Exploring Students' Thought Processes Involved in the Interpretation of Electric Field and Field Lines

Manasi Goswami*, Bijay Kumar Parida** and R. R. Koireng***

Abstract

Physics is introduced as a separate subject at the higher secondary stage in India. Many students who score good grades in physics in the examination even have significant conceptual difficulties and fail to apply their knowledge for further learning. In this context, teachers' understanding of the thought process of the students and the process skills of learning become significant. In this paper, we have critically examined the interpretation skills of higher secondary and undergraduate students on the concept of electric field and electric field line mapping. An exploratory method was designed wherein a diagnostics test comprising basic aspects of electric field and electric field line drawing were administered to 39 students of Class XII, JNV, Munduli, Cuttack; 47 students of Class XII, DM School, Bhubaneswar; 18 students of NISER, Bhubaneswar, and 32 students of the integrated B.Sc. B.Ed. Semester IV students of RIE, Bhubaneswar. Immediately after the test, a structured interview with eight randomly selected students from each institute was conducted. The study reveals some common inadequacies of students' interpretation skill and initial abilities on the concept of electric field lines. It also reveals that the thought processes of most of the students are inconsistent. The findings also suggest that the knowledge acquired by most of the students on the concept of electric field lines is nominal rather than functional. To acquire basic physics

**Professor,* Regional Institute of Education (NCERT), Bhubaneswar, India.
***Professor* (Retired), Regional Institute of Education (NCERT), Bhubaneswar, India.
****Associate Professor,* National Institute of Education (NCERT), New Delhi, India.

knowledge that students can apply in different situations, it is necessary for teachers to recognise the requisite thought processes of the students and to emphasise on those more explicitly. The findings also have implications on instructional strategies of teachers and teaching learning materials.

Introduction

Many students consider Physics as a demanding subject and face learning difficulties. Our instruction is often far less effective than we realise. Recent studies 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 and inability to apply their knowledge in further learning (Kim and Pak, 2002; Sabella and Redish, 2007; Pradhan and Mody, 2009). In short, students' acquired physics knowledge is often largely nominal rather than functional. This may be one of the reasons why most Indian students do not opt for a profession with physics. Thousands of teachers are engaged in teaching physics to young students. How a teacher approaches it depends on many factors. One of them is the teacher's understanding of the process of learning, which is more significant than the process of teaching. 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. Therefore, instructional implications (both text and teacher) need to be studied to better understand the thought processes underlying the various aspects of physics. Instructors must ensure that students can adequately interpret any concept or principle before they are asked to use it to perform more demanding problem solving tasks. Instruction and interpretation are complementary to each other. Interpreting a concept means identifying its meaning and implications, and judging its applicability in any particular context. Of course, effective interpretation skill of students predominantly depends on teachers' instruction, guidance, supervision and feedback. Besides these, at present, many innovative instructional materials and self-guided study materials are readily available to engage students in active thinking. The ability to interpret a scientific concept is clearly an essential pre-requisite for using the concept to make complex inferences. In this context, the concept of 'Electric Field' in physics is fundamental to investigate the conceptual understanding and higher order thinking processes of students. The concept of electric field is abstract in nature, first introduced by Farady through field lines to represent electromagnetic interaction. Most of the earlier studies (Greca and Moreira ,1997; Viennot and 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 and undergraduate students on the concept of electric field. But higher secondary level Indian physics syllabus devotes almost one volume of its textbook (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 sequential learning difficulties of students in electric field and field lines from the basis.

Need and Significance

In the present paper, we have made an attempt to study the in-depth knowledge, and interpretation skills 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 interpretation skills with the instructions provided by textbooks and live teachers. 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 formulae and a few field line drawings. We have tried to analyse the instructional implications on students learning and the interpretation deficiency in understanding the concept of electrostatic field. Unless we carry out research on the effect of our instructions on the performance of our students and make an analysis of their thought processes, we can neither address the deficiency in our instructions nor students' deficiency in interpreting and using the concept. These types of research or research studies conducted by oneself or others not only enriches teachers' instructional competency but also enhances students' understanding. These studies are indispensable for quality textbook designing, curriculum designing, good question setting, evaluation of answer sheets and above all, making a competent teacher and teacher educator. 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, the demerits of alternative conceptions have been weighed by us and a rational judgment has been made between competing ideas. While analysing the learning and interpretation difficulties of students, the concept specific instructional strategies provided by live teachers and textbooks have been discussed. In the following sections, we present the objectives of the study and test design followed by a detailed analysis of question-wise responses and a conclusion. We expect the findings will help students, teachers and teacher educators in this exotic domain of physics.

Objectives

The study was conducted with the following objectives:

- To identify students' comprehension of the pictorial representation of electric field and electric field line.
- To examine the interpretation skills in understanding the concept of electrostatic field.
- To study instructional implications on students' learning.

Test Design

The diagnostic test comprises of four questions on the 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 (RIE), Bhubaneswar. All 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 students of Class XII , JNV, Munduli, Cuttack; 47 students of Class XII, DM School, Bhubaneswar, 18 students of NISER, Bhubaneswar, and 32 students of the integrated B.Sc. B.Ed. Semester IV students of RIE, Bhubaneswar. Immediately after the test, a structured interview was conducted with eight randomly selected students from each school or institute. The higher secondary classes of DM school, which is the laboratory school of RIE, Bhubaneswar have also been observed. The rationale of selecting such schools or institutes lie 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 the interview was not specified. The interview protocol has been designed with appropriate scaffolding to bring out students' microstructure of knowledge presentation.

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

Analysis of Responses

The responses both in drawing and oral forms have been analysed question-wise below. This analysis will be equally beneficial for students, teachers and 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.

For locating the neutral point numerically, 92 per cent of JNV students, 67 per cent of DM students, 33 per cent of NISER students, and 27 per cent of RIE students have correctly worked out the problem using Coulomb's inverse square law. However, none of the students except one from DM school and one from NISER 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. The drawing shows that students have not understood that for mapping the field lines for charges of different magnitude, the number of field lines 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 or bending of the field lines according to the magnitude of charges has not been taken into consideration, and symmetry of the mapping has not been maintained. During the 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 they could not answer why the field lines bend in a particular pattern. During the 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 could 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. The following diagrams reproduce three sample sketches of the field lines (Figure 1.1, Figure 1.2 and Figure 1.3).

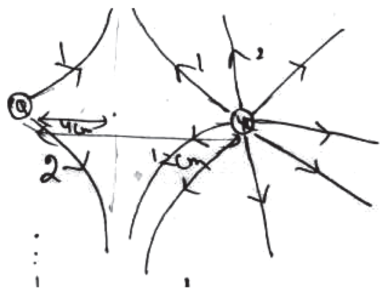

Figure 1.1

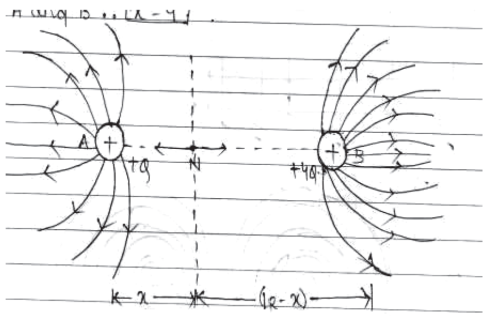

Figure 1.2

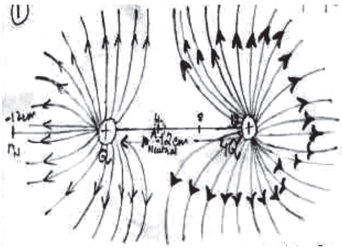

Figure 1.3

One typical answer in connection with the neutral point (Figure1.3) 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 the 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 +4 cm as neutral point which lies between +Q and +4Q. However, one student from RIE, Bhubaneswar assuming +Q charge as reference point has marked –12 cm left to the +Q charge as one neutral point and +4 cm 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 +4 cm is the appropriate neutral point which must lie within two similar charges. Using scaffolding in the reverse order, students were made to assume –12 cm 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 positive test charge at that point will be in the same direction and this does not qualify the concept of a balanced force. Here, students were given a chance to weigh their competing ideas and arrive at the right scientific conclusion. This finding seems to be very similar to the finding of Rainson. et. al (1994), where students do not recognise 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 Textbook. Live 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.

Q2. 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 Figure 2.1, Figure 2.3 and Figure 2.4. Assuming the metal plate as not being earthed, other respondents have shown the polarisation or separation of charges inside the metal plate and have utilised those bound positive and negative charges to draw the field lines (Figure 2.2.) Out of 39 students of JNV, 26 students (66.7 per cent) have drawn as Figure 2.1. They have correctly shown the induced negative charge only on the upper edge of the infinite plate and utilised 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. The 10.6 per cent of DMS, 38 per cent of NISER and 14.2 per cent of RIEB students have drawn like Figure 2.1. Of course during interview, one JNV students told that the teacher had discussed such problems in their tutorial classes, which is a very good practice of JNVs.

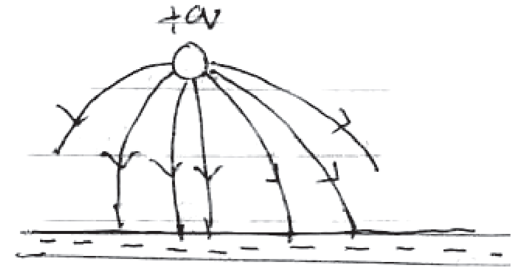

Figure 2.1

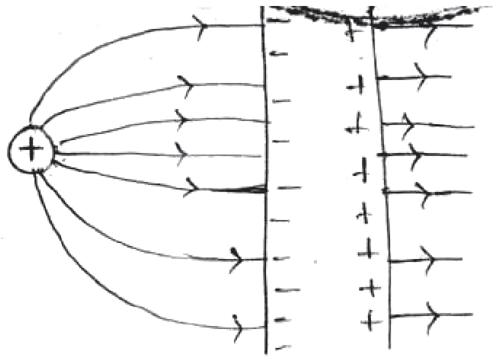

Figure 2.2

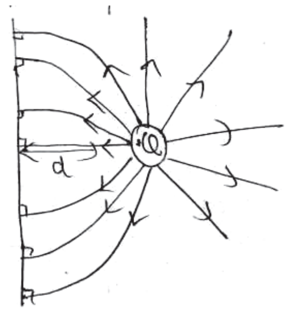

Figure 2.3

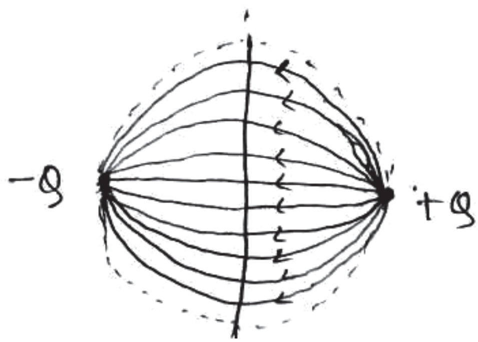

Figure 2.4

Maximum percentages of mapping by DMS students are like Figure 2.3. Two main learning difficulties of these students which are well visualised 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 the interview, most of the students were found to be aware of the principle but they do not think of it during mapping. Moreover, in some of the mappings of NISER students (Figure 2.3) 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 NISER students. They have used 'method of electrical images' for grounded metal plate. Some students 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 complete 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'. We do not expect higher order learning from school students but teachers are expected to understand the existing diversity of interpretation skills among various grade students.

Q3. 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 student of either DM School or JNV has drawn it correctly. They have joined the positive charge to the negative charge correctly with arrow sign, but have not paid any attention to the magnitude of charges. Their thought process has not been driven towards the fact that the direction of the 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 represented below.

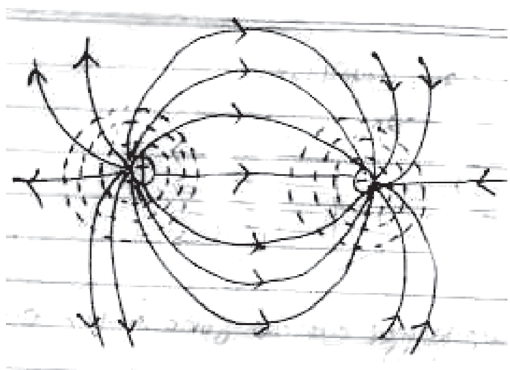

Figure 3.1

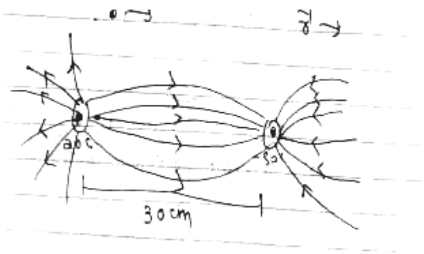

Figure 3.2

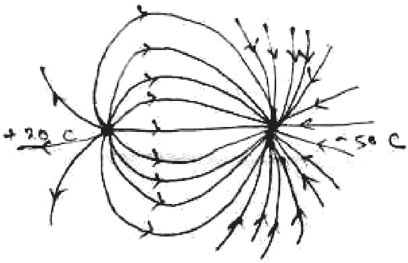

Figure 3.3

During the interview, one DM 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.

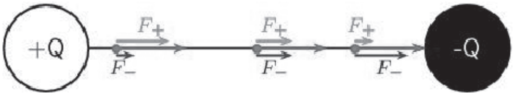

Figure 3.4

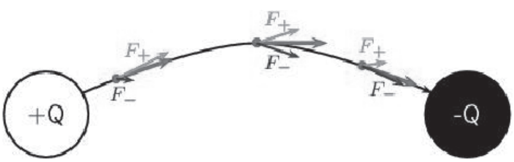

Figure 3.5

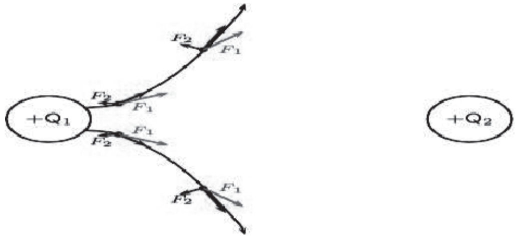

Figure 3.6

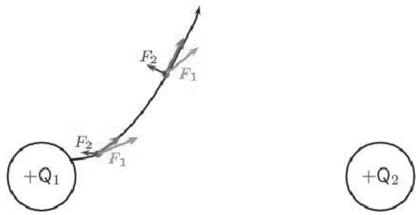

Figure 3.7

Students were hinted to recall the Law of Parallelogram of Addition of Forces and apply that for the comprehension of the field lines. If we put a +ve test charge near +Q (say on the line joining +Q and −Q) then it is pushed or repelled by +Q (shown by F+) and pulled or attracted by –Q (shown by F–) in Figure 3.4 (everythingmaths.co.za/science/Grade XI). 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 the resultant also points from positive charge towards negative charge. As the positive 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 the 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 Figure 3.5. The discussion was extended for two dissimilar charges of unequal magnitude (Figure 3.3). The students were hinted with the same principles to realise the curving of the field lines in case of two similar charges of equal magnitude (Figure 3.6 and Figure 3.7). These ICT based diagrams and a few YouTube videos in this concept were also utilised during scaffolding in Q1. The absence of these self-explanatory diagrams in the textbooks and lack of guided illustrations by the live teachers using ICT seems to be an instructional deficiency which might have led students to such pictorial comprehension problems.

Q4. Draw equipotential surfaces for a uniform electric field.

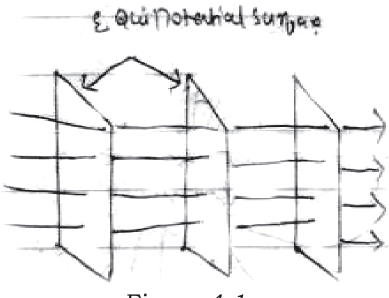

Figure 4.1

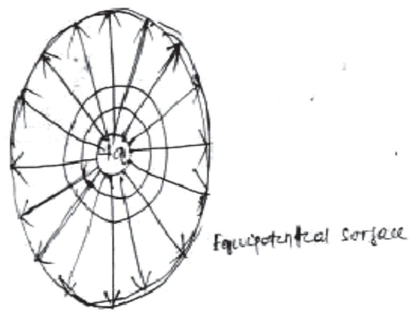

Figure 4.2

We mainly found two above varieties of answer. Maximum numbers of students of JNV (96 per cent) have answered correctly as it is a textbook based question and teacher follows the textbook line by line. However, during the interview, when those students who have answered correctly were asked why equipotential surface for uniform electric field should be a plane, only few were unable to answer. Those students who have drawn like Figure 4.2 have not understood the difference between uniform and non-uniform electric field, but have understood the meaning of equipotential surface. The RIEB students who have drawn it like Figure 4.1 argued 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°. But he could not extend this interpretation to equipotential surface of a non-uniform electric field. As diagnosed in Q1, most of the students of DMS do not recognise 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 Figure 4.2 are concentric spheres, not circles as shown in two dimensional diagram. Except few NISER and RIEB students, the school students of JNV and DMS are not very clear about the fact that 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 difficulty could have been avoided if the live 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. Figure 4.1 is an appropriate three dimensional representation which depicts that for a uniform electric field in X-direction the Y-Z 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 Figure 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 recognised 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 and Rainson (1992) where students were reluctant to recognise the penetration of electric field into and out of an insulator.

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 that 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 (Figure 3.5) depends 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 line mapping hardly finds any place either in textbook exercises or in routine test items. Hence, students are not skilled enough to organise their knowledge of field while depicting it 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 textbooks. 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

We all know introductory physics courses in India covers numerous topics but the knowledge actually acquired by the students is nominal rather than functional. Our higher secondary physics course mainly emphasises on facts, formulae and number munching. Hence, the students resist learning to do qualitative reasoning or to obtain mathematical results that can reveal important qualitative relationship. Although, many Indian students are known to be high achievers due to extra inputs from out of school resources, the numbers of high achievers are insignificant in comparison to the number of rural, semiurban and underprivileged higher secondary level physics students. For these students, the introductory level physics course still remains a passive learning experience. If students are to acquire basic physics knowledge that they can flexibly use, it is necessary for live teachers to understand better the requisite thought processes and to emphasise on those more explicitly. Within the limitation of this paper, we have briefly outlined some inadequacies found in the interpretation skill of the students and the possible genesis for those in instructional strategies of teachers, and text material.

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