PROCEEDINGS OF SCIENCE

Particle Physics Role-Playing Games in introductory physics courses

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An 18-hour course taught in role-playing and distance learning mode is presented. The course was designed in order to test innovative methods to engage students in active learning, to foster their identification with what is being studied and to boost their motivation in studying introductory physics courses at the Politecnico of Torino. Students are immersed in different settings and are asked to play the role of a physicist. As they continue in the adventure and overcome challenges, they gain skills (represented by experience points) and advance in ability. This advancement is expressed in terms of an increase in their level. The Role-Playing Game is set in the world of particle physics: from the neutrino hypothesis (1930s) to the study of collisions between pions and Helium nuclei (2000s). Students are exposed to experimental data (both simulated and from real accelerator experiments) and are asked to apply what they have learnt in the Physics I course. The central concepts around which the entire course revolves are the conservation laws (Energy and momentum). Students are organised into groups in order to stimulate teamwork and the use of soft skills. When a new concept or an in-depth study is required as a new tool to succeed in the game, students are invited to develop it independently through a problem-solving activity designed by the instructor.

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1. Introduction

Enhancing the active participation of the students is a crucial aspect in order to foster their motivation to study. Active learning techniques become even more important during the pandemic, when the courses are taught in distance learning mode. Between March and May 2021, an 18-hour class, entitled " From Conservation Laws to Scientific Discovery ", was delivered to 200 first-year students as an in-depth study of the main Physics I course. The class was conducted in distance learning mode and in the form of a Role-Playing Game (RPG). In this contribution we will present the main features of the course focusing on the educational outcomes that the RPG-based course achieved.

2. Why Role-Playing Games?

Designing and giving an RPG-based class [1][2] indeed opens the possibility to reach three main educational goals.

1. Boost the identification of the student with what is being studied. In a RPG the players (students in our case) are asked to play the role of a character. The identification process takes place in a setting, which is usually described by the Master (the teacher of the class) at the beginning. In this course we did not ask the students to play the role of a king or of a wizard, but rather the role of a physicist. Indeed, we have even done worse, asking them to play the role of a particle physicist. In the game (the course) they were put in direct contact with real situations from real experiments and where asked to apply what they were learning in the Physics I course to solve real challenges. They were explicitly asked to work, think and act as if they were real particle physicists.

2. Increase the active participation of the student. The RPG begins with a storytelling phase in which the instructor presents the setting and the challenge that the students have to overcome. Students work in teams. On the basis of their own reasoning, of the previous knowledge and of the collaborative skills each team comes to a "solution". Students are given time in order to think, discuss, propose and validate. Sometimes the game is designed to stimulate students to develop new contents and knowledge.

3. Foster the motivation to study. Within a RPG the instructor has the chance to break the typical educational pattern in which students learn concepts in order to pass the exam, having in mind the precise goal to learn how to solve exercises or how to answer to typical questions. In a RPG-based course student are given the opportunity to explore and discover the beauty of what they are studying. The concepts are put into action in a real world situation (real data from real experiments) and are merged with team-work, discussions and even the chance to fail.

3. Course practicalities

It is quite important to briefly discuss some practicalities about how the course was delivered and about the adopted supporting strategies and technologies.

3.1 Distance learning supporting technologies

The RPG course was held in the pandemic period, between March and May 2021, therefore it was delivered in remote teaching modalities via Zoom meetings. It was attended by 200 first-year students divided in three groups each of which took the same course separately from the others: therefore it was repeated three times. Within each course students were organized into a number of teams of 4 or 5. Each team played the various phases of the game working in separate breakout rooms, opened at appropriate times by the instructor.

In order to support the instructor in managing the class a website was built [3]. The site was hosted on the POLI-Lab@home project site (PL@h), where student-centered educational activities are collected (figure 1). Within the course site a different web-page was dedicated to each game session. Due to the pedagogical learner-centered orientation of the course, the supporting website was used as a framework where a number of interactive applications were embedded. Each interactive application was designed to be a sort of learning/exploring environment. A place where students were free to apply their previous knowledge and to create new knowledge, while addressing unexpected contexts. Furthermore, to collect the work of each team and to monitor the main streams of reasoning, the teams were asked to fill forms, again, embedded in the site. In this sense we can refer to the site of the course as to an interactive supporting website.

3.2 How a game session works

As teams progress through the game they overcome challenges and gain experiences that are converted in experience points (XP). The amount of XP determines the level of the team. All the teams started at level 1. Basically each game session was organised as a sequence of well defined phases:

- Students are divided into teams (once for all);
- The instructor asks the students to play the role;
- The instructor describes the settings and tells the story;
- Teams are asked to face a challenge concerning a specific problem of the setting in which they act;
- The Teams are given a certain amount of time to play the game. They work inside Zoom Breakout rooms;
- The Teams have to report their actions and conclusions in a form or a pdf which is collected by the instructor;
- Plenary discussion (Instructor + Teams) about the actions and conclusions each team have performed;
- Immediately after the end of each game session the Instructor assesses the reports and updates the table of the XP of all the teams.

4. The two Games

The course consists of two RPGs, briefly presented in the following list. In the next session we will describe with more details the first one, which is connected to Pauli's neutrino hypothesis.

Figure 1: The logo of the RPG-based course, hosted on the POLI-Lab@home project website.

- **A case from the 20th century Physics**. Students are asked to play the role of a nuclear physicist of the 1930s. On the basis of what they know about Conservation Laws (CLs), they are asked to analyze data from the neutron decay. Teams are told they are conducting an experiment on the decay of a particle (called 'd' in the game) and are given the experimental data they have collected. Each team has to discover the oddities hidden in the data and to propose a solution.
- **Nuclear Collisions**. The scene is now a modern Nuclear Physics facility. The players are inquiring the structure of nuclear matter by scattering a pion beam on Helium nuclei. The tracks of the particles involved in the collisions are photographed. On the basis of CLs students have to discover the type of reaction occurring in a specific collision (data from the PAINUC experiment [4]).

4.1 The RPG "A case from the 20th century Physics"

The game is divided into two parts. The first one is a sort of preparatory stage, useful to focus and recap some aspects of CLs that are vital for the solution of the game. Students are invited to consider simple situations in which a body, initially at rest, "explodes" emitting two or three fragments. In both cases, they have to write the CLs equations and to identify the number of the written equations and of the unknowns. Basically, they are asked to discover if the modulus of the momenta of the fragments is uniquely determined or not. It turns out that, given the masses of all the bodies and the energy release in the explosion, in the two-body event the momenta are bound to have a unique and well defined value. On the contrary, in the three-body scenario, the momenta may have different values.

The second part is the real RPG. In the fiction, the students are carrying out an experiment on the decay of a particle, which is called d. They are told that, according to the collected experimental data, d seems to undergo a two-body decay:

$$d \rightarrow e^- + f^+$$

Teams are made aware that the experimental apparatus in use detects only charged particles and are given experimental data in terms of the distribution of the momentum of the e-particle (figure 2). As in every experiment, once data are collected, they have to be analysed. The teams have to consider the plot in the hypothesis of a two-body decay and discuss possible oddities suggested by the distribution. If any, they are asked to propose possible solutions to the problem. The core concept is that in a two-body decay, according to CLs, the momentum of the e-particle has to be uniquely defined. Hence, the expected distribution is centered around a single value and not spread

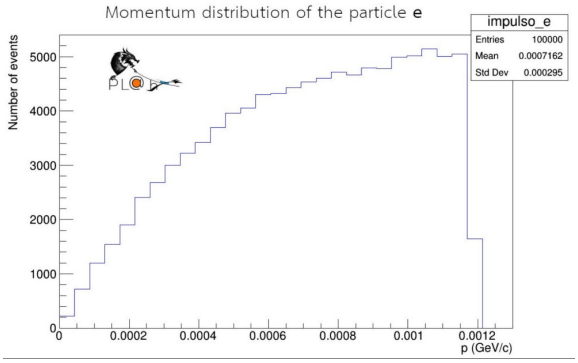

Figure 2: The momentum distribution of the e-particle.

over an interval like figure 2 suggests. A possible way out is to assume the emission of a third neutral (and therefore undetected) particle. In this case, the decay undergoes a three-body channel and the continuous spectrum of the e-particle is justified.

5. Conclusions

"A case from the 20th century Physics" is an RPG clearly referred to the problem of the "continuous beta spectrum" occurred within the study of the neutron decay: $n \rightarrow e^- + p^+ + \ldots$. The suggestion that a neutral particle should have been involved appeared in a letter Pauli wrote to Hans Geiger and Lisa Meitner on December 4th, 1930 [5]. Later, in 1931, Pauli presented his idea in public at a meeting of the American Physical Society in Pasadena, California.

The outcomes of the RPG were really striking and encouraging. The feedback, in terms of appreciation of the class, was quite high. The rating, in a scale from 1 to 5, was 4.40 (survey over 99 students). The same sample of students gave positive feedback about the use of a RPG for a physics course. The 98% of the teams reported something was odd in the experimental distribution (figure 2). The 33% of the teams realised that, in a 2-particle decay case, the distribution should have been centered on a single value. The same 33% proposed, as a possible solution to the problem, the existence of an undetected neutral particle, reaching, in a way, the same solution proposed by Pauli!

References

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