working with talented students is an important role of teaching in high schools, especially in natural sciences such as physics. By involvement in scientific research activities in all areas of physics talented students can achieve various knowledge, skills and competences, especially when analysing processes in high energy physics, because the work is very dependent to collaboration with researchers in universities and excellent technologically attractive laboratories. High energy physics is particularly attractive to a large number of students, but only the talented students can respond to challenges of an international competition and be prepared for such a competition, such as the competition Beamline for schools.

This paper presents the concept of guiding students through the processes of research activities in a modern laboratory, from elaboration of the theoretical idea, analysis of the characteristics of available detectors, design of the experimental setup, analysis of characteristics of the incident beam and targets, up to the use of experimentally achieved data in one of the world's famous laboratories (DESY, Deutsches Elektronen-Synchrotron, Germany). Also, the challenges that students went through and the way they solved them is described. In the preparation of the research activities with students we have used the Manual for optional teaching in physics and the official website of the competition Beamline for schools.

Keywords: *Design of experiment, optional physics teaching, talented students*

1. Introduction

Talented students need to thrive in learning in specific topics of their own interests and wider competences. Thus, there should be in place an extracurricular programme that gives additional objectives and purposes with specific learning outcomes, mode for teaching, training and learning, and assessments.

Talented students in physics should be trained for the following activities to design a research project by using a common research project steps in modern physics, from:

- selecting subjects of interests in physics,
- finding and reading relevant scientific literature about selected subjects,
- setting a physical hypothesis,
- preparing an experiment to test the hypothesis,
- simulating physical events, up to
- communicating the results through written and oral presentations.

Extracurricular learning outcomes for talented students in high schools should have specific characteristics, such as:

- presenting attractive topics,
- development of complex and abstract ideas,
- high-level thinking,
- flexible learning environment,
- use of alternative methods for demonstration, and
- use of specific assessment methods.

Encouraging excellence and working with talented students should be an integral part in teaching physics at pre-university education levels. By working with talented students, it is necessary to develop a scientific research approach to solve any problems in various subject areas. Modern physics topics, such as high energy physics, are particularly attractive to a large number of high school students, but only talented students can respond to various challenges that can appear within international competition in high energy physics. In addition to core subject knowledge and skills, attractive international competitions create new platforms for achievement of additional cross-sectoral competences.

This paper presents the activities of students and mentors in the scientific research process, which includes analysis of characteristics of available detectors at the DESY, the characteristics of the incident beams and targets.

2. Designing Research Project

Designing a science research project in high schools through extracurricular activities with talented students includes different actions: presentation of motivation, objectives of the research, setting the hypothesis and elaborating its theoretical basis.

For a relevant science project, it is useful to find answers to the following questions [1]:

- What topics could be researched and why?
- Who are the main users of the results, and the target groups to whom the results should be presented?
- What are the potential benefits of the results and how can they be exploited?
- What is the starting hypothesis?
- What is already known in relation to the hypothesis, and what is unknown?
- What has been analysed so far?
- What theoretical basis is taken for the planned research?
- How to choose relevant literature?
- Does the selected literature provide all the necessary theoretical basis for research?
- Does the selected literature include previous similar and related research activities and results?

In regular high school curricula, topics from modern physics are mostly at the level of facts or implementation of concepts and principles to unrealistic systems. Thus, for talented students we have decided to teach and train them for a potential experiment for the International BL4S Competition [2]. The BL4S International Competition is intended for high school students (16-19 years).

At our gymnasium, we have created a team of five motivated students of third grade. As a first step, the team of students with their teachers tried to gain a better insight into the basic topics of high energy physics, including the use of concepts from special relativity, basic characteristics of elementary particles (quarks, leptons, elementary bosons), interactions between them, cross sections, de Broglie relation on matter wave, and many other questions in modern high energy physics. To find the answers to such questions and better insight into the topics, the team of talented students analysed relevant literatures, communicated with researchers from the University of Split and DESY, and installed and used computer simulation packages [3-5].

Even after a relevant insight into the topics, for all involved students it was quite challenging task to set a relevant hypothesis, which should be attractive, feasible and understandable for them. The GiBUU simulation package on high energy reactions [4] has been a very useful tool in order to understand better the reaction systems. By simulating reactions of incident electrons to various nuclei at available beam energies at DESY, the students analysed characteristics of particles that were produced within such reactions. They analysed the cross-section as a function of beam energies of electrons to nuclei in the target. Very interesting particles that were produced in simulations at assumed beam energies of electrons (0.5 to 6 GeV/c^2) were pions.

After a series of lectures, discussions and simulations, the students accepted the following hypothesis – ”The ratio of the number of positive and negative pions, formed in the reactions of electrons to nuclei in targets, depends on their quark structure, which should be reflected in the cross-section of scattered electrons on targets”.

Students decided to use targets made of aluminium, copper, lead and silver where the ratio of neutrons to protons is significantly different from the ratio of down (d) and up (u) quarks, and an alloy (60% Cu + 40% Pb) which the ratio of the number of down (d) and up (u) quarks is the same as that of a silver target. Students expected that at high beam energies of electrons, of about 1 GeV/c^2, the influence of the quark structure of nuclei in the target will be more pronounced because the wavelength of those incident electrons is smaller than the dimension of neutrons and protons.

The qualitative picture of the cross section of electrons to a target of various nuclei is presented in the following picture [6].

From the cross-section we expect to recognise different types of electron scattering on target nuclei, such as: un-scattered electrons, elastic scattering on nuclei, approximately elastic scattering on nucleons, inelastic scattering in which new particles are formed, deeply inelastic scattering. After

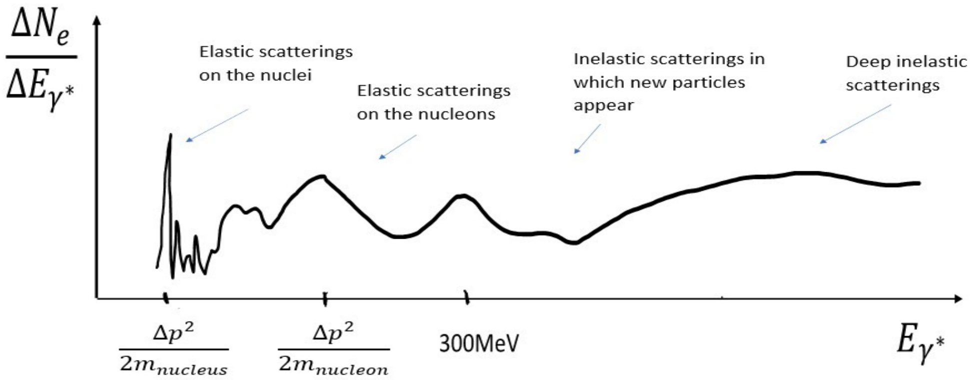

Fig.1. Qualitative illustration of the cross-section of scattered electrons on various nuclei as a function of energy transfer.

taught activities, learning and discussions with experts, the team of talented students independently compiled an application for the competition on experiments at DESY, in which they described, among other details, how they want to get the experimental cross-section of scattered electrons on different targets, energy transfer and transfer of momenta.

3. Preparation of the Experimental Setup

In order to select the required experimental devices and to design the experimental setup, the team of students analysed all the offered devices from the guidelines published on the Beamline for schools competition website [3].

The first part of the experimental setup is a permanent component which creates a beam of incident electrons and positrons of energy between 0.5 and 6 GeV/c^2 with 10000 particles per second. The other parts of experimental setup have been chosen according to their characteristics – beam telescope, delay wire chamber, dipole magnet and electromagnetic calorimeter.

The thickness of the target was determined taking into account the total available time to conduct the experiment and estimation of cross-sections.

4. Assessment of Learning Outcomes

By preparing this research project, the involved students have achieved the following subject knowledge and skills and wider cross-sectoral competences:

- Describe basic characteristics of elementary particles,
- Describe and applies concepts of special relativity theory,
- Explain the trajectory of a charged particle in a magnetic field,
- Apply concepts of the wave nature of the particles,
- Install and use the computer simulation packages in order to determine quantities that require complex mathematical calculations,
- Apply laws of energy and momenta conservations,
- Adapt and apply information technologies,
- Responsibly perform accepted tasks in the project,
- Successfully collaborate and communicate with other members during teamwork,
- Successfully self-organise and participate in the organisation of teamwork,
- Successfully communicate with scientists at universities and research institutes in foreign language,
- Preparation of presentations and videos.

The summative assessment has been carried out by allocation of grades for key steps during the preparation of research project, which includes the elaboration of a theoretical ideas, installation and running the simulation packages, analysing of data obtained by simulation, selection of relevant literature, communication with experts, elaboration of hypothesis, elaboration of selected detectors and other devices for the experimental setup, preparation and recording of 1-minute video for

competition. In addition to the summative assessment, we have prepared 10 questions for a formative assessment to evaluate the achieved knowledge and skills in high energy physics.
In order to evaluate our teaching and training activities with talented students (third grade, as a focused group), we asked also the final year students (fourth grade, as a control group) to answer the same set of questions. The overall success for the controlled group was only 48,1 %, and for the focused group the success was 78,0 %, which demonstrates the value of teaching and training activities with talented students.

5. Discussion and Conclusion

The science project activities, as presented in this paper, are very motivating, enabling progress for both, to students and to their teachers. Such activities make also possible to connect students from other schools and countries in a joint team, as well as to connect talented students in different fields – physics and other natural science, mathematics, information technologies, arts, photography and others. The science project activities enable talented high school students to go through all steps of a modern and authentic research very early and to become partially involved in it, while deepening the cooperation of high schools with universities and world-famous research institutions, which is recommended in many national curricula.
In this paper we have presented the engagement of a group of students, as extracurricular activities, in the preparation of a real research project in high energy physics. In order to create a methodology for optimal enhancement of talented students' according to their potentials, interests and unpredicted future, further activities and analyses are needed.

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