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A Teacher's Perspective on the CERN Beamline for Schools Competition

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We are a group of teachers who have independently participated in the CERN Beamline for Schools (BL4S) competition with teams of high school students from our schools between 2014 and 2021. All of our teams won the competition, and therefore our students had the opportunity to perform their proposed experiments at a particle accelerator. The experience of mentoring a team has been extremely beneficial to our professional development. In this paper, we will describe the effects that the participation in BL4S had on us, on our students and how it has impacted our approach to teaching STEM subjects.

Keywords: BL4S; DESY; CERN; high school students; science competition.

1. Introduction

Since 2014, CERN,[1] the European Center for Nuclear Research in Geneva, Switzerland, has organized an annual physics competition: Beamline for Schools.[2] This competition is open to teams of high school students from all around the world who are invited to conceive of an experiment that can be realized at the test beam facility of a particle accelerator. The experimental proposals are reviewed by a group of experienced scientists, and each year two teams win the opportunity to conduct their experiments at a particle physics laboratory.

This procedure is very similar to the one that teams of scientists must follow in order to request experimental time at a particle physics facility like CERN. The proposals consist of a written document (approximately 1000 words long) accompanied by a short creative video. The criteria considered by the judges to select the winners are:

- Student motivation
- Creativity of the idea
- Feasibility of the experiment
- Adherence to the scientific method

In order to prepare a proposal, the participants can consult a series of documents that provide a precise description of the experimental setup available for the competition[3] and a list of example experiments.[4] These resources can be a source of inspiration. In addition, participants have access to the proposals of all the winners of the past editions of the competition.[5]

Since the first edition of Beamline for Schools, 16 teams and more than 100 students have been invited to a test beam facility to perform their experiments. Until 2018, the Beamline for Schools experiments took place at CERN. Between 2019 and 2021, during the maintenance of the CERN accelerator complex, they took place at DESY,[6] The German Electron Synchrotron in Hamburg, Germany.

Beamline for Schools is very challenging for its participants, as they are faced with a project well beyond the expertise of traditional high school students. Nevertheless, they are not alone, and each team is represented by an adult supervisor, or "team coach". The coaches are usually school teachers who, on a voluntary basis, mentor the students and help them to establish contacts with experts that provide them with further guidance.

We are a group of high school teachers from different schools in different countries who took part in BL4S independently from each other, and we all led a team that won the competition between 2014 and 2021. Despite our different school systems and cultural backgrounds, we realized that our coaching approaches have many similarities and that the benefits that the competition had on us as teachers and on our students were very similar. In this paper, we summarize what we think are the most important effects of taking part in the competition on our personal and professional development and the impact it had on our students. Each message is correlated to personal statements and anecdotes.

2. The Main Impact of BL4S on the Teachers

2.1. *The role of the team coaches*

We all learned about Beamline for Schools in different ways, because CERN advertises the competition on many channels, including social media. Some of us have directly learned about the competition and shared the information with our students. In other cases we have been brought into the competition by our students, who heard about the competition, gathered a group of classmates with similar interests, and then contacted a teacher with a request to coach them. No matter how the team came about, we eventually all faced the same problem: providing the students an environment that allowed them to come up with a good proposal. The team coach does not need to be an expert in particle physics, but rather a motivator and leader who can guide the students to do their own research, to solve problems and to seek the help of experts where necessary. Shyam Wuppuluri, coach of an Indian team winning the competition in 2018, inspired his team by asking the question "what is reality?" He engaged in open and unstructured discussions with students and allowed the students' interest to guide their research and proposal, while keeping in mind the experimental constraints of the competition.

Using a long-standing collaboration with a local university, Marina and Kirsten, coaches of winning teams in 2021 and 2019, respectively, connected their students with professors of physics who discussed possible experiments. One of Kirsten's students also got in touch with a former BL4S winner who gave important tips on how to build a proposal. Later, once Kirsten's team won the competition, this same former winner came to her school to teach the team some basics about coding.

Fig. 1. Shyam Wuppuluri, coach of the "Criptic Ontic Team" who won BL4S in 2018, during a visit to a CERN facility with his students.

Similarly, Thomas, one of the coaches of the Swiss team, winner in 2020, coached his team more towards developing soft networking, communication and collaboration skills than the hard skills associated with high-energy physics. He guided his team to look for expert guidance in planning their experiments, and encouraged them to contact various researchers at CERN.

Despite the help from external experts, our role as team coaches still required us to have a deep understanding of the experiment that was going to be proposed. For many of us this was not an easy task because particle physics is not part of or our regular curriculum.

Laura, team coach of the Mexican team who won the 2021 edition of the competition, says: "*To be honest, during the preparation of the proposal, I was tempted to give up. But then I realized that, by staying in the project, I would be giving them a good example of perseverance. When I chose to take on this challenge with them I realized that I didn't only commit to them but also to myself.*"

Denis Jacques, coach of the Canadian winning team of BL4S 2017, adds: "*being a team coach exposes your strengths and weaknesses. BL4S challenged and changed me to my very core. Coaching, without having all the pieces in place, is where you discover a little more about yourself. Thank you BL4S.*"

Thomas likewise found the intricacies of high-energy physics challenging and had to attend several workshop sessions on the topic with (and organized by) his team members before he felt confident in offering any input from a scientific perspective (and even then, the students often found solutions independently). This was challenging alongside a full-time teaching schedule, but the students were doing it alongside a full-time learning schedule, so it gave him an incredibly valuable perspective on what students actually go through on a day-to-day basis.

Through this adventure, we found that we were going beyond our usual role of teachers and subject experts, and we showed our students that we are still learners (see Fig. 2). We shared that we do not know everything, and that we do not have all the answers. We found that we have as much to learn as our students.

In addition, the nature of this challenge lends itself very well to project-based learning, which is already common practice in some of our schools.

Fig. 2. On the right, Stefania Turbacci, coach of the "Team Extra" winner in 2021, works with her students on the analysis of their experimental data at DESY. Data analysis of particle physics data was new for her students as well as for her.

Manuela, one of the coaches leading the Italian team, winner in 2015, writes: "*The work-mode was based on a Cooperative Learning approach. This approach is a teaching and learning tool where groups of people work together on a common project. Each group member, or sub-group of students, is responsible for part of the group work, which is later evaluated as a whole. It is a teaching and learning strategy which integrates interaction and communication in the classroom with the study process of school contents. It enables students to learn, and, at the same time, creates a social system based on cooperation and coordination. The main idea of Cooperative Learning is to stimulate social interdependence, that is the relationship that is established between people to achieve a common goal, the responsibility for achieving that goal or not is entrusted to the whole group. In my class, there were three working groups with very specific and well-defined tasks*:

- *Scientific committee, which mainly dealt with the drafting of the project*
- *Technical Committee, which created some devices for the experiment*
- *Artistic committee, which worked on the creation and production of the video*"

Stefania, team coach of the Italian team, winner in 2021, states: "*As a coach, I worked to build relationships; to find ways to best support students' resilience and continued learning as well as to inspire students to engage with the project.*

Collaboration improves existing skills and encourages the sharing of knowledge and experience. For example, students much stronger in computer science than their peers, helped less experienced students. By shifting my role from instructor to coach, I have promoted team autonomy, checking in on students, providing immediate feedback, and helping them learn to work together productively to attain a common goal."

Like others, Thomas feels that the role of coach was much more about guiding the students and motivating them than providing solutions. This required modeling attributes such as patience, and determination, and exposing vulnerabilities. Establishing a working relationship with the students, based on trust, equity and respect, was essential. Once this was achieved, team dynamics and roles evolved in a natural way.

On the technical side, we and our students read the documentation about the properties of the beamline as well as the information about detectors provided by the organizers of BL4S. This document contained a lot of technical information that was unfamiliar to us. For example, some of us had to learn the basics of particle-matter interaction in order to understand the principles of how detectors such as scintillators or silicon pixel sensors function. In order to support our students, others had to update themselves on physics effects such as Cherenkov light, transition radiation or electromagnetic showers. Since most of these topics are not part of the high school physics curricula, the involvement in BL4S helped us to update and extend our knowledge of contemporary physics. This learning experience started during the preparation of our proposals but was much more intense during the two weeks we spent at CERN or DESY, together with our students. Running their experiments required them to go through a very steep learning curve. They not only had to understand in detail the experimental set-ups as well as the computer systems that were used for the acquisition of data, but they also had to acquire data analysis skills and to learn to use tools such as the ROOT S/W package.[7] In order to support the students, we went through a similar learning curve along with them. It has been truly amazing for several of us to recognize how much we have learned during the two weeks of our students' experiment.

Fig. 3. In the foreground on the left, Uriel Garcia Elorza, coach of the "Teomitzli team", winner in 2021, listens to the explanation of a data acquisition setup together with a group of students at DESY.

2.2. *The effects on our teaching and the creation of new educational offers at our schools*

Asked about the long term impact of BL4S on his school, Denis Jacques says: "*BL4S continues to shape our school five years later. Our uptake of Physics classes has increased by 40%. Furthermore, we have developed a High Skills Specialist Certification Program for* 40+ *students that encompasses physics, technology and the arts programs.*"

We have often realized that the tools we became familiar with through the competition lend themselves well to improving the educational opportunities at our schools. Maria Rita, coach of a winning team in 2017, writes: "*The experience of BL4S continues to have important echoes in my school. We have been conducting a Python Data Analysis course for students in the third, fourth and fifth classes* (*i.e. the last three classes of Italian high schools*)*, currently involving around* 40 *students.*"

About the role of extra-curricular activities like taking part in BL4S, Stefania Turbacci says: "*the more interested students are in a subject, the more involved they become in their assignments, putting effort into their studies and engaging in deeper levels of thinking. For this reason, we are carrying on with an outreach program in penultimate and final year classes, we are organizing courses aimed at providing technical skills about coding/scripting aspects for data analysis and planning activities on physics topics that are not a part of our regular school teaching.*"

[Thomas Riis-Johannessen] In Thomas' school, the winning BL4S team's achievements really captured the imagination of the community. Within the school, their legacy has taken the form of a thriving STEM club, led and run by students in the penultimate year group. Members of this club are still competing in competitions such as BL4S. In addition to this, they have created a rich extra-curricular program which features (i) talks (on all STEM subjects) from invited speakers, (ii) tutoring/support/workshop session for students in the younger years, (iii) Science promotion and outreach within the school community (maintaining digital displays, display cabinets, etc.).

We believe that the contact with contemporary science can be more motivational to students than the teaching of classical material. In this respect, the "physics masterclasses" that are offered by IPPOG (International Particle Physics Outreach Group)[8] are also a very interesting initiative.

3. The Impact of BL4S on Our Students

CERN recommends BL4S for students aged 16 to 19. Some of us had a few students that already at the age of 15 or 16 were capable of making a contribution. In most cases, however, our teams were composed of students that were in their last two years of high school (17 to 19 years old). In a number of cases, our teams developed through the interaction of younger students with older and more experienced ones, over multiple years. Some of us found it impressive to see the extent to which students in the younger years became engaged in Physics, and Science in general, when they heard about the success of their older schoolmates in the competition.

Once these students decided to take the challenge of proposing an experiment for BL4S, they developed an impressive amount of self-motivation. According to the data collected by the organizers of BL4S, on average (median value) the members of a team spend 30–40 hours on the development of their proposal. This is remarkable because the students prepare their proposal for BL4S in parallel with their school duties. In some cases, they must simultaneously prepare their final exams. What makes them accept this additional burden is probably not only the prospect of winning the competition and the opportunity to compete with teams from other countries, but also the interest in learning more about physics, engineering or software development. Some of us teachers have participated in BL4S for several years in a row with different teams of students. The rules of BL4S do not require a team or school to propose a new experiment each year but they encourage schools to refine their proposals from year to year.

For us teachers, this has several advantages. In the first year of participation, we have to invest a lot of time in order to get familiar with the competition. As we continue to engage in the competition, the workload is much reduced because the boundary conditions of the competition do not change much. More importantly, a multi-year participation allows students that are leaving the school or that have to focus on their final exams to pass their project on to younger students. This provides an opportunity for students from different years to work on a common project and allows the older students to pass on their knowledge to the team that takes the project over from them.

Maria Rita's winning team, for example, was the second generation of students working on a proposal about a Cherenkov detector.[9] The "first generation" team had the idea to work on a detector, they built a prototype and analyzed some data. The submission of this team was included in the "short-list" of BL4S, i.e. it was among the 20 best proposals, but did not win. The "second generation" team took over the project from their predecessors and won the competition. Sharing projects from generation to generation of students is very similar to what happens for scientists who might need decades, and one or more generations of scientists, to complete a research project.

The team building process of Enrique and Alison, coaches of one of the winning teams of BL4S 2019, was similar. Individual students graduated and new, younger students joined, but proposals or general ideas for proposals are often continued multiple years in a row.

Consequently, it makes a lot of sense to merge students from different years from the beginning when starting a team. This does not even have to be limited to students from just one school. The organizers of BL4S receive a growing number of proposals from multinational teams. One example is a school from Argentina that regularly includes students from Japan in their team.

Another aspect of BL4S that is very beneficial to the students is that it motivates them to get in touch with a university-level scientific environment

Fig. 4. In the center, Alison Bulson and her colleague Enrique with their team, the "DESY Chain" at their arrival in Hamburg in 2019.

at a crucial moment in their career, when they have to decide if they want to enroll at a university and choose a subject of study. Some of our schools have long standing links to local universities.

Manuela writes: "*My team already had experience in collaborating with scientists, due to their work with LENS — UNIFI and the National Institute of Nuclear Physics, Florence (INFN): The collaboration with research institutions allowed my students to approach complex problems. The students were encouraged to look at things from different perspectives; to ask themselves how they work, to understand how it is possible to exploit the technology available for different uses.*"

Stefania adds: "*For several years my school has been participating in a project aimed at detecting secondary cosmic particles. The project, as well as BL4S, has an educational and outreach objective, its goal being to motivate young people by involving them directly in a real experiment, students and teachers, supported by researchers, are involved in the construction, testing and start-up of the telescope in their school, then in its maintenance and data-acquisition, and later in the analysis of the data.*"

In Thomas' school, research links with the wider Scientific community were quite few and far between before BL4S. The BL4S project was the first time students from the school engaged in a long-term collaborative effort with researchers in the field of high-energy physics and, indeed, the school continues to nurture the links established from its first winning team.

We have also observed that the contact with researchers and engineers at CERN, even if very short, could trigger a process in the students' minds that make a large impact on their career choices. One female member of a Polish winning team in 2016 decided to study mechanical engineering because she was fascinated by the machines that she saw in CERN's mechanical workshop.

Maria Rita reports an example: "*Speaking to a girl in my team, who is now in a Medical and Surgery school, I made an interesting discovery: The choice, as she told me, was born during her stay at CERN. Learning about Hadron therapy and, above all, developing the feeling that the difficult things are the most stimulating and most interesting has determined her future orientation.*"

Even when teams have no direct contacts with a university, students are exposed to professional science. As students read scientific papers and books to research for the experiment proposal, they not only learn the jargon that is spoken in these communities, but also learn how experiments are designed and scientific results are presented.

While, in the first place, a BL4S proposal is about physics, there are many other skills required for a team that wants to make a high quality proposal. This enables students with different interests and skills to contribute their own unique ideas. While some students in a team focus on the physics, others look at the engineering aspects (e.g. the properties of the available detectors), the development of software (e.g. to simulate aspects of the experiment), project management, or even artistic (production of the video) and language-related aspects. This allows the students to realize that each one can contribute their personals skills to a multidisciplinary project. For many students this resulted in a strengthening of their self-confidence and communication skills. Lise Knapp, Vice Principal of École secondaire catholique Père-René-de-Galinée, Cambridge (Ontario), Canada and coach of one of the winning teams of the 2017 edition, writes: "*I was impressed by the improvement in their knowledge and in their desire to communicate their findings. We had the opportunity to share their experience mid-way through the experiment via a teleconference and a question and answer session with their classmates back in Canada. Everyone was excited to listen, to ask questions and our student team prepared their presentations well and were motivated to share their real life experience.*

This self confidence arose from the fact that they had an experience that was "out of this world", that was hands-on and that required teamwork. All skills necessary for the 21st century."

Marina, coach of the Italian team that won in 2021, states: "*As a winning team, our students spent two weeks at DESY in September 2021. Not to speak about the incredible opportunity to experience the typical day schedule of a researcher and the amount of technical and scientific knowledge they gained during this time, they got a strong human experience of work, perseverance, self-confidence and generosity toward each other. We believe that this experience will be fundamental for their future choices.*"

What has been described above applies to every team that participates in BL4S, and not only to the few teams that win the competition. We want to express clearly that participation itself is the most important aspect of the competition. There is much to be gained, for students and teachers alike, in the process of researching and proposing a high-energy particle physics experiment. However, there is one aspect of BL4S that is limited to the winners. The organizers of the competition encourage the teams to document the results of their experiments in a scientific paper. This is a challenging task and not all of our teams have been able to take this opportunity because some of our teams dispersed once the students left secondary school. A few teams have stayed connected for up to two years after their departure from CERN or DESY and have continued to analyze their data and write a paper for publication. The BL4S organizers stayed in contact with the teams for this entire period and assisted them as required. In the end, some papers have been published in peer-reviewed journals. It is difficult to judge how much of an impact these publications had or will have on the careers of our students, but all students involved have been incredibly proud of their achievements.

4. Summary and Conclusions

BL4S is demanding. For us teachers it has meant additional, often voluntary tasks, that required us to go through a steep learning curve. We find the extra work worth the effort, because participating with our teams in BL4S has not only allowed us to update our knowledge on particle physics, but it has also had many positive effects on the way we teach science. Our involvement in BL4S helped us to establish new educational offers in our schools, and generally promoted wider interest in STEM subjects in our schools and communities. Even more, it has given us the opportunity to get to know some of our students on a personal basis that otherwise would not have been possible.

We are also convinced that our students have greatly benefited from this opportunity. They have realized that they can learn subjects that go far beyond our curricula, have made significant steps in their personal development with respect to both academic and soft skills and received important input for the choice of their professional careers.

We invite all schools to participate in the competition. Considering the potential final result, including the possibility to spend two weeks in a physics laboratory, BL4S, like every challenge, opens new horizons, a different way to interface with students and teachers, a new way of "doing school."

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Beamline for Schools *is an International Physics Competition for high school students. The competition is currently run by a core team of two people, Margherita Boselli and Markus Joos, with the help of two scientists who support the winning teams in the preparation of their experiments. This paper was written by a group of high-school teachers and educators who lead teams of students who won different editions of the competition.*

Information about the teachers:

Manuela Lima has won BL4S 2015 with her team "Leo4G"
The team has studied if low-cost image sensors can be used as particle detectors.

Janusz Kempa has won BL4S 2016 with his team "Pyramid hunters"
The team has investigated the absorption of muons in limestone in order to better understand muon radiography.

Maria Rita Felici has won BL4S 2017 with her team TCO-ASA
The team has developed a Cherenkov detector with a CMOS based light sensor.

Denis Jacques and Lise Knapp have won BL4S 2017 with their team "*Charging cavaliers*" *The team has searched for elementary particles with fractional electric charges.*

Shyam Wuppuluri has won BL4S 2018 with his team "Cryptic ontics"
The team has studied the motion of relativistic particles in magnetic fields.

Alison Bulson and **Enrique Arce-Larreta** have won BL4S in 2019 with their Team "DESY Chain"
The team has measured the performance of scintillators of different dimensions and materials.

Kirsten Stadermann has won BL4S 2019 with her team "Particle Peers"
The team has studied particle showers.

Thomas Riis-Johannessen has won BL4S 2020 with his team "Nation's Flying Foxes"
The team has looked for $\Delta+$*Baryons in Electron-Proton inelastic scattering.*

Uriel Garcia Elorza and **Laura Helena Gonzalez-Trueba** have won BL42 2021 with their team "Teomiztli"
The team has compared the performance of different liquids for their performance in Cherenkov radiators.

Maria Filomena Muscarella and **Stefania Turbacci** have won BL4S 2021 with their team "EXTRA"
The team has studied Transition Radiation.

Margherita Boselli *is an Italian scientist. She studied at the Universities of Pavia, Italy and Paris-Sud, France, before moving to Geneva where she obtained her PhD in Solid State Physics. In* 2020, *she joined the Education, Communication and Outreach group of CERN where she is in charge of the Beamline for Schools Competition and other programmes for pre-university students.*

Markus Joos *is a German Engineer who joined CERN in* 1993. *He works on the development of software for modular electronics used in data acquisition systems and is intensively involved in education programs both for scientists, as the co-organizer of the ISOTDAQ schools and for high-school students, as the technical coordinator of Beamline for Schools.*