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Perplexity of the FIELD concept in teaching-learning aspect

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PERPLEXITY OF THE FIELD CONCEPT IN TEACHING-LEARNING ASPECT

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ABSTRACT

The 'field' concept, being of the central importance in physics curricula, deserves much more elaboration besides the formal introduction employed by most of the textbooks. The recently performed study with high school students and prospective teachers shows that some misconceptions that students have learning electricity and magnetism could be explained as stemming from the unawareness of the methodological change introduced to the interaction description in electricity and magnetism by the concept of field. A misinterpretation of the applied method to treat interaction, in its turn, can promote the revival of the 'mechanics' misconceptions about interrelations of forces, force and motion, work and energy, etc.

INTRODUCTION

Any knowledge, and particularly the scientific one, is structured around the basic, fundamental concepts. One of such concepts, commonly introduced in the domain of electricity and magnetism (E&M), is "field". The way the basic concepts are introduced and defined by an instructor have a many-fold importance for the quality of the students' acquired knowledge and the difficulties they face later on, passing through the standard electricity and magnetism curriculum. The concept of "field" is a rather sophisticated scientific concept which was introduced to physics only in the XIXth century by Michael Faraday. There is no physics textbook, which does not introduce and use the concept. There are few of them which elaborate it conceptually beyond the immediate formal definition of parameters which characterize its features (field strength - E and field potential - φ). Moreover, in some cases, the word "strength" (or "intensity") is even omitted in the label (of the first from the two mentioned parameters) and E becomes just an "electrical field", actually, substituting the concept itself (Halliday and Resnick 1988). When researchers in science education adopted the ideas of constructivism the awareness of the role of basic concepts understanding by students in designing of the recommended strategies for science educators has tremendously increased (Driver 1981, Driver *et al.* 1985). The concept of 'field' has only recently started to attract attention of researchers (Shaffer *et al.* 1992, Viennot 1992). The study we report here was aimed to identify some specific features of students comprehension of the "field" concept itself. We tried to localize students' difficulties in operating with this concept, to identify their misconceptions regarding it and to see the origin of the alternative frameworks they develop. This complex attempt should provide the necessary basis for the *constructive* intervention by the science educator. The hypotheses of this research is that the existence of some students' misunderstandings stem from the mismatch of methodology applied in mechanics and E&M, as they are currently taught: mechanics - *without* using the concept of field, E&M - *with* an extensive use of the field concept as the central concept in the domain. A misconception might result from the constructive impact of knowledge: that acquired in the lessons on mechanics with that coming from the lessons on E&M. The confirmation of the research hypothesis could have a direct influence on choosing proper teaching strategies and on changing of the currently adopted ones to promote better progress in students' understanding of science (physics).

RESEARCH SAMPLE

Though the area of relevancy of this study extends the limits of high school, the subjects for this study were recruited mainly from the high school environment - 88 students of grades 11-12 after they studied the pertinent topics in physics curriculum. To facilitate the diagnostic goal of this research we questioned students mainly from a prestigious urban school, keeping only a small control group, 14 students, from an ordinary high school of the city. Furthermore, the group of 19 more gifted students from an advanced program class were all included in the tested group. We additionally enforced the sample by adding a group of 28 college students which were pre-service teachers of technological disciplines (electronics, computers) to enhance the reliability of the accumulated results. All together, we tried, on one hand, to increase our sensitivity in detection students novice knowledge views and, on the other hand, to smooth the influence of other factors of an occasional character (like teacher's personality) which could causes some distortions in responses distributions.

TEST, RESULTS, INTERPRETATIONS

A paper and pencil test was administered to all sample groups.

In task 1 we asked students about the trajectory of a negatively charged small ball placed without any initial velocity at location **a** in a static electric field shown in the provided figure (Figure 1a).

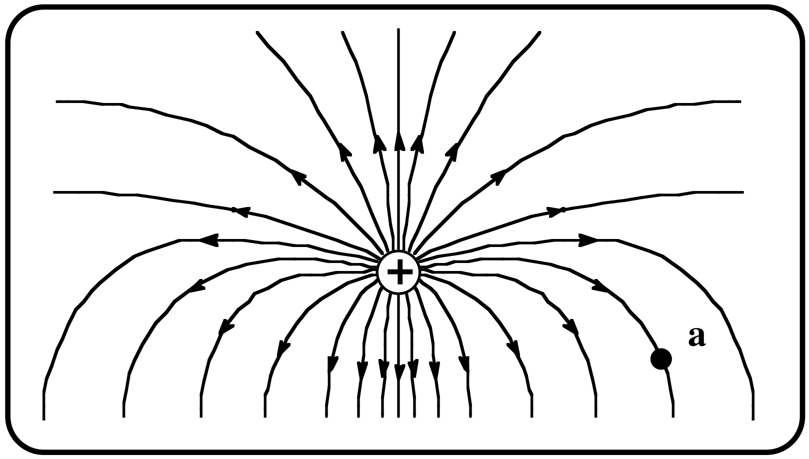


Figure 1a.

The results of task 1 are presented in figure 1b. We report the results in an integrated form, making no distinction between different students groups. The reason for that was that, contrary to our expectations, in most cases, our processed data did not show a strong enough non-homogeneity to justify the separate presentation of the results: students of ordinary and prestigious schools, advanced program students and students of teachers college provided rather similar results as far as we are within the goals of this study. So, unless otherwise indicated, the results were averaged over all subjects' groups.

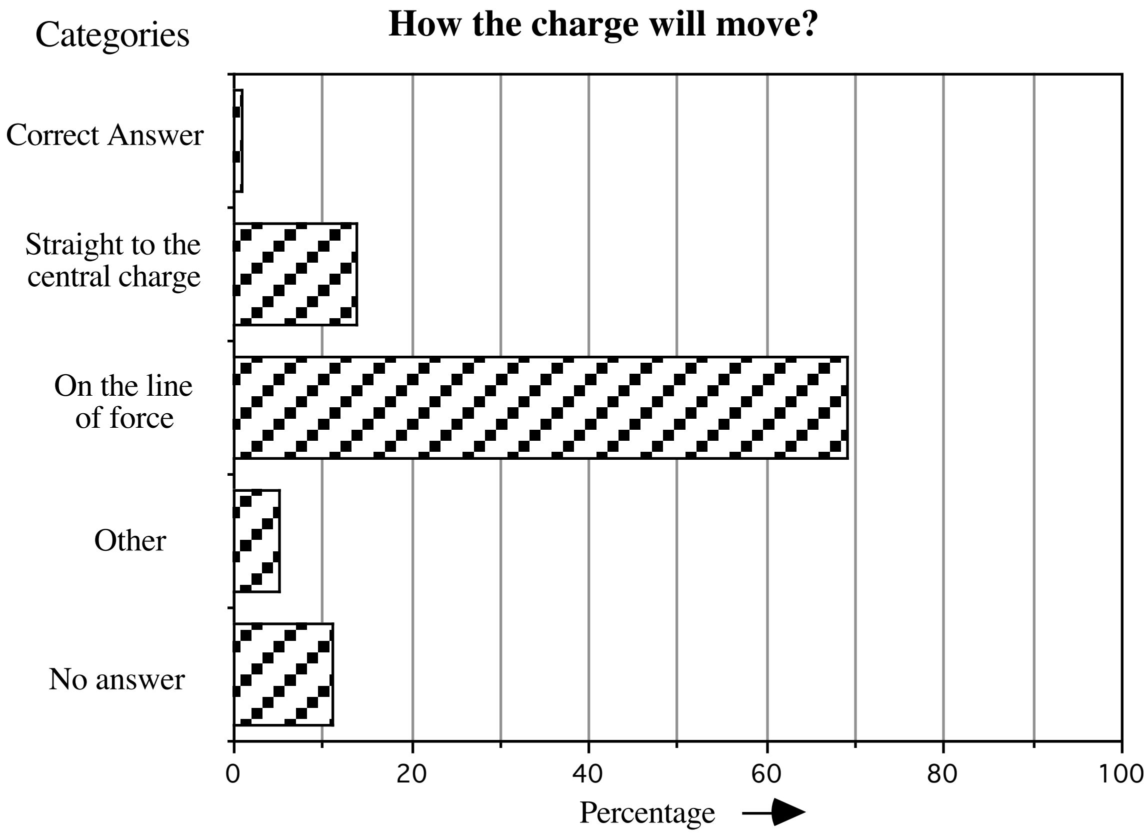


Figure 1b.

Only two students (both from the advanced grade 11 class) provided the correct answer, the explicit form of which (a kind of a spiral closing to the central charge) was of no importance for the research goal. A relatively small group of students stated the trajectory of the moving charge as a straight line towards the central charge (category 'Straight to the central charge', figure 1b).

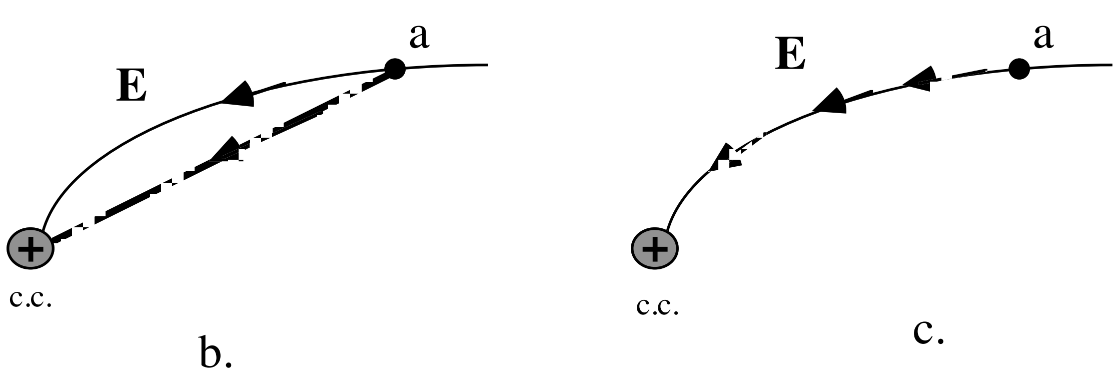


Figure 1c. **Figure 1d.**

To an expert, this response (Figure 1c) might suggest that the student has disregarded the field complex structure in the region. But, it could also indicate a different interpretation of the field lines by the students. (We will not speculate on this significant point here). A very striking result, however was given by about 70-80% of those who answered the question: they indicated that the *line of force* would be the actual *trajectory* of the moving charge (category 'On the force line', figure 1b). A straightforward interpretation of this response (figure 1d) is rather tempting: a single line of force includes only one piece of information, the direction of the force applied on the charge. The statement that the particle's trajectory coincides with the line of force represents *exactly* the Aristotelian understanding of the force-motion relationship. Namely, his 'compulsory' movement case, in which force causes and determines the movement in a unique way or, in other words, force drags object along its trajectory. There is still a distance between the novice students' views and the ideas of Aristotelian philosophical system and this notion by no means implies the equivalence of both visions. Still it might indicate a possible common intuitive ground in both cases. This issue has been already discussed extensively in a mechanics context (Clement 1982, 1983, McCloskey 1983, diSessa 1983).

It is still surprising that a problem of such a simple qualitative content (some of our subjects even mentioned it to their testers) could provoke such a high failure rate and a homogeneously Aristotelian response, especially if one takes into account the well above average academic level of our sample. An additional alternative and/or complementary interpretations could be looked for. This task presented a difficult problem if one wanted to treat it quantitatively, to get a precise answer, a precise shape of the charge trajectory. It might be the case if our students were used to solve quantitative problems, to look for a simple, preferably numerically presentable answer. So, they faced a difficulty in a novel situation and they looked for an alternative, simpler answer. In this novel situation their efforts resonate with the deeply installed intuitive ideas ('common sense') about the force-motion relationship which they usually held previously, before studying Newton's laws. A kind of regression in students' knowledge could be observed in this case (Galili and Bar 1992). This resonance was even enhanced here by the contextual crossover which provided the additional dimension of the problem. Newton's laws of motion were adopted in mechanical context. Mechanics and electricity-magnetism are two separate units of the physics curriculum. They are traditionally separated in the process of physics teaching in high school-college-university. So, some problems could stem just from this modular structure. For further illustration of this specific aspect we will move now to the following task. Then, we will try to make the general assessment about the origin and nature of the phenomenon.

Task2. A positively charged particle was placed with no initial velocity at location **1** between two parallel plates carrying equal and opposite, uniformly spread charges.

The particle moves toward the negative plate, location **2**. The plates are isolated.

a. Show **ALL** the forces exerted on **ALL** the components of the system.

b. What was the 'source' of the kinetic energy increase of the particle?

c. Did the intensity of the electric field of the plates change following the particle's velocity (kinetic energy) increase?

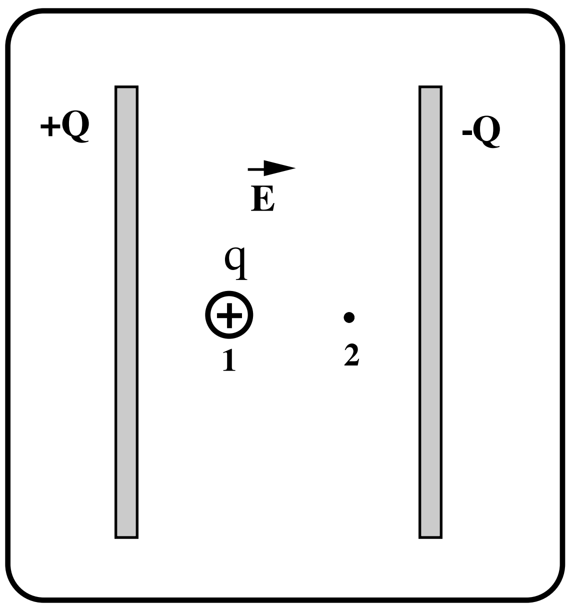


Figure 2a

The spectrum of responses regarding the forces active in the case is presented in figure 2b. A majority of students (75%) showed "one-force" picture of the plates-field-charge system (Figure 2c), few added the attraction between the plates (Figure 2d) and two (advanced program class) showed the full force picture (Figure 2e) which included the *reaction forces* acted on plates from the charge. All this after being emphatically asked to consider all forces in the system.

The question is then, whether this distribution of responses is the result of an occasional careless reading of the question or, may be it is an evidence of something else. We incline to think that one observes here an evidence of the fact that in "electrical" environment students consider forces reality differently from what they did in mechanical problems. To increase the confidence of the inference and clarify why this approach is not only different but wrong, we asked this question again in the context of the magnetic field.

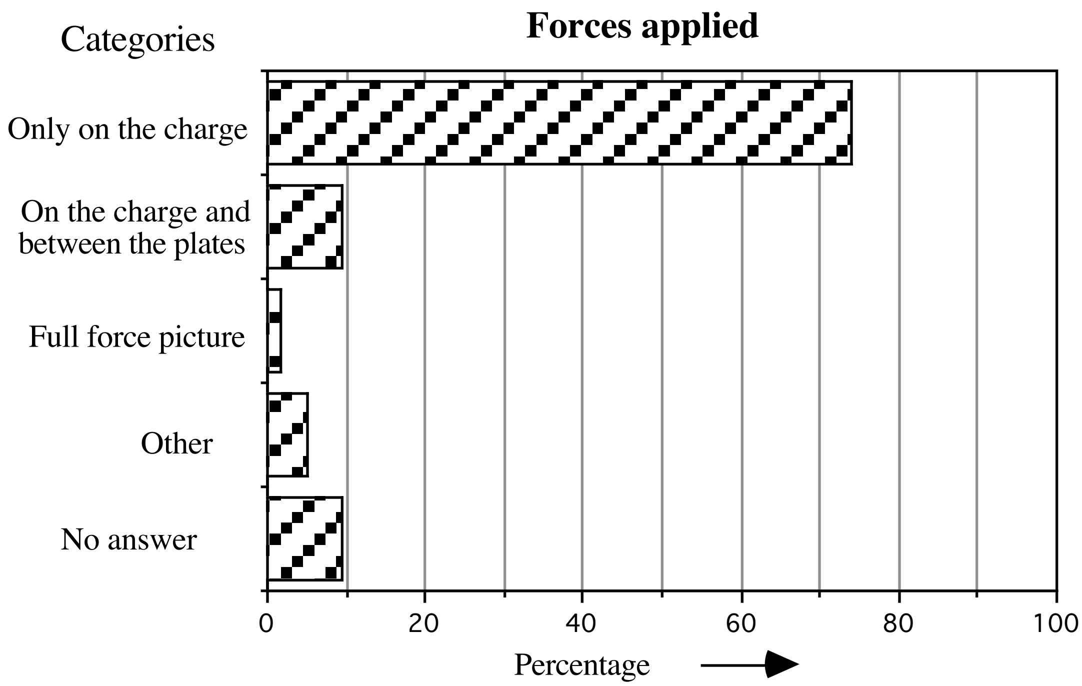
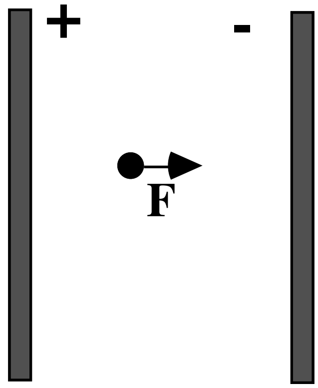
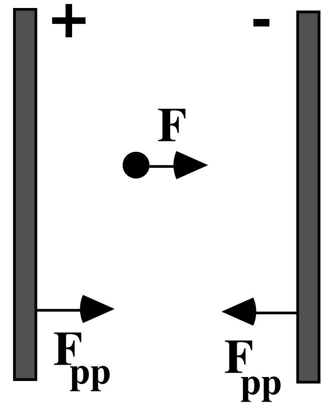


Figure 2b





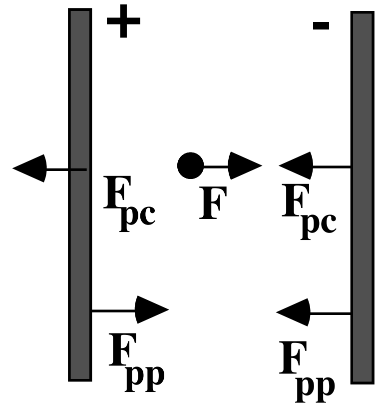


Figure 2c **Figure 2d** **Figure 2e**

Task 3. A straight current-carrying wire is placed in a magnetic field between the poles of a horseshoe magnet (Figure 3a).

a. Show **all** the forces exerted on **all** the components of the system.

b. Is Newton's third law applicable to this case?

c. Has the magnetic field of the magnet become weaker after the current-carrying wire was pushed out?

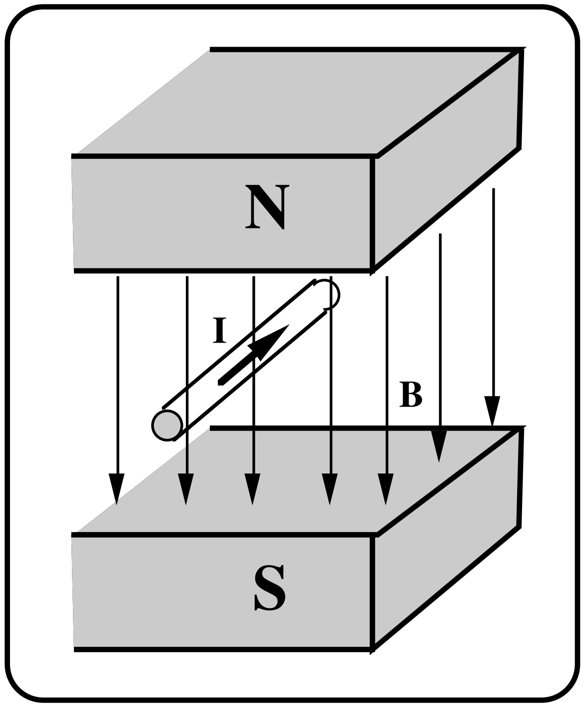


Figure 3a

The responses to the first question of this task were not less unanimous. Namely, only about 3% of all the students showed a force applied to the magnet, a reciprocal interaction partner of the force applied on the current-carrying wire. Others did not include any other force but that applied on the current-carrying wire. Answers to the next subquestion, 3b, further reduced the ambiguity of the conclusion. Students were explicitly queried if the Action-Reaction law (Newton's third law) is applicable to the situation when the magnetic force is applied to the wire. The answers, figure 3b, were quite articulate.

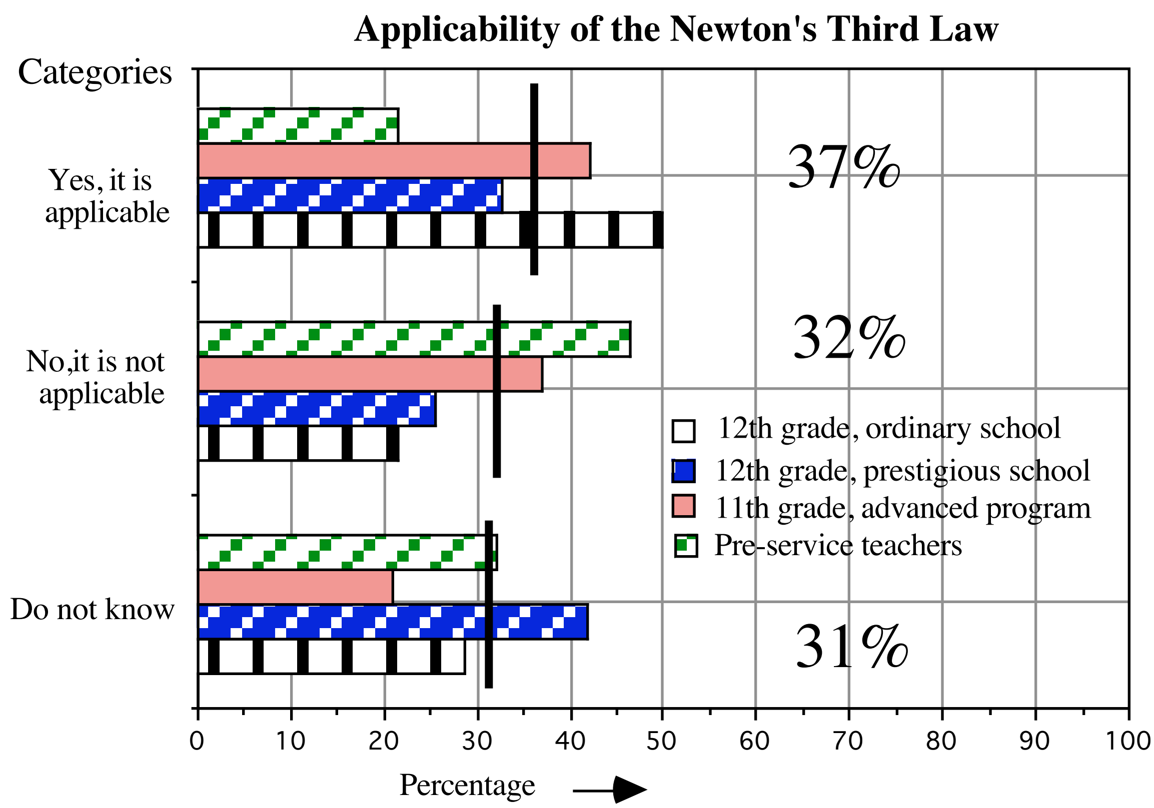


Figure 3b

First, the results (Figure 3b) showed *no* advantage of the students from the prestigious school (both, regular and advanced classes). Therefore, we kept the differentiation between the sample groups results. The difference between the groups seems to be appealing if not significant. Indeed, students of the control group, from an ordinary school correctly stated the applicability of Newton's law at a slightly higher rate than other groups. Furthermore, the prospective teachers group showed the worst result - about 20% of correct answers. Integrated results show that about *two thirds* of the investigated students evidenced their disbelief that the frame of interaction they learned in mechanics keeps its form in electromagnetism. Here are some quotes from students answers:

'I am not sure, it might not work here. We never talk about that...',

'This is not like two bodies pushing each other...',

'Here the laws are different...',

'It is the field which pushes the wire and that is why it does not work any more...'

Our data provides the evidence that while considering the task, students tend to miss the general considerations of action-reaction, or *inter-action*, context. Instead, they seem to think in asymmetrical terms of the field-on-charge *action* .

There is another point illustrating the perplexity of the field concept and could cause its alternative understanding by students and provoke a very pronounced misconception. This point is dealt with *work-energy* relationship in the system where the field is present. Subquestions 2b, 2c, and 3c probed the *work-energy* considerations in presence of electric and magnetic fields

The settings and scenarios of tasks 2 and 3 are very common at physics classes and in many standard physics textbooks. Same could be said about the search for the amount of the kinetic energy increase of the accelerated charge (Task 2). Usually, a much less discussed aspect of the problems is deals with the origin of the kinetic energy increase, either of the accelerated charge (Task 2), or of the current-carrying wire (Task 3).

The distribution of students' ideas about the source of the kinetic energy increase of the electric charge placed in an electric field is presented in Figure 4a.

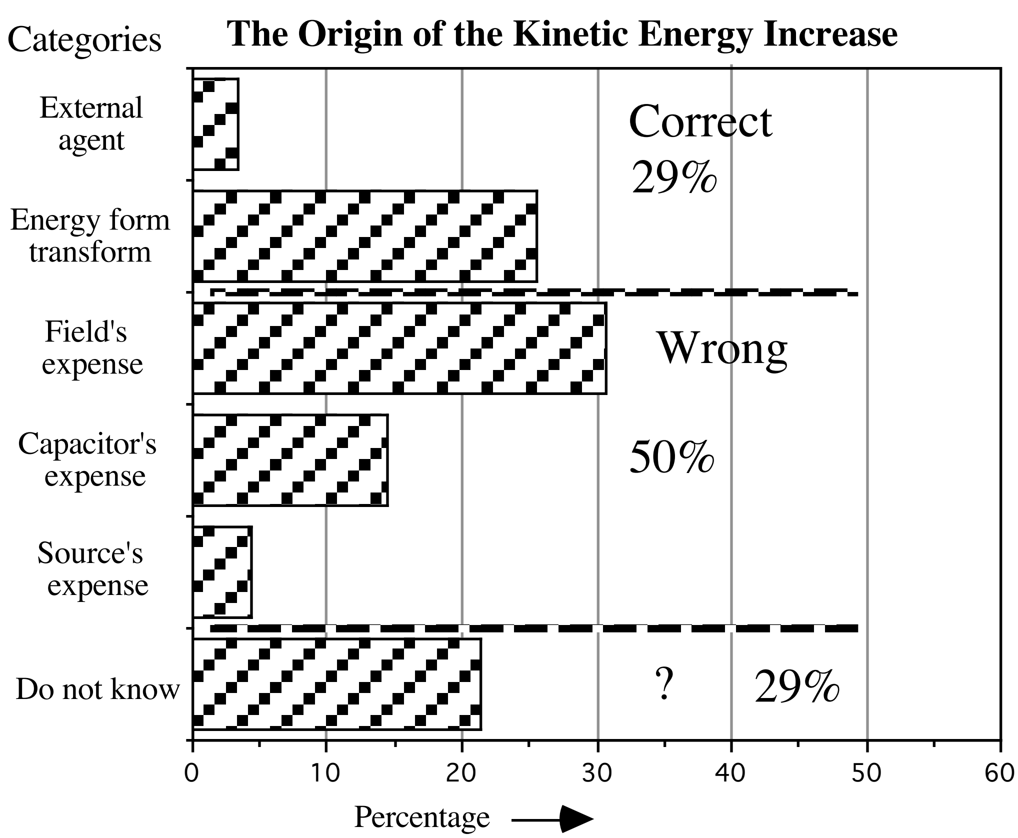


Figure 4a.

The low general rate of the correct response (less than a third) indicates the problem quite clearly. Moreover, the 'fine structure' of the correct answers could elucidate the situation more. Most of the students, from those who provided the formally correct answer: "The increase of the kinetic energy is at the expense of the potential energy" (category "Energy transformation"), did not go beyond this general statement and did not specify the necessity of an *external* agent. An *external* agent was an essential as a source of the energy to initially bring the charge to point 1 and to provide it, this way, with the potential energy. Hence, the rate of students who understood this point was actually much lower. Only few students from the best groups (prestigious school) mentioned the role of an external agent in tracing the origin of the kinetic energy increase. The majority of the investigated students connected the kinetic energy increase with some 'investment' made by other parts of the system: charged plates ('Capacitor expense') or a battery ('Source's expense'). But, most of them *saw the **field** as an 'investor' of the energy increase of the accelerated charge* ('Field expense' category). This chain in students' reasoning seems very important, as it has a strong misleading potential. We observed it in students' responses to the following question 2c (figure 4b). We inquired there whether the field had changed (become weaker) as a result of the charge acceleration. About *half* of the students did not answer correctly. Some of them predicted that the field became weaker (32%). Others found it difficult to give any answer at all (15%). Even among those answered correctly that the field intensity remained the same, the majority refrained from providing an appropriate justification or reasoned incorrectly by referring to the support of a battery ('Source expense') not presented in the task (Another illustration of 'correct-answer-wrong-reasoning' within 'alternative frameworks'- Osborne and Gilbert 1980, Driver 1981).

We find important the rate of correlation between those who saw the *field as the source of the charge energy increase* (statement 1) and those who claimed the *weakening the field intensity following the charge acceleration* (statement 2). Figure 5 shows the rate of this illustrative correlation for different sample groups. On the average it was about 60%. It might be significant that this correlation at the class of students with average skills was about 90%. It seems plausible that the students who positively contributed to such a correlation were driven by thinking that *the field provides the energy increase at the expense of its strength* .

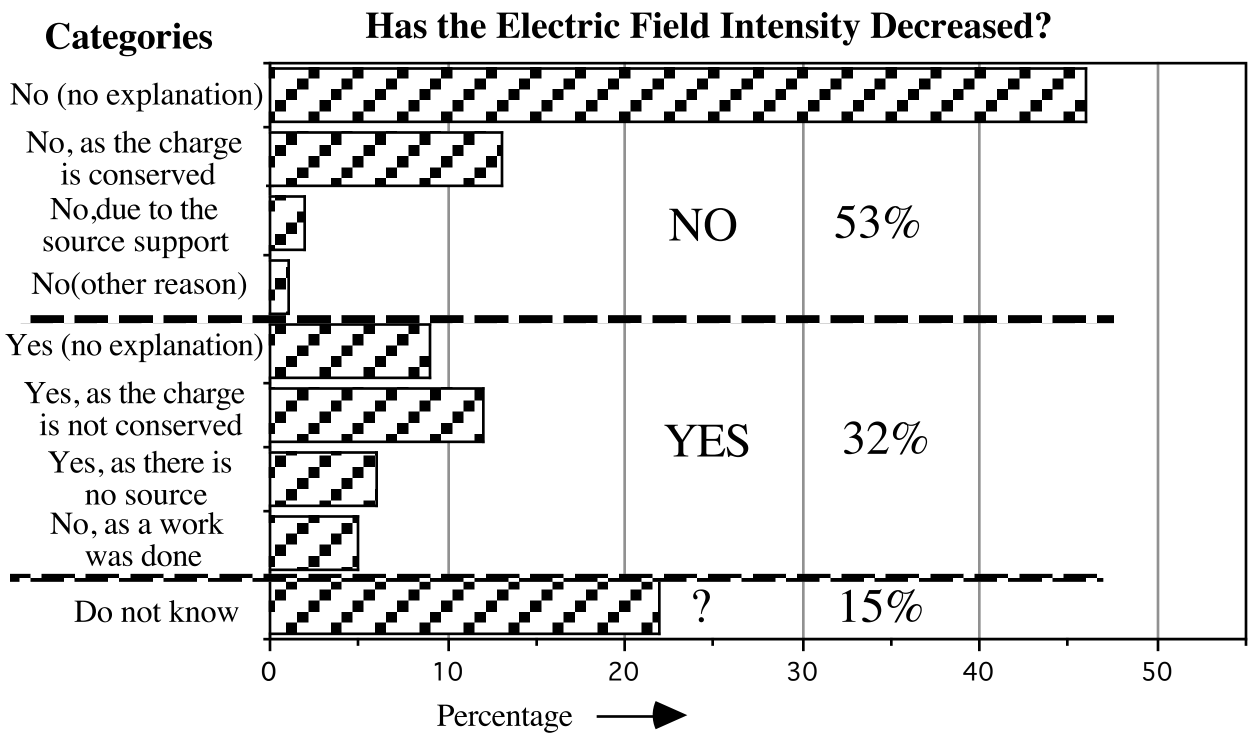


Figure 4b

Sample Group	**Correlation** (%)
12th grade ordinary school	90
12th grade prestigious school	62
11th grade advanced program class	51
Pre-service teachers	39
On average	60

Figure 5

We tried to observe the similar students' thinking chain in the environment of the magnetic field too. Task 3c "invited" similar predictions of the magnetic field weakening which could follow a force pushing out the current carrying wire. But in that case, only 15% predicted the field would be weaker: (though some specified like: 'it weaken, but at a small rate so we do not observe it' (12th grade, ordinary school), 45% did not think the field changed and 40%(!) did not answer at all. It seems that *permanent* (we call it this way!) magnet context was too 'hard' a scenery to show the chain of reasoning which would produce the field *change* , similarly to the case of electric field in task 2. Yet, the extremely high rate of 'do-not-know' responses might indicate the students' considerable hesitation on the issue.

LOOKING FOR THE RATIONALE

Our research data provides evidence for a specific students' difficulty while operating with the concept of "field" in the domain of electromagnetism. The perplexity of the field concept causes students problems to include the concept 'field' in the mechanics framework previously acquired in physics courses, to apply 'mechanical' concepts - laws and principles. They show a regression in understanding force-motion interrelation, they easily confuse considering energy -work relation in the presence of an electro-magnetic field.

All this forces us to overlook the field concept again and to review the rationale which stays behind its introduction in physics, the role it plays in classical electromagnetism.

Historically, the **first** role of the field was to solve the famous problem: *"action at a distance"* versus *"contact force"*. Namely, the field was the mediator for the conveying of the electrical (as well as magnetic) interaction between charges, magnets, currents and magnets etc. This was the main idea of Michael Faraday (1791-1867) the inventor of field concept or, as he called it, 'physical lines of force', in classical physics:

"...the existence of physical lines of force in relation to magnetism and electricity was inferred from the dual nature of these powers, and the necessity in all cases and in all times of a relation and dependence between the polarities of the magnet, or the positive and negative electrical surfaces." (Faraday 1853)

Faraday did not go far beyond the qualitative, more descriptive understanding of mediating role of field in magnetic and electric interaction. The practical realization of the idea was done by his follower, James Maxwell (1831-1879). He highly elaborated the idea when proposed the explicit *mechanistic* model for the field (ether) structure published in 1864 (Wise 1979).

"It fortunately happens that the electromagnetic measurements have been made from which we can calculate by dynamic principles the velocity of propagation of small magnetic disturbances in the supposed *electro-magnetic medium* (my emphasis, I.G.).

...And these lines must not be regarded as mere mathematical abstractions. They are the directions in which *the medium* (my emphasis, I.G.) is exerting a tension like that of a rope, or rather, like that of our own muscles." (Maxwell 1873)

This study did not check if students intuitively seek for the mediator in the electric or magnetic interactions. There could be an ideological problem of this kind (interaction transfer) that students have. If so, it seems that "field" concept introduction is resonating with the intuitive seeking for the agent for the "interaction transfer". As this point could propel the motivation of students, it is worthwhile for the physics educator to elaborate more about Newton's and Faraday's ideas and hesitations on the issue as the justification for introducing the field concept. In formal physics a line of formula transformation is standing for illustrating the philosophy of science in this case (Figure 6):

$$F = k\,\frac{q_1 \cdot q_2}{R_{12}^2} \Rightarrow q_1 \cdot k\,\frac{q_2}{R_{12}^2} \Rightarrow q_1 \cdot E$$

Charge ⇔ Charge Interaction   Field⇒ Charge Action

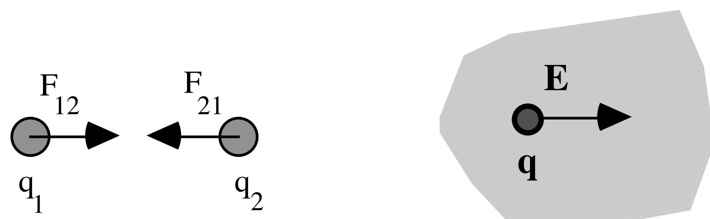


Figure 6

The **second** aspect of the field concept usage in classical physics is convenience. The introduction of field provides a tremendous short-cut in accounting for electro-magnetic interaction in the presence of many (up to an infinite number of!) charges or currents. Instead of calculating the force influence on a charge placed in an electric field, and on a current - in the magnetic, basing on the laws of point-charge - point-charge interaction (Coulomb's law), or element-of-current - element-of-current interaction (Ampere's Force law), physicists make use of the extensive character (more precise, linear dependence) of these laws on the charge (current) amount. They make the calculation in two stages. In cases of a specific configuration of charges (currents) they, first, summarize the contributions of myriad pair interactions of this configuration with a hypothetical unit charge (current) located at a space point and, second, multiply the result with the charge actually placed at that point. The result of the first stage of this procedure is called "Field Intensity" and could be used in a variety of cases in no connection with the second stage when an actual charge (current) is subsequently placed in a "previously prepared field". For example, such a procedure brings the results that a charge sphere acts outside its radius as a point charge placed in the center of the sphere". Physicists may say, that a spherical charge "creates a field outside like a point charge placed in the center of the sphere". (Once this claim was not trivial to proof and caused years of delay for "Principia" publication.) Finally, the reason that the field concept was originally not introduced in gravitation is the prevailed body-Earth interaction in comparison with really diminishing gravitational interaction between any two common bodies. This rationale enriches the standard textbooks definition for the field intensity beyond the 'specific' (particular) force acting on a charge ($E = F / q$)[1].

If so, from the methodological point of view, the introduction of field means actually the change in treatment approach, a new model to describe interaction. The model of interaction employed in mechanics could be seen as a one stage model:

$$\text{OBJECT} \Leftrightarrow \text{OBJECT}$$

The two interaction partners (both physical objects, like two gravitating objects, for instance) are observed by students and acting forces involved are symmetrical (Newton's third law). However, as we saw, in learning electromagnetism, quite a different operational framework for the interaction is suggested to students to imply: a two stage procedure:

$$\text{OBJECT} \Rightarrow \text{FIELD} \Rightarrow \text{OBJECT}$$

Both new successive stages ([1] first object - field created by it, [2] field - second object action) are asymmetrical in the sense that the field is *not* (in the classical physics, presented to the high school-college students) treated as a physical object[2]. Namely, Newton's third law becomes inapplicable on each of the two stages though it *does* apply to the whole process, when both stages are considered together. In other words, the field is now a mediator but *not* a physical object in the sense that it applies force on the object, but the object does not do the same reciprocally. This contradicts the ideas of the inventors (Faraday and Maxwell, see above) as well as the ideas of the relativistic theory of electromagnetism (which does treat the electromagnetic field as a physical object possessing momentum, as well as energy).

Students, being unaware of these methodological change, show ideas, contradicted to the mentioned two-stage model. We could see them now in different light. Indeed, students' inferences about the weakening of the field following the charge acceleration fit the understanding of the field-charge interaction as that between two material objects. Here are some of the students' comments about the 'charge-in-a-field' situation (task 2):

'...the charge was accelerated, the work was performed, somebody had to pay for it, so the field had to get weaker... ' (12th grade, prestigious school);
'...the wire was pushed from the region near the magnet and because of energy conservation the magnetic field should slightly weaken ...' (11-th grade, advanced

program class).

Some of them looked for an alternative model to describe the situation as best they could:

'It's like in a free fall... it works on you, but you can not do anything back...' (11-th grade, advanced program class)

Finally, it seems, we can infer that:
The introduction of the field (in the formal way it is usually done on the high school-college level) masks, and therefore questions, the reciprocal character of the interaction.

SUMMARY, RECOMMENDATIONS

The field concept presents a topic of high conceptual difficulty for students. Science instructors so commonly use the field concept that they often do not explicitly discuss or even mention some motivate considerations regarding field. This way this information is converted to a tacit knowledge used by experts but not known to novice students and among them, which is important, to prospective teachers. This lack of pedagogical sensitivity might cause students misconceptions based on "natural", but wrong preconceptions or peculiar confusion, like rejecting the symmetry of interaction, revision of force - motion understanding, energy transformation in physical system. A physics educator should elaborate on the introduction of field approach more than with formal operational definition of the "field intensity". The ideas justified the field introduction in physics should be explicitly discussed with students. This might remind of the promotion of a metalearning aspect of the learning process (White and Gunstone 1989). Namely, a discussion of the reasons for introducing the 'field' concept, 'learner's understanding of purpose' (*ibid.*), and the elaborating of the 'field' concept in the general scheme of physics knowledge might be effective. For instance, a possible introduction of the field concept already in mechanics (field approach to gravitation) could be profitable. This way one could prevent, to a smaller extent, some specific mistakes in learning electricity and magnetism and, in general perspective, promote the consolidation of a uniform scientific outlook on nature in science class.

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[1] Only in modern physics (relativistic and quantum) the situation is changed, the field got its momentum-energy and exchange them with the matter in a symmetrical way.

[2]The "field" story is not complete after these two points we mentioned. It was developed in modern relativistic and quantum theories where the field really got its own independent identity, but for in the framework of the classical physics these two points exhausted the field concept.

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