An Alternative Proposal for the Graphical Representation of Anticolor Charge

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We have developed a learning unit based on the Standard Model of particle physics, featuring novel typographic illustrations of elementary particles and particle systems.[1] Since the unit includes antiparticles and systems of antiparticles, a visualization of anticolor charge was required. We propose an alternative to the commonly used complementary-color method, whereby antiparticles and antiparticle systems are identified through the use of stripes instead of a change in color. We presented our proposal to high school students and physics teachers, who evaluated it to be a more helpful way of distinguishing between color charge and anticolor charge.

Education research shows that carefully designed images can improve students' learning.[2] However, in practice, illustrations commonly contain elements limiting students' learning, as underlined by Cook[3]: "Visual representations are essential for communicating ideas in the science classroom; however, the design of such representations is not always beneficial for learners." To determine what aspects of the typographic representations used in our learning unit (Fig. 1) hinder or promote learning, we tested and adapted them in the context of design-based research[4] using Jung's technique of probing acceptance.[5] In the course of developing our unit, we also formulated this proposal regarding the graphical representation of anticolor charge.

In the Standard Model of particle physics, elementary particles are sorted according to their various charges. A "charge" in this context is the property of a particle whereby it is influenced by a fundamental interaction. In quantum field theory, the electromagnetic, weak, and strong interactions are each associated with a fundamental charge. The abstract naming of the strong interaction's associated charge as "color charge" originated in the work of Greenberg[6] and Han & Nambu[7] in the 1960s. They introduced red, green, and blue as the "color charged" states of quarks and antired, antigreen, and antiblue for antiquarks. According to this model, quarks have a color charge, whereas antiquarks are defined by having an anticolor charge. In addition, particle systems must be color neutral, i.e., "white". This includes mesons, composed of two quarks each, and baryons, made of three. In each case, the distribution of color charge must "balance out" among the quarks. For mesons, this can only be achieved if a color charged quark is bound to an antiquark with the respective anticolor charge. In the case of baryons, all three (anti)color charge states must be

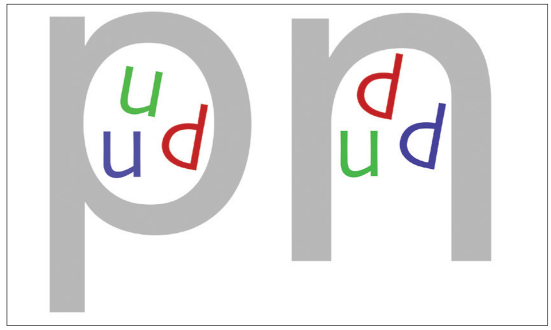

Fig. 1. Typographic illustrations of a proton and a neutron.

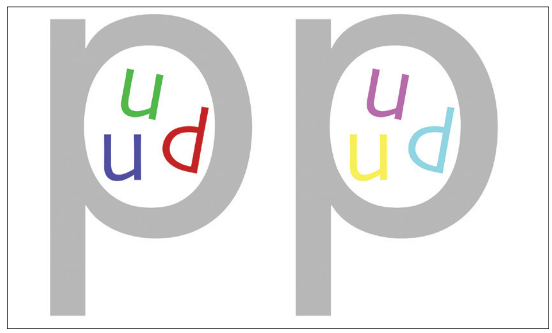

Fig. 2. Traditional illustrations of a proton and an antiproton, relying on readers' prior knowledge of the relevant color wheel. Obviously, using colors complementary to the quarks' red, green, and blue presents a challenge for identifying anticolor charges, e.g., cyan as antired.

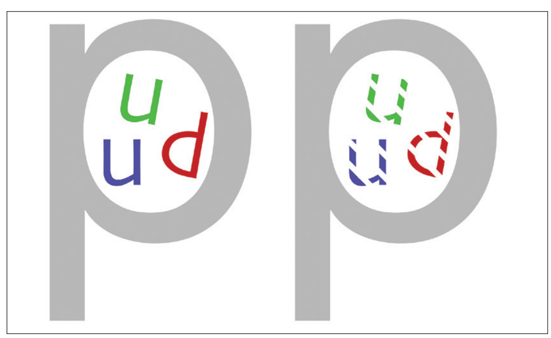

Fig. 3. Alternative illustrations of a proton and an antiproton, using a stripe pattern to denote anticolor charge. This representation clearly shows corresponding color and anticolor charge states while doing away with any requirement for prior knowledge of complementary colors.

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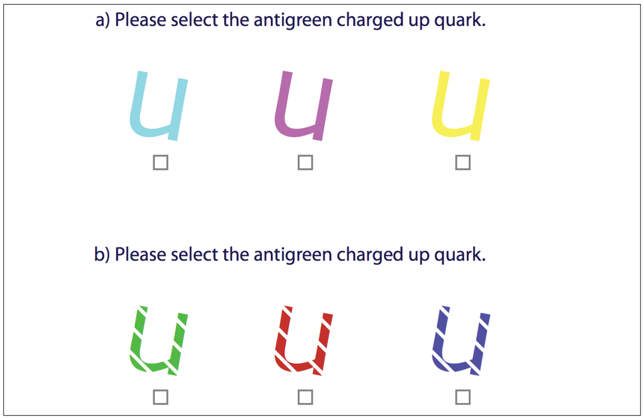

Fig. 4. Excerpt from the questionnaire used to evaluate the two different graphical representations of anticolor charge. The full questionnaire is available on request.

present, one per (anti)quark.

When it comes to graphical representation of color charge, one is faced with a challenge, particularly when considering anticolor charge. Looking at standard physics textbooks, one finds that such graphical representations are almost completely neglected at university level. Instead, (anti)color charge is only explained through text and accompanying Feynman diagrams, if at all. Nonetheless, there have been sporadic attempts to illustrate the abstract concept of anticolor charge. These can be found in selected textbooks and mainly in educational resources available online, in which the common solution is the use of the colors complementary to red, green, and blue (Fig. 2). However, this relies on previously established optics knowledge, namely, additive color mixing. The overlapping of such content can be expected to be detrimental to learning.

Furthermore, the complementarity of colors must always be defined as a function of the color wheel being applied in a given model of color. This inevitably leads to problems, especially given the existence of multiple models of color, such as those of Newton[8] or Goethe.[9] The following quote, gathered during the evaluation of our proposal, illustrates this: "Is not the complementary color of blue, orange, of green, red, and of yellow, pink?" [student, age 17; translated by the authors from the original German]. To avoid the overlapping of this prerequisite knowledge from optics, our proposal represents anticolor charge using a stripe pattern (Fig. 3).

Doing so preserves the original colors red, green, and blue for antiquarks, and it is only the stripe pattern that identifies the anticolor charged state and thus distinguishes quarks from antiquarks. By giving up complementary colors, this method of representation purposefully avoids the notion that particles with opposite color charge states cancel out in a "color neutral" way. While this idea is clearly elegant, it is problematic to introduce it at an early stage in the physics curriculum, because the metaphorical use of additive color mixing for the "canceling out" of color charge states could promote the transfer of macroscopic properties into the world of quarks. Therefore, we have decided to avoid any

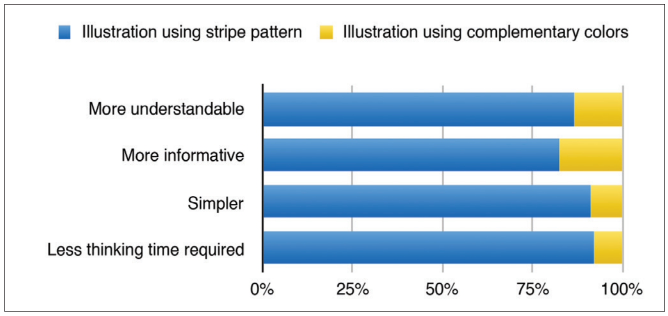

Fig. 5. Students' assessments of the two illustration methods (ages 16-17, *n*=78).

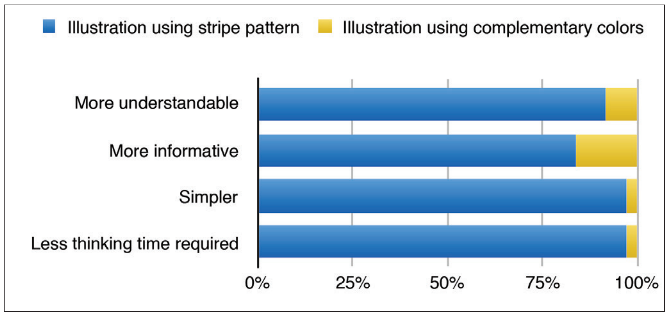

Fig. 6. Teachers' assessments of the two illustration methods (*n*=45).

notion of color mixing within our reconstructed alternative proposal. Instead, the model character of physics is taken into account by emphasizing that the illustrations are only graphical representations, which thus cannot be attributed real-world characteristics. In this way, possible misconceptions regarding elementary particles' "appearance" should a priori be avoided, while unequivocally enabling the distinction between particles and antiparticles.

The final version of the alternative proposal presented here was tested on high school students (ages 16-17, n=78) and physics teachers (n=45). Each group was given a short written summary of color charge, including both forms of representation of anticolor charge. These were then evaluated using a questionnaire, composed of multiple-choice questions, where each correct anticolor charge was to be selected. Each question was asked when using complementary colors for antiquarks as well as when using the stripe pattern (Fig. 4). Rather than probing understanding of the concept of color charge, the aim of the questionnaire was solely to evaluate the two graphical representations and how they appeal to students and teachers.

The testing of the alternative proposal proved to be very successful. Both students and teachers answered considerably more questions correctly when using the stripe pattern illustrations as opposed to complementary color illustrations. In addition, individuals' assessment of each method of illustration was gathered using binary questions regarding their understandability, informativeness, simplicity, and thinking time requirement. A clear majority of students (Fig. 5) and teachers (Fig. 6) judged the use of the stripe pattern to be easier to understand, more informative, and simpler, as underlined by the following quote from the evaluation: "From the point of view of pure understanding, the complementary colors are logical, given that they illustrate an opposition. But, for me, the stripe version is simpler, because it is easier to recognize." [student, age 16; translated by the authors from the original German]. Of particular note is the drastic reduction in the perceived amount of time needed to answer the questions. It is in this sense that our alternative proposal proves itself to be particularly helpful for learning and extremely promising for future applications. We therefore strongly recommend the use of a stripe pattern in representations of anticolor charge.

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