ROLE OF INTERACTIVE SIMULATION IN UNDERSTANDING THE ELECTRIC FIELD

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The subject of Physics mostly deals with abstract and non-intuitive concepts. To ameliorate functional understanding of such concepts and physical processes, learners need an effective medium. Simulation being one such tool can render an opportunity through varied experiences and hence can facilitate conceptual understanding. Electric field is one such abstract concept which entails tangible experience. The present study investigates how simulation influences in elucidating the electric field concept. The first stage of the study explores the initial understanding of the field concept, followed by the use of simulation activity and validation test. Results indicate improved performance in the perception of the electric field concept, though procedural difficulties in vector representation are not completely eliminated and suggest explicit instruction implication.

INTRODUCTION

Understanding learning has been the quest of cognitive scientists, neurobiological scientists, psychologists and many others, and more recently of physicists so as to make learning more effective (Larkin, 1981; Van Heuvelen, 1991; Hake, 1998). The new area of research on how people learn Physics has instructional implication, as well as application for understanding how specific learning in the domain under consideration occurs (Bao & Redish, 2006; Hake, 1998; Heckler & Sayre, 2010). This new domain based education research has opened up many avenues for research in understanding aspects of effective learning of Physics. Physics has often been perceived as a surly subject thus causing many students to move away from it. Even among those who choose to pursue Physics, learning is tenuous. Extensive research initiatives have probed in to the various aspects of Physics learning. Often, the readiness with which a new idea or concept gets accepted is strongly influenced by the learner's perception of the relevance of the concept. This often does not happen in many domains of learning, also in Physics. Many Physics concepts, like electric field, do not possess associated physicality which makes comprehending experiences with the concept tedious. In addition to the complex concepts, Physics learning brings in use of novel representational formats - like graphical, vectorial, mathematical, etc which deter effective learning (Tornkvist, Pettersson & Transtromer, 1993; Beichner, 1994; Sherin, 2001; Torigoe & Gladding, 2011; Pepper, Chasteen, Pollock & Perkins, 2012).

In addition, the teaching-learning processes strongly influence the manner in which the understanding of a particular concept develops. Learning, more often than not, is influenced by the learners previously held ideas and beliefs. Pedagogical studies have been carried out in several domains of Physics learning - many in the domain of mechanics and relatively few in the domain of Electricity and Magnetism (E&M) (Viennot & Rainson, 1992; Tornkvist, Pettersson & Transtromer, 1993; Galili, 1995; Maloney, O'Kuma, Hieggelke & Heuvelen, 2001; Singh, 2006; Pepper et al., 2012; Gire & Price, 2014; Karam, 2014).

Concepts involved in the discipline of E&M are predominantly abstract and non intuitive more so while learning advanced Physics. Forming a mental model as a consequence of this becomes a serious impediment while learning the concepts for which the analogous mental picture is not feasible. In addition, physical experiences cannot be tangibly associated with the concept. However, what can positively influence understanding is the experience with features of the concept that can be illustrated (Shubha & Meera, 2015a). Along with the introduction of concept, comes in the requirement to adopt novel representations, for example vector representation for the electric field concept. Research has shown difficulties learners possess in using vector representations in the context of Physics (Knight, 1995; Nguyen & Meltzer, 2003; Flores, Kanim & Kautz, 2004; Van Deventer & Wittmann, 2007; Van Deventer, 2008; Barniol & Zavala, 2014; Gire & Price, 2014, Shubha & Meera, 2015b). Results indicate a lack of procedural knowledge. Interactive simulation tool with its visual attribute has the potential to generate experiences and hence can supplement traditional teaching/learning. It can also be an effective medium to reinforce the procedural understanding (Shubha & Meera, 2015b).

Studies have indicated that learning with virtual labs or computer simulations can have a positive effect on the acquisition of conceptual knowledge (Lindstrom, Marton, Ottosson & Laurillard, 1993; Jaakkola, Nurmi & Veermans, 2011; Sarabando, Cravino & Soares, 2014; Shubha & Meera, 2015a). Simulation is one of the effective learning tool that renders an opportunity to visualize varied experiences with the concepts and helps to build a mental model. The use of simulations in learning ameliorates conceptual understanding by use of visual representations (Finkelstein, Adams, Keller, Kohl, Perkins, Podolefsky & Reid, 2005; Van der Meij & de Jong, 2006; Adams, Paulson & Wieman, 2008; Podolefsky, Perkins & Adams, 2010; Zacharia & Olympiou, 2011; Chini, Madsen, Gire, Rebello & Puntambekar, 2012; Shubha & Meera, 2015b). We have chosen the simulation from the available repertoire of simulations, not really designed them for this study.

METHOD OF INVESTIGATION

This study intends to probe the model of students' understanding of the electric field concept and to obtain an insight on the role of the effect of interactive engagement activities using simulation. Student interviewees are volunteers from first year Masters Physics Course, Department of Physics, Bangalore University. The activities were conducted in three stages. In the first stage of study, seventy students were presented with ten questions in Multiple Choice Questionnaire (MCQ) form, related to elementary concepts (such as force, field & flux) of E&M. In this study, the responses to questions related to the concept of electric field are analyzed. Responses to the MCQ enable us to tailor and design the activities that explicitly deal with the relevant aspects. Based on the conceptual and procedural difficulties identified in the first stage of the study, after thorough review of available simulations pertaining to the electric field concept, we selected the Electric Field in One-Dimension Easy Java Simulation. In this stage, students' exploration of the simulation is accompanied by a set of questions framed on specific aspects pertinent to those aspects that were uncovered in the first stage of the study and that is in tandem with the features of the simulation. In the final stage, a validation test interview was conducted to evaluate the influence of interactive simulation on conceptual and procedural understanding of electric field representation.

PRE-INVESTIGATION STUDIES

The first stage of this study involved eliciting student responses to questions that probe their understanding of questions related to electric field concept.

Pre-test Questions and Responses

i. *Two point charges are arranged symmetrically about the y-axis. The direction of the electric field at point P is*
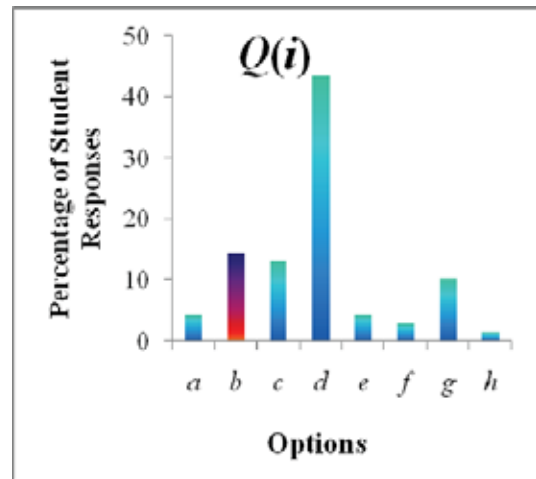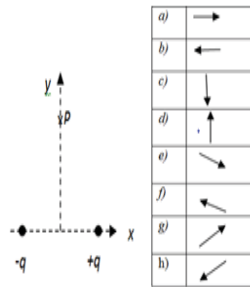

Figure 1: Question *Q(i)* and responses of students to *Q(i)*.

Answering question Q(i) requires students to use their conceptual and procedural understanding to draw field vectors and to obtain resultant field vector. Considering that students have had a rigorous course on vectors and have had the experience of drawing the vectors and their resultant in the context of mechanics, the answers for these questions were surprising. Fig. 1 shows the responses of students. About 15% have selected the correct option (b) whereas about 44% have selected the (incorrect) option (d). Though responses for Q(i) show faulty understanding, they do not depict underlying thought process. We reiterate here again that the MCQ questions are meant to provide us with a pointer for framing our simulation activity.

ii. *Two spheres Q and R carrying equal positive and negative charges, respectively, rest on a frictionless surface. Spheres 'Q' and 'R' are equidistant from another small sphere 'P'carrying a positive charge. If the sphere 'P' is released from rest, along what direction will it begin to move? Note :Tick the correct option in the box*
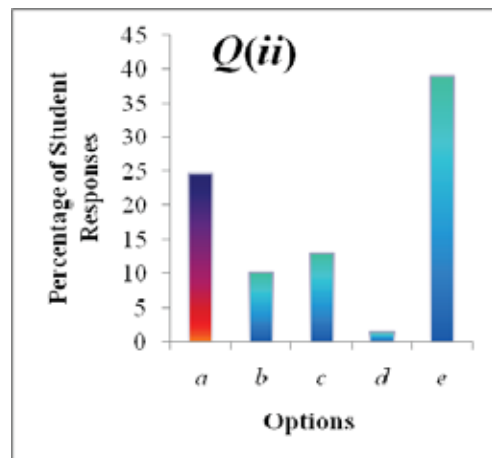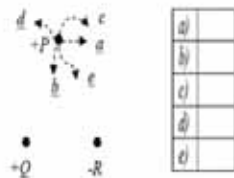

Figure 2: Question *Q(ii)* and responses of students to *Q(ii)*.

This question *Q(ii)* evidently is *Q(i)* but *Q(i)* is a Physics problem and *Q(ii)* is a physical problem. The response to the question *Q(ii)* is expected to mimic the responses of *Q(i)*. 24.64% have selected the correct direction (*a*). Fig. 2 shows the responses of students. Nearly 39% have selected the incorrect direction (*e*).

RESULTS OF PRE - INVESTIGATION STUDIES

Responses to questions in the pre-investigation study shows that the student difficulties observed in the MCQ test may be, to begin with, due to the lack of procedural understanding in the geometric representation of individual vector and finding resultant field vector for point charges. Research studies on usage of interactive simulation in teaching/learning process in different domains of Physics have established that a simulation enriches students' knowledge through experiences in conceptual understanding by visualization and interaction. To set up an intuitive understanding with varied experiences, this study is extended with interactive simulation as a learning tool.

SIMULATION – BASED LEARNING ENVIRONMENT

This research work uses Electric Field in One-Dimension interactive simulation as shown in Fig. 3 by using a software tool Easy Java Simulation (EJS).
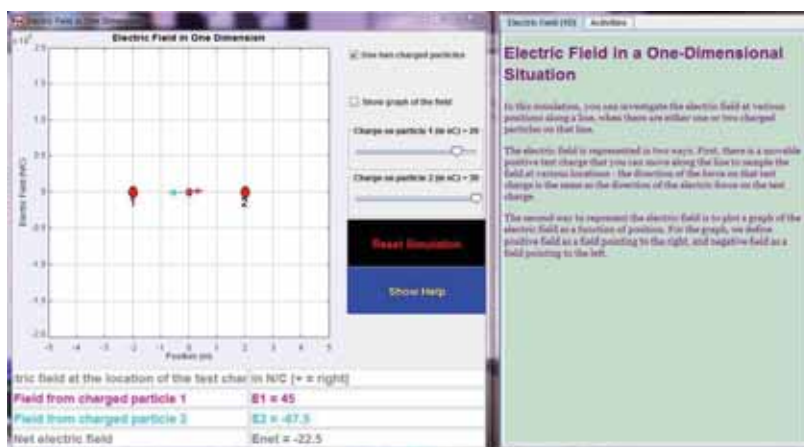

Figure 3: An illustrative screen shot of electric field in 1-D simulation.

Eleven students were provided with the simulation activity. The students were provided with an electronic writing pad by which answers to the questions posed has been recorded and interactions with simulation controls are recorded using CamStudio software. This provides us responses to the questions in real time.

SIMULATION ACTIVITIES

Five questions/activities were framed to bring to focus the functional understanding of vector arrow representation of physical quantities in concept learning by using simulation. The activities explore students understanding of the vector representation of electric field for the case of single charge and two charge situations as charge and distance parameters are varied.

ANALYSIS OF RESULTS OF ACTIVITIES

Activity 1 and 2 reinforces student understanding of the electric field vector with varying charge and distance. It is observed that all students interacted with charge control slider (to change charge quantity) and the click and drag tool (to change distance). In activity 1, six students did identify the proportional relation of the electric field vector (E_1) with charge (q_1). Of the remaining responses, one student who depicted the field vector in pictorial form had not drawn the longer arrow (with increase in charge). In activity 2, nine students did identify

the inverse relation of vector arrow length (magnitude) with varying (increase or decrease) distance.

Activity 3 tests often explored conceptual inference of the effect of electric field E_2 (due to charge q_2) on E_1 and E_{net}. The simulation window presents the numerical values of individual electric fields and net electric field and also the question did bring in the attention to this aspect. Out of eleven students, ten students clicked on the checkbox (use two charge particles) to select second charge particle on the simulation window screen. Among the ten, majority students namely nine noted the numerical values of E_1, E_2 and E_{net}. Of these, three of them pointed that the length of the vector (magnitude) of E_1 remains same when q_2 is on. Two students recognized that net electric field (E_{net}) as the algebraic sum of constituent electric fields (i.e., $E_1 + E_2$). The betterment in answer is made by one student who translated the observation pictorially and depicted the distinct field (E_1, E_2 & E_{net}) vectors on the positive test charge.

Activity 4 was framed with an objective to know whether the student can recognize the change in the length of field vector E_2 (by decreasing charge q_2) and its effect on E_1. It is noted that six students identified and inferred the answer correctly. Of the remaining five, three students could not identify the decrease in the arrow length of the field vector (E_2) but however they could enumerate that there is no change in the magnitude of E_1. In contrast, the remaining two students who identified the decrease in arrow length of field vector E_2 but not its effect on E_1.

Activity 5 was framed to consolidate the nested ideas of activities from 1 to 4 and transfer it to graphical illustration of electric field as a function of distance. Ten have executed the understanding of E vs d in the graphical form. Among them, six interpreted the same even in verbal form as an increase in arrow length with a decrease in the distance and two of them has corroborated it as parabolic curve.

VALIDATION TEST

In order to validate learning gain, we presented students with two problems. Five students were presented with these problems after they participated in the simulation activities (immediate response group) and four were given these after a gap of six months since they had used simulation (delayed response group).
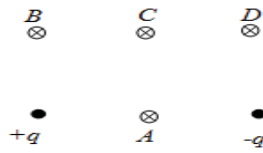
Validation questions

A. *Sketch the electric field lines for the point charges.*

a)   +q

b)   − 2q

B. *The two point charges +q and –q which are separated by a distance 'L'. In the diagram, draw the net electric field vector due to the charges +q and -q at the locations A, B, C and D respectively.*

Responses to Validation Questions

For *Q(A),* five students sketched the field lines on a positive charge (*+q*) and indicated the direction outwardly and for charge (*-2q*) have indicated the direction inwardly. Among them, four students are from the immediate response group and one student is from the delayed response group. Two students from the immediate response group, did not give attention to the proportional variation of line density with the increase in charge (*-2q*) shown in the Fig. 4.

Figure 4: Sample representation of incorrect proportional line density.

Of the remaining students, two have drawn the field line representation erroneously and in contrast two have depicted field lines as a field vector. Fig. 5 shows the representations.
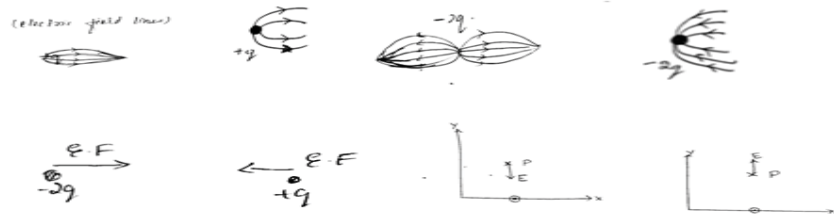

Figure 5: Incorrect representations made by students for charges +q and -2q.

For *Q(B),* two students have represented the resultant vector at all points (*A, B, C & D*) correctly. Among them, one student is from the immediate response group and another one is from the delayed response group. And a student from the delayed response group has joined the vector arrows at sampling points in space as a connected field line representation. Of the remaining seven students, three of them have decomposed the vectors "component wise" and drawn constituent field vectors due to (*+q and –q*) but not the resultant field vector at locations (*A, B, C & D*). And four of them have given the representation in fuzzy manner.

DISCUSSION

The present study was carried out to obtain an insight on the nature of concept student possess and role of use of simulation activities on developing conceptual understanding of the electric field. It also looks at how simulation influences understanding the vector arrow representation in visualizing the electric field at different points in space which inherently helps in acquiring procedural and conceptual knowledge for the same. Since the questions are presented in MCQ form and the question requires identifying the correct option and not really drawing the resultant vector, functional analysis carried out by students to find the solution is hidden.

As discussed earlier, simulation can be useful in developing experiences that promote intuitive conceptual understanding. The learning flaws observed in pre-investigation studies provide an insight in framing simulation activities. These activities cue directions while exploring the simulation. The validation test intends to assess the functional use and creation of vector representation that follows the simulation activities in altered situations. Results do indicate weak intermediate stages in learning even in post simulation experience which present instructional implications. Learning and general cognition can be influenced in a positive way by using visual inputs as it reinforces pattern formation. However in domains with strong abstractness, this may generate faulty patterns and in such situations simulation should only bring out features associated with the concept. Notwithstanding the proven effectiveness of the use of visual inputs, careful considerations in certain domains are essential.

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