# Learning difficulties in the interpretation of Feynman diagrams

**Abstract**. Feynman diagrams are an essential part of theoretical elementary particle physics but they are also used in popular science publications as well as in scholar teaching. In an exploratory research study, questionnaires were presented to teachers and university students in which simple Feynman diagrams were to be interpreted and judged concerning their usability at school. In particular, topologically equivalent diagrams with different line geometry and different visualizations of the time direction were used. In the responses, general as well as visualization-specific potential learning difficulties and misconceptions were identified and categorized.

## 1 Feynman diagrams in theoretical physics and their reception in educational literature

Feynman diagrams (FD) play a crucial role in quantum field theories such as the Standard Model of particle physics. They are used, on the one hand, for organizing perturbation theory calculations and, on the other hand, for communication, both in the scientific community and in popular science publications as well as in school textbooks and teaching materials. Many high school courses and curricula on particle physics include the model of exchange particles as the currently accepted model to describe the fundamental interactions of nature. The exchange particle model and the fundamental interactions were recently identified as two of the most relevant contents of the subject of particle physics in a Delphi study carried out with particle physicists and teachers [1]. FDs can be regarded as graphical visualizations of the calculation method, that gives rise to the concept of virtual particles and therefore is the theoretical footing of the exchange particle model.

FDs appear to offer an accessible way to introduce the messenger particle model without the need of the underlying mathematics, which Passon et al. regard as one reason why FDs to many people are fascinating in an educational context [2]. The authors furthermore summarize and strengthen arguments against the literal reading of FDs as pictures of actual processes (see also [3]). Intensively discussed manifestations of this type of interpretation are the association of the lines in FDs with particle trajectories and the assumption that a single FD tells an explicit time-ordered story about the transition from an initial state to a final state.

The fact that there are many different and also inconsistent ways of drawing FDs is also seen critically [4,5]. From an educational point of view this might seem problematic, but considering the role of FDs in theoretical physics those discrepancies are rather unsurprising. Soon after their introduction by Feynman in the late 1940s the diagrams were used by research groups in various contexts and they were adapted in a way to suit the respective needs best [6]. This is not a problem when the diagrams are seen as calculation aids and not as pictures of actual physical processes. Nevertheless, differences in the drawing of the same FD might affect the

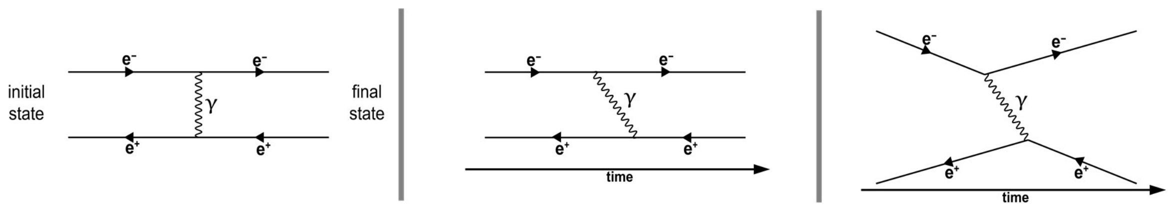


Fig. 1 Three examples of topologically equivalent diagrams with different line geometry and different visualization of the direction of time used in the study (translated from German).

intuitive interpretation of the diagram especially by non-experts. Considering that, we carried out an exploratory research study with the following main research questions.

1. Which learning difficulties can be expected when non-experts read and interpret FDs?
2. Do the observed learning difficulties vary between different visualizations of topologically equivalent FDs?

## 2 Outline of the study

Physics teachers as well as students of physics education with different levels of experience were shown a simple FD. They were asked to write down the information that they can gather from the diagram as well as to phrase a suitable picture description. Furthermore, they were asked to state which aspects of the diagram appear unclear to them. The used FDs were mainly topologically equivalent[1] leading-order diagrams that contribute to the modeling of the electromagnetic interaction of an electron and a positron. Those diagrams differed only in the geometry of the lines, the positioning of the vertices (the points where the lines meet) and the visualization of the time direction. Three examples of the used diagrams are shown in figure 1.

In addition to those surveys, we analyzed statements made by participants in in-service teacher training sessions and university seminars during and after learning sequences on FDs. The participants, for example, were asked about learning difficulties they would expect when teaching FDs at school and to rank various topologically equivalent diagrams considering their usability in class. All the statements were analyzed with respect to possible learning difficulties and misconceptions, which then where categorized. Some of the categories have already been suggested in the literature, like the interpretation of the lines as particle trajectories, while others were found inductively. The category system will be presented and potential implications for the use of FDs in teaching will be discussed.

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[1] Topologically equivalent means they stand for exactly the same mathematical contribution to the calculation of the interaction in perturbation theory.