PROCEEDINGS OF SCIENCE

From students to experts: an example of flipped classroom during the INFN-INSPYRE International School

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Active learning is key to improving students' learning, especially in STEM subjects such as physics. This approach requires students to go beyond passive absorption of information, instead becoming actively engaged through experiments, real-world applications and investigations. An example of an effective active pedagogical strategy is the flipped classroom model, in which preparatory teaching materials are assigned for study prior to class, enabling in-class time to be dedicated to student-led activities, such as producing presentations or leading guided discussions. During the 2025 edition of INSPYRE, the International School of Modern Physics and Research school that was held at INFN Frascati National Laboratory, we implemented for the first time a flipped classroom. The proposal, focused on the topic of dark matter, provided students with a unique opportunity to explore this subject from an active and central perspective, and revealed strengths and areas for improvement that offer significant insights applicable to similar educational contexts.

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1. Introduction

For years now, research in education has consistently highlighted the indispensable role of active learning in improving student conceptual understanding in many fields, including STEM subjects and physics [1-3]. These methods shift the focus from a teacher-centered transmission of facts to a student-centered educational approach, that encourages students to take an active role in their learning process. Instead of passively absorbing information from the teacher, students are encouraged to engage with experiments, interactive activities, course material, ask questions, and apply what they learn to real-world scenarios.

A powerful pedagogical approach that makes this shift operational is the *flipped classroom model*, where the typical way of proceeding teaching is reversed: students study a set of preliminary materials before class, as if they were homework, and during class apply their learning through specific activities such as problem-solving tasks, group discussions, presentations [4]. The flipped classroom model thus provides students with more time and opportunities for active learning, collaboration, and problem-solving while teachers take on the role of facilitators [5].

Since this method has proven to be valid and effective also in contexts other than formal learning in school [6], in 2025 we decided to include it among the activities of the Frascati National Laboratory (LNF) edition of INSPYRE, the "International School on modern PhYsics and Research" of the Italian National Institute for Nuclear Physics (INFN) addressed to high school students from all over the world. In this paper, we illustrate how we incorporate this approach in the School and the results we obtained.

2. The INSPYRE School

Focused on modern physics, INSPYRE is an intensive seven-day school targeting a cohort of 30 to 40 high secondary school students worldwide (ages 16–18) [7, 8]. It has been organized by INFN since 2011 at the Frascati National Laboratory and, since 2025, also at another INFN National Laboratory. The primary objective of the School is to utilize the study of modern physics as a tool for STEM career orientation. The specific theme of the School changes every year, so that it always addresses the most current topics, but the general approach remains unchanged, namely highly experimental and hands-on. During the program, in fact, participants enjoy a full immersion experience within the research laboratory environment attending plenary lectures, performing laboratory-based investigations, and engaging in direct dialogue with researchers. In this way, students become active protagonists in their own learning process, fostering the acquisition of practical competencies while gaining exposure tThe Io the research facilities and professional personnel of the INFN and partner institutions.

To further encourage this active approach, and confirming INSPYRE as a place where methodologies straddling research, outreach and teaching are experimented with [9], we decided to include a flipped classroom in the program of the 2025 edition of the School at the Frascati National Laboratory.

2.1 The flipped classroom during INSPYRE Frascati 2025

The Frascati edition of INSPYRE 2025 was held from 7 to 11 April 2025 at INFN Frascati National Laboratory and welcomed 40 high school students from 8 countries (Italy, Czech Republic, French, Germany, Romania, Serbia, Slovakia, UK). It was entitled "*Glimpses into the Universe's hidden realms*" [10] as the invisible universe was chosen as a common thread - from phenomena too small to be observed with the naked eye, such as those of quantum mechanics, to invisible messengers such as gravitational waves, to dark matter, that does not emit light. The scientific program was very rich, as it included 6 seminars (Introduction to particle physics, Technologies for particle physics, 100 years of quantum mechanics, Gravitational waves, Young People of Frascati National Laboratory, What is yet to be discovered in physics) and 10 laboratory-based activities, from which students could choose two (Accelerators, Particle detectors, Spectroscopy, Superconductivity, quantum mechanics, environmental radioactivity, Cosmic rays, medical applications, virtual reality in physics).

As the topic on which to develop the flipped classroom we chose dark matter, for various reasons. First of all, it fit perfectly with the School's central theme. Moreover, dark matter typically fascinates and intrigues young people and often appears or is mentioned in science fiction products and television series [11]. From a more practical point of view, it also lends itself well to being divided into several sub-topics, as it is possible to explore both theoretical and experimental aspects, and to retrace the various approaches of current research.

Once the main topic of the flipped classroom was decided, together with the Scientific Committee of the School we selected five sub-topics related to it and of interest for INFN and its research: (1) *What is dark matter*, (2) *Detection with accelerators*, (3) *Direct detection with DarkSide*, (4) *Indirect detection with IceCube*, (5) *Astrophysics and gravitational lensing*. For each sub-topic, we identified one or more experts in the field who could help us to collect all the materials to be given to students before the School [12].

At this point, we began to compile a preliminary list of materials. First of all, a researcher from LNF recorded an online seminar that gave a general overview of what dark matter is and how scientists are searching for it [13]. Next, we asked the experts to identify five or more resources related to their specific topic: web pages, popular articles, or videos. At the end of this process, we compiled a list of 12 products divided by subtopic, to which we have added a section of 14 optional supplementary materials [14]. About two weeks before the start of School, we informed participants that they would be working on a flipped classroom during INSPYRE, shared the list and asked them to watch the introductory video and carefully review the mandatory materials.

At the beginning of the School, we randomly divided the 40 participating students into 5 groups of 8 people each, and assigned each group one of the sub-topics. Only at this point we gave them their final task: to prepare three presentations lasting 10, 5 and 1 minute on the topic assigned to them to be delivered at the end of the week in front of an audience composed by peers and researchers invited for the occasion.

During the week, three full afternoons (about 7 hours) were devoted exclusively to this activity. The first afteroon was dedicated to an initial preliminary discussion between the members of the groups followed by questions and answers sessions with experts on the topic, either in person or remotely. It is worth noting that, in this case, we asked the experts not to give a lecture on their topic, but to limit themselves as much as possible to answering questions or

clarifying doubts raised by the groups. This approach was intended to emphasise the change in role envisaged by the flipped classroom and to empower the students, who would immediately understand that they were to be the subjects of knowledge, not the objects. The second afternoon was devoted to independent work by the groups on developing their presentations. On the third and final afternoon, the groups presented their work.

At the end of the activity, all groups were able to present clear and fairly comprehensive products on their topics, through presentations rich in references, images and videos. The most interesting products were certainly those related to the one-minute presentation: three out of five groups abandoned the traditional presentation format and produced an Instagram reel-style video interview, a film trailer, and a rap song, which they then performed live.

3. The impact of the flipped classroom

In order to assess the impact of the flipped classroom, we added the following open-ended questions to the questionnaire that we typically ask students to complete anonymously at the end of the School: *What did you like most about the flipped classroom? What did you like least about the flipped classroom?* All 40 participants responded to the questionnaire. The responses received are summarised in **Tables 1** and **Table 2**.

By analysing the responses received to the two questions, it is possible to identify some recurring themes. As for the aspects that received the most appreciation, the one mentioned most often was teamwork, cited 22 times. Specifically, the students demonstrated to enjoy working with their peers also because it allowed them to discover what it means to work as a team in a scientific context and "under pressure". Another 7 responses mentioned the importance of having had the opportunity to interact directly with experts, which made them feel less exposed and more comfortable. Another aspect mentioned (6 times) concerned the new, more active role they played during the activity: the opportunity to speak first-hand about topics that interest them and thus feel like scientists. Finally, 3 students stated that they felt they had learned more through this methodology than through typical lectures.

As for the aspects that were least appreciated, the most recurring theme, mentioned 13 times, was time management: students felt that the time given to them was too short for the task required. Teamwork was also mentioned 8 times as a negative aspect, but in this case the emphasis was on the difficulty of coordinating work and interacting with new people they had not chosen themselves. Some students (7) criticised the type of output required, and in particular the fact that they had to create three presentations on the same topic. In 3 cases, a low perception of self-efficacy emerges, while in 2 cases there is a shared feeling that more could be learned through lectures. It is interesting to note that one student cites the problematic use of AI as a potential critical issue.

4. Discussion and conclusion

The Frascati edition of INSPYRE 2025, which involved 40 high school students from 8 countries, proposed a new mode of active learning and peer interaction we never experienced before, in the form of a flipped classroom. Overall, the organisation of the activity involved the Scientific Committee of the School and other 10 researchers, who worked both before the activity, to gather materials, and during the school, to answer any questions and attend the

student's final presentations. Despite this considerable effort, the activity proved to be very useful to the students in many ways. First of all, the new, more active role required of students allowed them to gain practical acquaintance of teamwork, which, while appreciated by many because it made them independent and able to interact with their peers, also highlighted the difficulty of managing the work of different people in stressful situations. In all cases, this experience was highly educational and allowed them to experience a fundamental aspect of scientific research. Also the time management, which proved difficult for many students, highlighted how realistic the challenge was. The new role played by students during the flipped classroom also served as a means of empowerment, as students felt like true protagonists, so much that in many cases this increased their confidence and, in a few, let them to doubt their own abilities. Again, these few negative perceptions are synonymous with more active involvement, which, in any case, does not leave students indifferent.

Category	***Number of times the topic is mentioned***	***Example of responses***
Group work	22	*Understanding how group projects are in scientific field*
		The cooperation beetween the students and the teacher
		Understanding that is really difficult to work in a group of people you don't know and learning to find a solution good for everyone
		The fact that we were put to work under pressure with new people
		That we can work as a team lonely
		The fact that I could work with other people
		We had the occasion to cooperate with people our age with same interests
Direct interaction	7	*Taking with the experts in smaller groups because I felt more comfortable asking questions*
		Having the opportunity to ask an expert
		The discussion with experts
		That I got a chance to talk to experts and have everything explained nicely
		Having actual conversations with researchers
Active role	6	*The possibility to speak on a topic I love*
		I liked the feeling of talking of physics in front of all the researchers
		We were able to feel like "researchers" for a couple of hours
		Experience to talk in front of a public
		The possibility of feeling like "scientists" and being able to speak in front of such a large audience.
Learning	3	*The increased amount you learn compared to lectures*
		Starting from zero and trying to understand and explain a difficult subject

Table 1. Some of the responses received to the open-ended question '*What did you like most about the flipped classroom?*' with the relevant categories and the number of times they were mentioned.

Another aspect worth considering is the impact of the flipped classroom on learning when compared with traditional learning methods. The responses we received from students paint a mixed picture, as some students felt they learned more, and others felt they learned less. This may be linked to each student's expectations and also to the more traditional way in which they are accustomed to learn in a formal setting. In any case, the generally positive feedback on the flipped classroom leads us to believe that, in order to satisfy a greater number of students, it is worthwhile to include more learning methods within the same educational programme, as we did at INSPYRE.

Category	***Number of responses***	***Example of responses***
Time management	13	*The amount of time given.*
		Not enough time to prepare
		I think we didn't have so much time to prepare them
		Maybe we were given very little time to prepare
Group organization/management	8	*Not being able to choose the groups*
		The organization of my group
		Not being able to coordinate all the group and having some people that thought they were more important than the others
		the miseducation of some of the persons
Required output	7	*The topic that i had, cause i hoped to get a different one*
		The fact of preparing 3 different presentations on the same topic
		I don't see the interest to do 3 differents presentation on the same subject
		It would be better if it was based in the experiments that we did during these days […] to have all the same preparation
		The fact that we had to make three presentations made it difficult to make it interesting
Low self-efficacy perception	3	*I felt a bit overwhelmed and I couldn't always [understand] the topic*
		The difficulty of the challenge
		Mini lack of confidence
Flipped classroom vs other methodologies	2	*The time spent doing it could have been spent talking with the experts*
		I would have preferred to use this time to attend more lectures
Problematic use of AI	1	*Most people hadn't read the preparatory materials and everyone made their presentations with A.I. and very little work involved.*

Table 2. Some of the responses received to the open-ended question '*What did you like least about the flipped classroom?*' with the relevant categories and the number of times they were mentioned.

The final aspect to consider is related to the specific task that students were asked to complete at the end of the flipped classroom. If the idea of giving three presentations of 10, 5 and 3 minutes on the same topic was designed to facilitate their transition from longer to shorter

content, it proved to be repetitive and uninspiring. This aspect will certainly need to be taken into consideration for a future edition of the classroom, which will also need to take into account the use of AI, that in our case was not specifically addressed.

Therefore, overall the flipped classroom we proposed during INSPYRE – Frascati 2025 has proven to be a very valuable experiment, which encouraged students' engagement and improved their perception of science work, also bringing to light very useful aspects that can facilitate the implementation of these kind of approaches in other contexts as well.

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