EXPLORING STUDENTS'THOUGHT PROCESSES INVOLVED IN THE INTERPRETATION OF ELECTRIC FIELD AND FIELD LINES

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The study concerns exploration of students' deficiency in interpreting the concept of electric field and field lines. A diagnostic test comprising four questions on basic aspects of electric field and field lines has been administered to higher secondary (CBSE) and undergraduate level students. The test requires paper pencil drawings of field lines and interpretation of the same in given situations. Test was followed by a structured interview with appropriate scaffolding accompanied by think aloud protocol. Students' inadequacies in interpreting the concept of field and interlinking the thought processes have been identified through detailed analysis of their field mapping diagrams. Important learning difficulty of students reveals poor visualization of physical concept related to electric field lines even when mathematical cognition of the same seems to be satisfactory. Few possible causes of these difficulties of students with reference to instructional strategies of teachers and text materials have been identified.

INTRODUCTION

Physics is an important subject in higher secondary level science and many students have learning difficulties in it. Further, our instruction is often far less effective than we realise. Indeed, recent investigations have revealed that many students, even after solving many quantitative problems and scoring good grades in examinations, emerge from their basic physics courses with significant conceptual difficulties (Kim & Pak, 2002; Sabella & Redish, 2007; Pradhan & Mody, 2009) and inability to apply their knowledge in further learning. In short, students' acquired physics knowledge is often largely nominal rather than functional. This may be one of the reasons why most of the students do not opt for a profession with physics. Broadly speaking, teaching is what a teacher does and learning is what a student does, and the result may be unsatisfactory without a consonance between the two. Hence, significance of both text and teacher mediated instructions need to be studied to realise better the thought processes underlying the various aspects of physics. The ability to interpret a scientific concept is clearly an essential prerequisite for using the concept to make complex inferences. In this context the concept of 'field' is a key one to investigate the conceptual understanding and higher order thinking process of students. The concept of field is abstract in nature, first introduced by Farady through field lines to represent electromagnetic interaction. Most of the earlier studies (Greca & Moreira, 1997; Viennot & Rainson, 1992; Rainson et. al., 1994) pertaining to electric field and superposition of electric fields have been carried out on college/ university and engineering level students. Literature survey shows that not much pedagogical studies have been carried out on Indian school/undergraduate students on the concept of field. But higher secondary level Indian physics syllabus devotes almost one volume of its text book (Physics, Part-I, Textbook for Class XII, NCERT, 2007) dealing with electric field ,magnetic field and electromagnetic field. So it is imperative to investigate the hierarchical learning difficulties of students in electric field and field lines from which they begin the concept of field.

OUR STUDY

In the present paper we have made an attempt to study the features of the understanding as well as representation skill of the higher secondary and undergraduate students on electric field and electric field line mapping. We have tried to find the genesis of their effective and ineffective representation skills post the instructions provided by textbooks and practicing teacher. The concept of 'field' is a significant one which usually starts at higher secondary level and goes a long way as prelude to many branches of physics like particle physics, plasma physics, electrodynamics, astrophysics etc. This concept is usually taught (Physics Part I, Textbook Class-XII, Chapter-1, Electric Charges and Fields) through a bunch of formulas and a few field line drawings. We have analyzed the instructional implications on students learning as well as the interpretation difficulty in extending the concept of electrostatic field. While constructing knowledge it is not sufficient to know the reasons for one's belief, it is also necessary to know the reasons why alternative conceptions are not credible. Hence, demerits of alternative conceptions have been weighed by us and a rational judgement has been made between competing ideas. While analyzing the learning and interpretation difficulties of students the concept specific instructional strategies provided by practicing teacher and text books have been discussed. In the following sections we present the test design followed by the detailed analysis of question-wise responses and conclusion. We expect the findings will help students, teachers and teacher educators in this abstract domain of physics.

TEST DESIGN

The diagnostic test comprises four questions on basic aspects of electric field and electric field line drawings. Before administration these questions were ratified by the physics faculty members of NISER Bhubaneswar, post-graduate teachers of DM School (RIE, Bhubaneswar) and Jawahar Navodaya Vidyalaya (JNV), Munduli, Cuttack, Odisha, and the physics faculty of the Regional Institute of Education (RIEB), Bhubaneswar. All the four questions are designed to probe the understanding of the students on electric field through electric field line drawings. The test requires paper pencil drawings of field lines and interpretation of the same. The test was administered to 39 higher secondary students of Class XII, JNV, Munduli, Cuttack; 47 higher secondary students of Class XII, DM School, Bhubaneswar, 18 undergraduate students of NISER, Bhubaneswar, and 32 undergraduate students of the integrated B.Sc.B.Ed. semester-4 students of RIE, Bhubaneswar. Immediately after the test a structured interview was conducted with eight randomly selected students from each school/institute. One of the authors (MG) recently spent three months at a stretch at JNV, Munduli, Dist. Cuttack, Odisha as a school experience program of NCERT, New Delhi and observed mostly the higher secondary classes engaged by single physics PGT of the school. The higher secondary classes of DM school, which is the laboratory school of RIE, Bhubaneswar have also been observed by the authors. The rationale of selecting such schools/institute lies on the fact that JNV is a rural residential school, DM School is an urban non- residential school, NISER is a premium national level institute, and RIE is a regional (eastern) teacher training institute. The maximum time given for the test was half an hour and time for interview was not fixed. The interview protocol has been designed with appropriate scaffolding so as to bring out students' microstructure of knowledge presentation.

The interviews were recorded using a video camera and the drawings and formulas etc. written during interviews were collected. The transcripts of the interviews, students' written answers, and the steps followed in scaffolding were analyzed subsequently.

ANALYSIS OF RESPONSES

The responses, both in drawing and oral forms, have been analyzed question-wise below. This analysis will be equally beneficial for students as well as teachers/teacher educators. The genesis of students' deficiency in interpreting the concepts has been discussed in detail to design more effective instructional materials.

Q1. Two point charges +Q and +4Q are fixed at a distance of 12 cm from each other. Sketch the field lines and locate the neutral point.

The following diagrams reproduce three sample sketches of the field lines (Fig 1.1, Fig 1.2, Fig 1.3), Fig 1.1 being the most appropriate mapping.

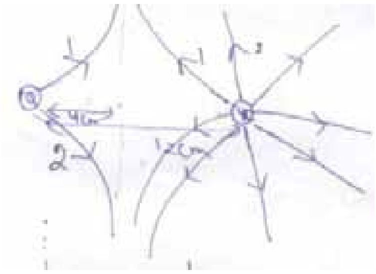


Figure 1.1

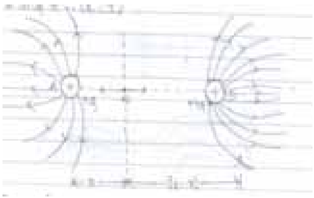


Figure 1.2

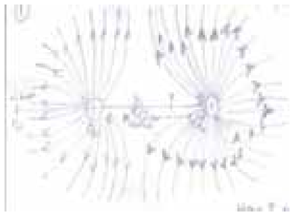


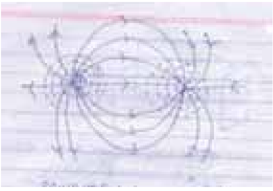
Figure 1.3

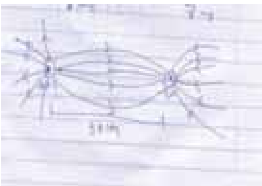
For locating the neutral point numerically, 79% of higher secondary students and 30% undergraduate students have correctly worked out the problem using Coulomb's inverse square law. However, only one higher secondary level and one undergraduate level student have drawn the field lines correctly. This is a very unusual but interesting finding that students even if good at solving numerical problems to locate a neutral point of an electrostatic field are very poor in mapping the field lines. One typical answer in connection with neutral point (Fig 1.3) has revealed the fact that students put much importance to mathematical forms of representation rather than physical phenomenon. While solving the above numerical problem using Coulomb's law and Newton's third law of motion for locating the neutral point where resultant force on a positive test charge due to both +Q and +4Q charge is zero we get a quadratic equation whose solutions are +4 and -12. Most of the students without stating any reason have discarded -12 cm option and has accepted +4cm as neutral point which lies between +Q and +4Q. However, one student assuming +Q charge as reference point has marked -12cm left to the +Q charge as one neutral point and +4cm right to the reference +Q charge as another neutral point. With guided scaffolding the students were first directed to grasp the meaning of neutral point to realise that at neutral point two forces balance each other and their directions are opposite and hence +4cm is the appropriate neutral point, which must lie within two similar charges. Using scaffolding in the reverse order students were made to assume -12cm left to +Q charge as neutral point. Then they were hinted to explore that the directions of two forces due to both +Q and +4Q charges on a +ve test charge at that point will be in the same direction and this does not qualify the concept of a balance force. This shows students have not been alert to the direction of force. Here students were given a chance to weigh their competing ideas and arrive at right scientific conclusion. This finding seems to be very similar to the finding of Rainson et. al. (1994) where students do not recognize field lines as a set of curves representing a vector property of that space. No discussion about the neutral point in an electrostatic field has found a place in the NCERT text book. Practicing teachers were also found to be silent about it during classroom instructions. But neutral point is a very essential field element to understand the configuration of both electric and magnetic field.

The drawing also shows that students have not understood that for mapping the field lines for charges of different magnitude the number of field lines per unit area emerging from each source charge should be proportional to the amount of charge. For charge Q, if for example 6 field lines are drawn, then for charge 4Q, 24 field lines are to be drawn. The amount of curvature/bending of the field lines according to the magnitude of charges have not been taken into consideration and symmetry of the mapping have not been maintained. During interview most of the students could draw the field lines of isolated charges correctly. But when two similar or two dissimilar charges are brought near each other why the field lines bend in a particular pattern they could not answer. The scaffolding to construct the field lines for two similar and two dissimilar charges by referring to calculation of resultant was provided through ICT based diagram Fig 2.4 to Fig 2.6. During interview it was also diagnosed that even if students have solved the numerical problem correctly for locating the neutral point using Coulomb's law they do not relate this inverse square law in the spacing of field lines. This shows that success in numerical problem is not a reliable measure of conceptual development.

Q2. Draw electric field lines between two charges +20 C and -50 C placed 30 cm apart.

This question is similar to Q1. The attractive nature of the field between two dissimilar charges of different magnitude needs to be used for drawing field lines. Unfortunately, not a single higher secondary level student has drawn it correctly. No doubt they have joined the positive charge to the negative charge correctly with arrow sign. But here also they have not paid any attention to the magnitude of charges. Their thought process has not been driven towards the fact that the direction of resultant field on a positive test charge near the positive charge of the lower magnitude will be different than near the negative charge of higher magnitude. Three typical mappings of the field lines are reproduced below, where Fig 2.3 is most appropriate.





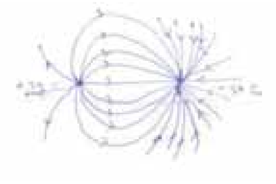


Figure 2.1 Figure 2.2 Figure 2.3

During interview one higher secondary School student first joined the two charges with a straight line and, when asked, she pointed that it is the axis, but said that it is not a field line. She thinks field line needs to be curved always. She was convinced about the incorrectness of her answer using the following diagrams and guided scaffolding.

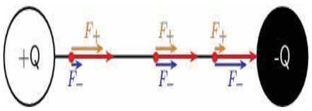


Figure 2.4

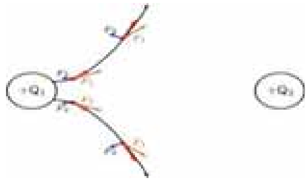


Figure 2.6

Figure 2.5

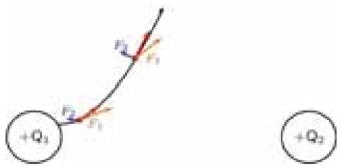


Figure 2.7

Students were hinted to recall the law of parallelogram of addition of forces and apply that for computation of field lines. If we put a +ve test charge near +Q (say on the line joining +Q &-Q) then it is pushed/repelled by +Q (shown by F_+) and pulled/attracted by –Q (shown by F_-) in Fig 2.4 (everything maths.co.za/ science/Grade11). Indeed repulsive force being larger than attractive force at that space point has been shown by longer arrow, F_+ than F_-. The resultant of F_+ and F_- obtained by parallelogram of forces is shown by longest arrow. At the mid-point of the line joining the two charges both attractive and repulsive forces are of equal magnitude and resultant also points from +ve charge towards –ve charge. As the +ve test charge gets nearer to –Q charge the attraction due it is more than the repulsion due to -Q charge as depicted by longer vector F_- than shorter vector F_+. The resultant vector obtained by parallelogram of forces is shown by longest vector. When +ve test charge is placed slightly higher than the line joining the two dissimilar charges of equal magnitude the similar discussion as illustrated above follows and direction of field takes the shape as shown in Fig 2.5. The discussion was extended for two dissimilar charges of unequal magnitude (Fig 2.3). The students were hinted with same principles to realise the curving of the field lines in case of two similar charges of equal magnitude (Fig 2.6 and Fig 2.7). These ICT based diagrams and few "youtube videos" in this concept were also utilized during scaffolding in Q1. The absence of these self- explanatory diagrams in the text books and lack of guided illustrations by the practicing teachers using ICT seems to be an instructional deficiency which might have led students to such pictorial comprehension problems.

Q3. A charge +Q is fixed at a distance 'd' in front of an infinite metal plate. Draw the field lines indicating the direction clearly.

This question is open for free interpretation by the students. The question does not explicitly mention whether the infinite metal plate is grounded or not. So, we do not remark their drawings as correct or incorrect rather we try to trace their thought processes. Some respondents have assumed the metal plate to be earthed and have drawn the field lines as shown in Fig 3.1, Fig 3.3 and Fig 3.4. Assuming the metal plate as not being earthed other respondents have shown the polarization or separation of charges inside the metal plate and have utilized those bound positive and negative charges to draw the field lines Fig 3.2.

Maximum number of students of a particular school, 66.7 % have drawn as Fig 3.1. They have correctly shown the induced negative charge only on the upper edge of the infinite plate and utilized those to draw field lines. Moreover, as expected they have directed all field lines towards the plate but none of them have shown pictorially the grounding of the plate. 10.6 % of higher secondary level school students and 22% of undergraduate students have drawn like Fig 3.1.

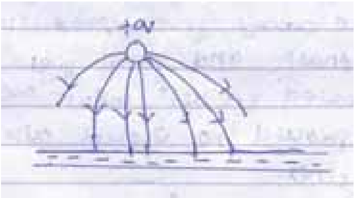


Figure 3.1

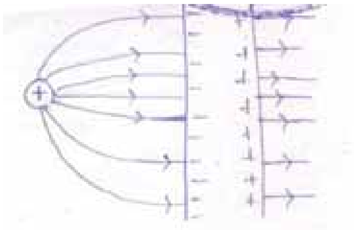


Figure 3.2

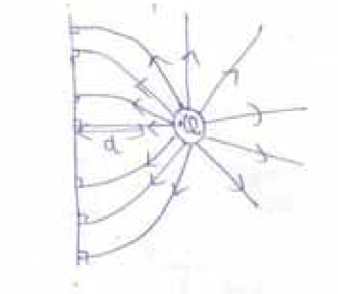


Figure 3.3

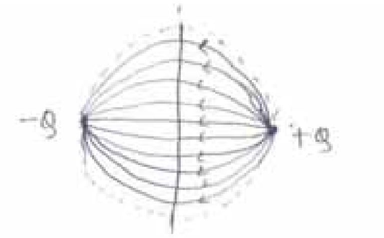


Figure 3.4

Maximum % of mapping by higher secondary level students of a particular school is like Fig 3.3. Two main learning difficulties of these students which are well visualized in their drawings are (i) the induced negative charges are not shown on the metal plate (ii) the number of field lines emerging from +Q charge should be the same entering into the infinite metal plate in consistence with gauss law. The students have never thought that +Q amount of charge in front of a grounded metal plate induces exactly –Q amount of charge. But during interview with scaffolding most of the students were found to be aware of this principle but they do not think of it during mapping. Moreover, in some of the mappings of undergraduate students (Fig 3.3) the concept of equipotential surface being perpendicular to the field lines has been correctly depicted. Other respondents even if aware of this concept do not realise the accuracy of the drawings and have casually drawn the mapping. It was interesting to find different drawings of undergraduate students. They have used 'method of electrical Images' for grounded metal plate. Some student simply through drawing assumed the plane plate as a plane mirror and put a fictitious charge -Q on the other side of the mirror and completed the field lines. They could not explain why abruptly one should take a fictitious charge on the other side of the metal plate. However, the other students could continue their arguments by explaining the basis of method of images using 'Uniqueness Theorem'. Of course we do not expect this higher order learning from school students, but teachers are expected to understand the existing diversity of interpretation skill among various grade students.

Q4. Draw equipotential surfaces for a uniform electric field.

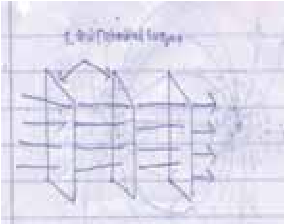


Figure 4.1

Figure 4.2

We mainly found two above varieties of answer. Maximum numbers of higher secondary students have answered correctly (Fig 4.1) as it is a text book based question. However, during interview the students who had drawn correctly could not explain the reason for equipotential surface to be a plane for uniform electric field. Those students who have drawn like Fig 4.2 have not understood the difference between uniform and non- uniform electric field, but have understood the meaning of equipotential surface. The 36% of students who have drawn it like Fig 4.1 argued properly that the work done in moving a test charge in the plane of equipotential surface is zero and mathematically derived that the angle between direction of electric field and equipotential surface is 90^0 . But he could not extend this interpretation to equipotential surface of a non- uniform electric field. As diagnosed in the Q1 most of the higher secondary students do not recognize the field around an isolated point charge as non- uniform field and hence face the difficulties to answer. Moreover, the equipotential surface in case of a non- uniform electric field as shown in Fig 4.2 are concentric spheres, not circles as shown in two dimensional diagram. Except few undergraduate students the higher secondary school students are not very clear about the fact work done on a test charge in moving it from one point to another on an equipotential surface is zero. The scaffolding hinted the students to relate work done to potential difference. This interpretation difficulties could have been avoided if the practicing teacher had interpreted it by showing mathematically, F.dl=dw=dv=0, on an equipotential surface and subsequently interpreting the field lines to be always perpendicular to the equipotential surface. Fig 4.1 is an appropriate three dimensional representation which depicts that for a uniform electric field in X-direction the YZ pane ought to be an equipotential surface. Then the students would have been facilitated to realise that for non-uniform electric field of the type shown in Fig 4.2 direction of field line is perpendicular to the equipotential surface because radius of a sphere always makes a right angle to its surface. The interview was extended to explore the students understanding about uniform and non- uniform electric field. Most of the students recognized the field between two finite plates capacitors as uniform field. But field inside a finite plate parallel capacitor is nearly uniform whereas field at both the edges of a finite plate capacitor is non- uniform as field lines bulge out at the edges due to edge effect. Students were reluctant to realise that electric field exists beyond the dimension of a capacitor. A similar finding is reported by Viennot & Rainson (1992) where students were reluctant to recognize the penetration of electric field into and out of an insulator.

OVERVIEW OF THE FINDINGS

The question wise analysis and discussion has definitely revealed some common inadequacies of students' interpretation skill and initial abilities. The most significant inadequacy is to identify the direction of field lines at different points of the field in various specific cases such as in Q1 and Q4. Many students deem it obvious that field lines are any convex curves those start from positive charge and end at negative charge. They do not realise that field lines are imaginary lines, a continuous locus that are guided by the resultant direction of the electric field vectors. The amount of curving and consequently the directions of tangent on every point of the curve (Fig 2.5 to Fig 2.7) depend upon the magnitude as well as the type of charge. The charge configuration for uniform and non-uniform electric field has not been grasped properly by the students. Field mapping hardly finds any place either in text book exercises or in routine test items. Hence, students are not skilled enough to organize their knowledge of field while representing through diagrams. Interviews reveal that the thought processes of most of the students are not consistent. What they think does not seem to be in consonance with what they show in diagram. Apparently the learning difficulties identified here have not been successfully addressed by the standard presentation of materials in the text books. Moreover, the best instructional material may not help if it does not foster the active mental participation of students in the learning process. For ensuring this a composite strategy based on pedagogy and subject matter needs to be adopted.

CONCLUSION

In this paper we have identified a common learning difficulty of the students' namely poor visualization of physical concept pertaining to electric field lines even when the mathematical cognition of the same seems to be satisfactory. The students need to realize that field lines basically are field vectors at a given point. In most of the cases students have not paid attention to the direction of resultant of force while dealing with the representational aspect of field lines. The convention regarding presentation of various electrostatic field lines pictorially has not been illustrated in instructional materials. The finding of this paper may throw light on this particular aspect of teaching which usually gets neglected during instruction.

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