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ARTICLE

Research-based teaching at Wigner Research Centre for Physics, Hungary[1]

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Abstract: Teaching modern physics in school is a hard task. This is especially true for particle physics where the typical size scale is 10^{-18} m. It is difficult to visualize these particles, which are invisible to the eye, or to make experiments. At the same time the number of scientists and engineers is decreasing in Hungary. It is obvious that we need to find ways to interest students in these professions. In Budapest, at the Wigner Research Centre for Physics of the Hungarian Academy of Sciences, a research laboratory was established for high school students where, under the supervision of teachers and with the help of the local scientists, students can take part in particle physics research. In the program students can get involved in real work and construct particle detectors for demonstration purposes. Measurements prove the positive change in the students' attitude, motivation, and particular knowledge of the subject.

Key words: research-based teaching, motivating students, winning students for science, particle detectors, teaching particle physics.

Résumé : L'enseignement de la physique moderne à l'école est une tâche difficile. Ceci est particulièrement vrai pour la physique des particules où l'échelle de grandeur est de l'ordre de 10^{-18} m. Il est difficile de visualiser ces particules invisibles à l'œil ou de concevoir des expériences les concernant. Dans le même temps, le nombre de scientifiques et d'ingénieurs décroit en Hongrie. Il est évident que nous devons trouver des moyens pour attirer des étudiant/es dans ces professions. À Budapest, au Centre de recherche Wigner pour la physique de l'Académie des Sciences de Hongrie, un laboratoire de recherche a été établi pour les étudiant/e/s du secondaire, où sous la supervision de professeurs et avec l'aide de scientifiques locaux, les étudiants peuvent participer à des recherches en physique des particules. [Traduit par la Rédaction]

Mots-clés : enseignement basé sur la recherche, motivation des étudiants, intéresser les étudiants aux sciences, détecteurs de particules, enseignement de la physique en équipe.

Changes are needed in teaching physics

Teaching physics has gone through fundamental changes in the last few years, mostly thanks to the initiation of the national curriculum. The different disciplines have started to fuse into one and the curriculum advises new ways of finding these connections between several subjects. The driving principle is to evolve a universal way of thinking in the natural sciences among students. If these skills and the proper knowledge of natural sciences are obtained, it makes them capable of utilizing those in practice. The development is embedded in the content and is in close relation to the key concepts, fundamental theories, and models. Inquiry or inquiry-based teaching is also emphasized in teaching science worldwide [1] and in Hungary [2] as well. According to Yager, in high school science little change seems to occur; inquiry alone is a word with no unique meaning [1]. Beside this, there is a difference between its meaning in general and in science education. The National Research Council in its Inquiry volume lists five essential features for classroom inquiry in which the role and importance of questioning, evidence, explanation, and comparing explanations is mentioned [3]. There are aspirations concerning the fact that students should deal with so-called "open problems"; teachers should not tell the result of an experiment, for instance [4], which can facilitate their inquiry and creativity. In Sokoloff's eight-step process in active learning every step has a role [5]. By asking students to make predictions before experiments we wake up their inquiry and by asking them to talk about their predictions in small groups we make them participate in the process. After making predictions, they are involved, so they are interested in the outcome of the experiment. It is clear that in teaching science the role of students' active participation, their engagement in questioning and finding an explanation, is essential.

It is also a known problem worldwide that fewer high school students choose physics or the stream of research. Therefore, changes need to be made from both sides: both in education and research institutes as well.

Researcher–teacher laboratory

Péter Lévai, the Director General of Wigner Research Centre for Physics of the Hungarian Academy of Sciences, also has recognized that the institute needs an influx of new researchers and started to work on a solution of the problem. The aim was to find and educate science-oriented young people in the rising generation. Among other programs — like open days, which are only a

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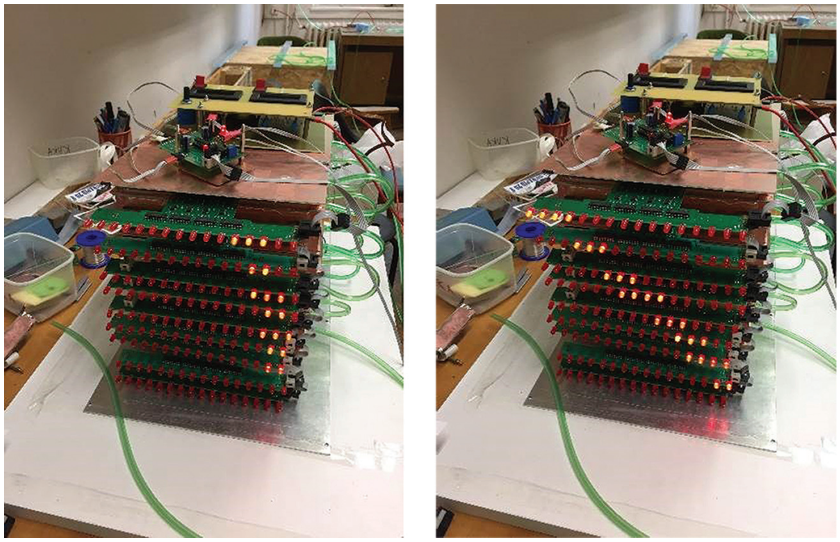
Fig. 1. The LED lights show the track of the particles traveling through the detector. [Colour online.]



day long — his new action was to establish a research laboratory where, after their classes, high school students can perform various jobs in a weekly practice and take part in the research activities of the physicists. Research-based education is widely used in lots of countries, although in our country it is still not implemented. That is why the initiation was innovative.

Such a program provides aims and questions for the students. They get engaged when applying for the participation, they have the possibility to ask questions, find answers, and change their concepts according to their findings. They also have to find appropriate or sometimes alternative tools for the experiences. During the research, students can get acquainted with certain areas of physics that are not part of high school material. For example, the curriculum does contain the physics of the atomic nucleus and quantum mechanics, but the discussion of what is inside the nucleus still remains a study group field.

For the first time, the so-called "researcher–teacher program" was announced as a pilot program by the Wigner Research Centre for Physics, with the purpose of enabling the involvement of physics teachers along with their students in active research. In the school year 2017–2018 two high schools from Budapest (Fazekas Mihály Primary and Secondary School and Baár-Madas Secondary School) earned the opportunity to let chosen students, led by their physics teachers, take part in a detector constructing program. Éva Oláh has been working on research-based teaching for multiple years with the support of the detector developer laboratory and its employees. Right now, she is guiding a research group containing only girls from the 10th grade of Bálint Márton High School. Three different groups from distinct schools made up of three to four members took part in the experimental program. They visited the research centre weekly in the afternoons after school.

A group in the institute undertook the task and the responsibility of hosting and working with students. The Innovative Gaseous Particle Detector Development Research Group performs international level research, for example, they take part in the ALICE experiment at CERN and the development of the so-called time projection chambers (TPC). They have also achieved remarkable accomplishments in the research together with the University of Tokyo. They develop muon-detectors (AHEP) for mapping large objects (e.g., active volcanoes). It is an enormous achievement that high school students have been given a role in these activities, and it is even more incredible that they can contribute the construction of professional tools.

The detector

In addition to the professional muon detectors, which received international fame, we have designed with the help of the research team an apparatus that can be used in high school, or even at the university B.Sc. level for demonstrative teaching of modern physics. It is based on the multi-wire proportional chamber (MWPC) [6] by George Charpak (Nobel Prize, 1992) which is widely used to obtain various information via detecting cosmic muons. The chamber is based on the ionizing effect of charged particles. It works similarly to the Geiger–Müller counter [7]. The particle passing through the inner part of the detector collides with the atoms of the gas inside, and the abruptly formed and accelerated free electrons make further collisions, creating an electron avalanche, which induces a signal on the conductor threads inside the chamber [8]. The purpose of the many threads is to enable us to determine the path of the particle from the location of the electronic signals.

Particle physics is not included in the National Curriculum in Hungary, but the contemporary research results and their appearance in the media makes it necessary to deal with this topic, at least facultatively. For this purpose, the Department of High-Energy Physics of Wigner Research Centre for Physics provides facilities.

The students enjoy performing experiments in the classes and we teachers try to reach a better understanding using demonstrative methods and models. With that aim we like to use the famous "hands-on minds-on" teaching method, but modern physics provides very limited ways to do this. Teaching elementary particle physics is especially hard as those processes are difficult to visualize.

The detector we have built is for demonstration purposes so instead of collecting data it shows the tracks of invisible particles by using LED lights (Fig. 1).

Building of the chamber

Before the various work processes, the students took part in preparatory theoretical classes when the leading researchers of the laboratory told them what, why, and how to use the equipment, what kind of process resulted in the design of the devices, and of course the necessary physical background was discussed with the students. They talk about the principle of operation of the chamber, phenomena like ionizing, electron avalanche, and particles that can be detected by the chamber.

Fig. 2. Special tool for arranging the wires. [Colour online.]

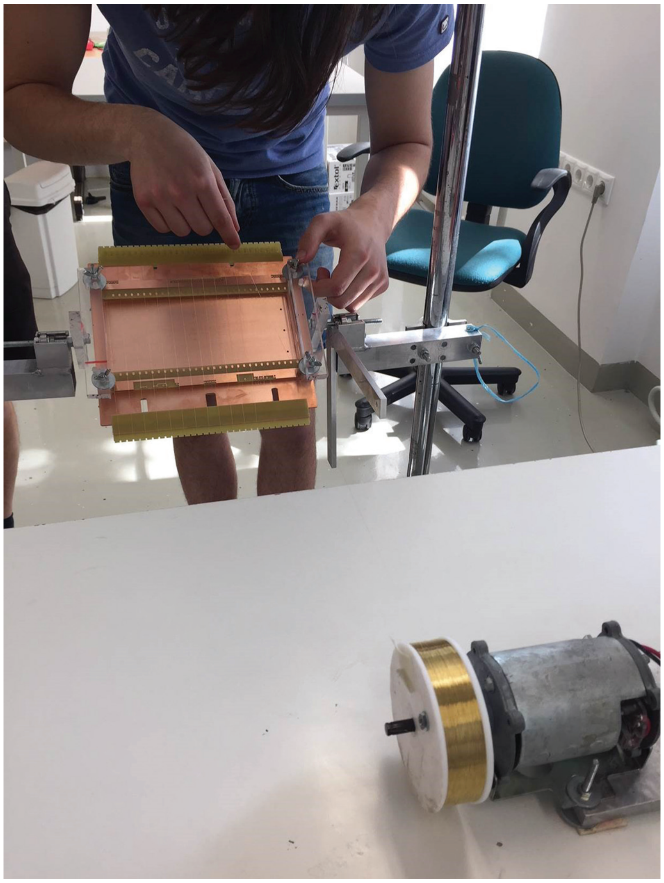
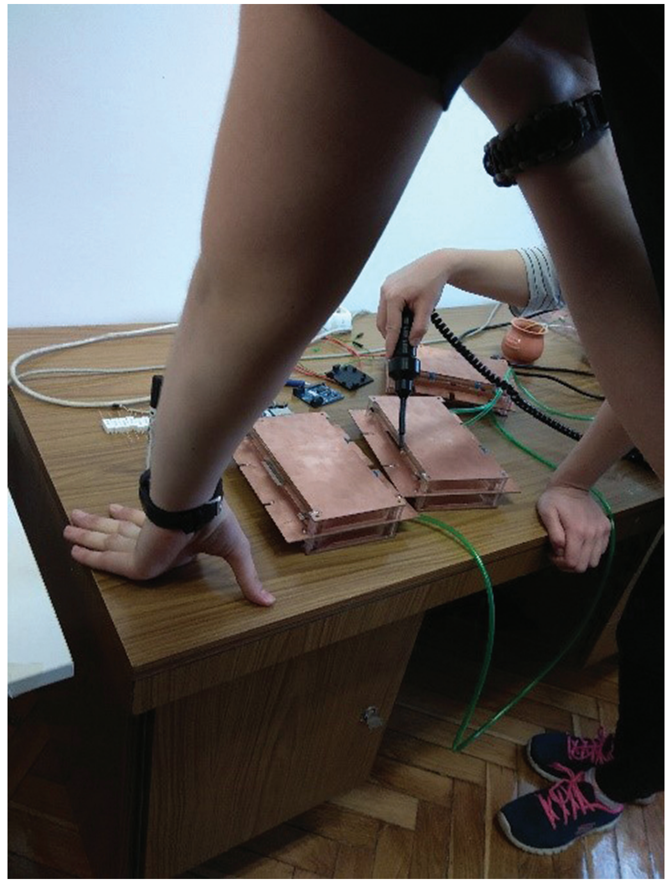


Fig. 3. Using leak hunter for finding holes. [Colour online.]



The base and the top cover of the chamber are two printed circuit board (PCB) plates while the sidewalls are made of plexiglass. After precise setting, we fix these plates by using a two-part epoxy. The special wires are wound up to their places using a device particularly implemented for this task, then soldered to the plate (Fig. 2). The thicker threads are typically made out of bronze with a thickness of 100 μm and the thinner ones of gold-plated tungsten with a thickness of 24 μm. The distance between the two wires is 12 mm. The anode threads, these are the earlier mentioned W–Au threads, are connected to 1650 V high voltage. The sufficiently small diameter is important to maintain the magnitude of the field strength and they must also withstand the mechanical stress. This represents a considerable part of the expenses, because of the high price of the gold-plated thread. The institution-invented winding device makes the work more convenient and faster but also reduces the amount of wasted threads. It is used in the following way. We take two chambers and fix them to the two sides of a frame that can rotate around a horizontal axis. On the two sides of the frame parallel to the axis, one can find a plastic cylinder with properly placed grooves on it. These grooves help stabilizing the threads while winding. At the end of the procedure, we finalize the fixing by soldering the wires down. Using this method, we can wind up two chambers at once while only those pieces of wire fall off needed for the turn. The thicker threads mentioned above are called "field-forming" threads and are placed alternately between two anode threads and optimize the arrangement of the lines of force in space. These are coiled to the chamber with the same tool and connected to ground potential, just like the top and bottom plates. After sealing the chambers, we check whether there are any holes left where gas can permeate. This is not an easy task because these holes usually cannot be seen. Therefore, we use special gas leak-detecting machines (Fig. 3). When the detector is ready, we slowly fill it with gas at a speed of 5 L/h and continue to do so while the detector is working. Based on a series of experiences it can be said that the most advantageous gas we can use in the chambers is a mixture of 80% argon and 20% carbon dioxide.

The chambers produced by us have a base area of 20 cm by 12 cm and a height of 2 cm. Occasionally, students help with building the 80 cm by 80 cm (base area) detectors. Thanks to the recent innovations of the institution's physicists, we also build 120 cm by 80 cm devices.

During the construction and measurements the students get acquainted with various concepts and laws of physics and also with various manual tasks. While arranging the wires in the chamber we have to talk about electrostatics and electrostatic fields. When filling the detector with gas, students asked about the role of carbon dioxide, trying to find out why this proportion of the different gases is optimal. Besides, theoretical knowledge, students improved their manual skills. They got to perform tasks that they would never be able to get acquainted with in a high school environment. They used industrial drills, saws, and cutting equipment in the workshops to prepare the fundamental parts of the detectors, naturally under proper supervision. During these works many unplanned phenomena occurred. For instance, when cutting the wires, we talked about peak effect, and when drilling the parts made of plastic, they realized that it melted, so had to be drilled discontinuously. These unplanned lessons added something that we usually cannot produce in routine lessons in school.

Teachers do not always know the answers to the questions that arise during the works; we also continuously need to learn from the professional physicists of the field, however, in today's quickly developing world we have to be informed about the latest research results, too. There are topics such as electrodynamics, which are part of the high school curriculum, but alongside those, we must deal with disciplines like particle physics, the theory of relativity, and quantum mechanics, which are discussed in additional courses or at higher-level lessons in the best case.

Experiencing the whole process, students realized that science improves by small steps that sometimes are difficult or tiring. There were moments when we did not really see the end of the process, moments when we did not know how to correct a mistake, but in the time we planned we completed the detector and it worked. We had help, but these experiences showed that it is not always clear how to solve particular problems. Researching means finding these solutions.

The program altogether took two school years, with students having built two detectors. In the first half year the parts of the detector were completed. After that, we had to find and fill the holes, put parts together, and see if it worked, which took another half year. The scenario was similar in the second year, but new members had the possibility to join the program. In this second year the first few participants had new roles: they helped and taught the new members of the group, which also helps in learning and understanding.

Results

Beyond the detector

The students who took part in the work were enthusiastic and open-minded previously as well, besides active participation in the lessons we could count on them in other physics-related programs too. The conversations conducted with students also showed that they acquire a lot of knowledge on their own, and always try to dig into the subject. During the program, their classmates got involved as well and a change in their attitudes to science and undertaking extra tasks was perceived. This encouraged us to continue the work in similar programs. We found new connections to different institutes and universities and launched new researching student groups with their help.

Participant students introduced their work in their own schools and for others in different events. They also made measurements next to mountains, observing the changes in muon flux. These programs gave them self-confidence, and hopefully their experiences will help them later in similar situations.

At the end of the second year-long program we asked the participating students to fill in an attitude test. The questions were divided into three groups. In the first part we asked students to write freely about what they liked, what they did not like, and what they learnt in the program. According to their answers, most of them enjoyed getting insight into the life of researchers, in the everyday life of a research center. They listed different aspects of physics as what they learnt, but mainly particle physics. Most of the students left the dislikes unfilled; we got only two answers. One of the participants mentioned that sometimes it felt inconvenient to miss lessons because of the program, the other would have appreciated if we had dealt with electronics more. (Students missed two lessons in a week in school when going to the Research Center.)

In the second part of the questionnaire we listed statements about the program and participating in it and asked students to indicate on a 1–6 scale how true they find it for themselves. Answers show that they enjoyed working on the project and working in a group, learnt more than in school, and would take part in similar projects. They found the mentor student relationship a bit different from the teacher student relationship but not as much as we expected. In our opinion, it is because the teacher student relationship changed in an out-of-school environment, working together brought all the participants closer together.

With the third part of the questionnaire our aim was to find the changes the program made in the students' knowledge and attitudes toward science, their plans, and their own potential. Answers confirmed that the program affected their plans for further education, their attitude to physics as a subject and as a profession, their self-evaluation, and their idea of their own capabilities. In this part we asked them again to write freely about the changes they found important. Some of the answers are as follows:

"My experiences put physicist profession in a new light."

"Now I know that I am able to do similar works so my attitude to my own possibilities has changed."

"I wanted to be a physicist, now I want to be an engineer instead."

"I got more interested in the parts of sciences I not used to be."

"I got to know the different fields of physics, it makes easier to choose a profession."

"Now I see why we learn that things in the school."

"The physicists and my mates were a host company, I am glad to be the member of this group."

Plans for the future

Wigner Research Centre for Physics of the Hungarian Academy of Sciences has already advertised the opportunity of participating in the program for the next school year. This means that the plan is to continue the work in the next years, finding new attendees in every year. A new viewpoint occurred to affect the choice of the next participants. The leaders of the Wigner Research Centre decided to help teachers to commence and complete their studies in a Ph.D. program of methodology of teaching physics. According to it Ph.D. students or those who plan to commence Ph.D. studies are favored in the choice of the next participants of the program.

By now there are similar initiatives at various institutes in the country. We have regular relations with other research groups, comparing experiences we find very important to learn from each other. The long-range goal is to form a country-wide network.

Summary

Doing research seems to give even more opportunity for learning than expected. While at classes we mostly introduce new topics in an inductive way, these research projects allow them to learn the theory without even noticing through experimenting and constructing. They realize themselves what knowledge is required for a deeper understanding of how a device works. As mentors, we are always with them while working and usually talk to them about further interesting fields. Besides this, the program is quite motivating in itself too. The extent of curiosity is the only limit for them to acquire even more knowledge. The program presents an extraordinary opportunity, but maybe the method itself to learn actively can be implanted into the school environment. While participating in building the detector, students could realize that research includes consecutive steps. In some cases, during a particular activity we do not see its utility, but it is still part of the process that leads to finding something new. The effects of the program are observable not only on the participants but on their classmates as well. It is motivating and encourages students and also teachers to find new ways of experimental learning and teaching.

As the answers to the attitude test's questions show, students feel that their knowledge and self-confidence has improved and they are more aware of their further plans and their motivation is stronger than before. All the participant students have chosen to learn physics at the advanced level in 11th and 12th grade. Some of them are applying for colleges nowadays and it seems that most of them chose physics at university as well.

Acknowledgements

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