Electric field lines: The implications of students' interpretation on their understanding of the concept of electric field and of the superposition principle

Esmeralda Campos[a)]
Tecnologico de Monterrey, Escuela de Ingenieria y Ciencias, Monterrey 64849, Mexico

Genaro Zavala[b)]
Tecnologico de Monterrey, Escuela de Ingenieria y Ciencias, Monterrey 64849, Mexico and Universidad Andres Bello, Facultad de Ingenieria, Santiago 7500973, Chile

Kristina Zuza[c)] and Jenaro Guisasola[d)]
Department of Applied Physics, University of the Basque Country, San Sebastian 20018, Spain

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A common way to represent an electric field in a course on electricity and magnetism is with the electric field line diagram. Some literature claims that students have difficulties understanding this representation and relating it to their understanding of the electric field concept. We conducted a study at the introductory level that aims to understand the effect of students' interpretation of electric field line diagrams on their application of the superposition principle for the electric field. The results give some evidence that an incorrect interpretation of the electric field line diagram may hinder the understanding of the superposition principle. Students who understand a vector representation of a field at a position tend to answer a superposition principle question better. We question whether teaching the electric field line representation is productive at the introductory level, and we discuss the need to have a representation that helps students reach a better understanding of the electric field concept and of the superposition principle.
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I. INTRODUCTION

Electricity and magnetism (E&M) courses in science and engineering play a crucial role in students' understanding of the physical world and its potential application of E&M to the development of new technology.[1] In the topic of electrostatics, students often need to apply concepts and principles for problem-solving, such as the concept of the electric field and the superposition principle. Learning the concept of the electric field is difficult for students who are not familiar with vector fields, due to its abstract nature. Chabay and Sherwood[1] attribute this difficulty to the fact that students are faced with abstraction and mathematical sophistication for the first time. Moreover, Furió and Guisasola[2] showed that high school and university students have ontological and epistemological difficulties in understanding the electrical interaction by the field model in contrast to the Newtonian model of action at a distance.

To reduce the electric field's challenges in abstraction and epistemological understanding, representations of the electric field are used. Representations are understood in the field of physics education as symbols that stand for a concept. Electric field line diagrams are used in E&M courses to represent the electric field. This representation is associated with Faraday's field model since he perceived electrical interactions as the reciprocal action between the charges and a medium.[3] In this model, the medium is altered by the presence of electric charges, creating an electric field, which exerts a force on electric charges. This model replaces the Newtonian model of action at a distance.

In E&M courses, there is an epistemological change when moving from electric force to the concept of the electric field. The understanding of the electric field as compared to electric action at a distance drives the student to think differently. It also allows for a new representation, where the electric interaction is not limited to the position of a test charge but is a property of each position in space.[4] Electric field line diagrams are believed to serve as an instrument to mediate comprehension of the concept of the electric field and reduce the abstraction caused by this epistemological change. Many introductory physics textbooks explain this representation at the beginning of the topic of the electric field.[5–8] Even though the rules to interpret electric field line diagrams seem simple, their construction is quite challenging (except for the most straightforward cases, like a point charge). Moreover, the incorrect interpretation of electric field lines may contribute to mixing in some alternative conceptions and may interfere with the application of the superposition principle.[1,9,10]

Besides electric field lines, alternative representations of the electric field include variations of vector diagrams, such as the vector representation[11] and the color representation.[12] All three of them, shown in Fig. 1, try to help students visualize something they cannot see since the epistemological change from the Coulombic force interaction to the field model creates an additional barrier for student understanding.

The science education research on students' difficulties when reading images shows that the visual language has its norms and structures, as does verbal language.[13] Thus, images cannot be considered trivially comprehensible and transparent. Misuse of the visual language can affect the communication of the concepts intended to be represented by the image. On one hand, an image that has not been well designed may transmit wrong ideas, and on the other hand, a lack of knowledge of the visual language may hinder the interpretation of an image.[14] It is necessary to investigate whether the electric field line diagram efficiently transmits