Educ Inf Technol (2009) 14:163–187
DOI 10.1007/s10639-009-9087-y

Educational software for improving learning aspects of Newton's Third Law for student teachers

Anna Spyrtou · Evripidis Hatzikraniotis · Petros Kariotoglou

Published online: 4 March 2009

Abstract In this paper, we present the design, development, implementation and evaluation of educational software "Newton-3", aiming at the learning of Newton's Third Law by student-teachers who are not Physics majors. We describe the theoretical issues of our teaching approach and the various software tasks that we designed in order to promote students' understanding. Specifically, the software is designed for the teaching of gravitational and electrostatic interactions between two distant bodies at rest. It is a web-based application and runs on a simple web browser with Macromedia Flash plug-in installed. The development of software and its integration into teaching–learning sequence is based on three main characteristics: the range of contexts in which the concept of force interaction applies, in the specification of the concept, and in an appropriate teaching learning environment (IDRF). We trialled the software on two groups of 8 primary school and 8 pre-school student-teachers, for 3 teaching periods, in the School of Education of our University. The research results indicate that the implementation was effective as the majority of the teacher-students improved their own knowledge concerning the existence and representation of gravitational and electrostatic interactions. An interesting result reveals that student-teachers have difficulty in perceiving the equality of magnitudes of action and reaction forces. This problem seems to be overcome after the teaching of the Inverse square law.

Keywords Educational software · Force interactions · Newton's Third Law · Student teachers education · Alternative conceptions

A. Spyrtou (✉) · P. Kariotoglou
School of Education, University of Western Macedonia, Florani, Greece
e-mail: aspirtou@uowm.gr

P. Kariotoglou
e-mail: pkariotog@uowm.gr

E. Hatzikraniotis
Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
e-mail: evris@physics.auth.gr

1 Introduction

Scientifically, force is related to the fundamental concept of interaction through Newton's Third Law, in a variety of contexts: for example, gravitational, electrostatic, and magnetic interactions. Specifically, the idea of force gives us a quantitative description of the interaction between two entities, e.g. masses; it is the physical quantity that defines the interaction between two entities (Young 1994). It is, therefore, important for the teachers of natural sciences as well as their students to comprehend explicitly the intimate relation of the concepts of interaction and force, so that they can interpret the results of interaction (change in movement and static equilibrium) in different contexts, e.g. the static equilibrium of two charged spheres on a table, the static equilibrium of an iron sphere hanging from a rope and attracted both by the Earth and a magnet. We know, however, that research conducted over recent decades has revealed that numerous difficulties have been experienced in the learning of these two concepts.

Over the last 30 years, the field of relative studies has mostly included the recording of students' conceptions in cases of change in movement, as well as in static equilibrium (Watts and Zylberszajn 1981; Terry et al. 1985; Hestenes et al. 1992; Grimellini-Tomasini et al. 1993). In more recent studies, emphasis has been placed on the need to go beyond the recording of alternative conceptions to the investigation of the nature of change in these concepts. For instance, there is a development of theoretical interpretations concerning the investigation of the nature and process of conceptual change (Ioannides and Vosniadou 2002), interpretations supporting the "theory of fragmentation" (diSessa et al. 2004), others studying *"contextual features that are frequently used by students in their reasoning"* (Bao et al. 2002), others seeking "founder notions" for the understanding of the concept of force interaction (Küçüközer 2001). Others have designed and put into practice studies of the process of conceptual change through the teaching of the Three Laws of Newton (Tao and Gunstone 1999a; Savinainen and Scott 2002a). Recent years have seen the development of a new research trend, in which efforts are made to use educational software for the teaching of force interaction, as well as the Three Laws of Newton, taking into account the findings of the above mentioned research (Finegold and Gorksy 1988; Gorksy and Finegold 1994; Tao and Gunstone 1999b; Yeo et al. 1999; Kolokotronis and Solomonidou 2003; Pol et al. 2005).

In our research, we have designed, implemented and evaluated a Teaching–Learning Sequence (Meheut and Psillos 2004) for the force interaction between two bodies, which are either at a distance or in contact, in a gravitational, electrostatic or magnetic field. Especially for the teaching of gravitational and electrostatic interactions at a distance, we have developed educational software. In this paper, we focus on that part of the research which concerns the development, implementation and evaluation of the software.

2 Force interactions—An instructional problem

In the following, we present the findings from the literature review that we took into consideration to design and develop the software. We sought the situations in physics which the relevant literature review has dealt with, as well as students' special difficulties in comprehending force interaction and Newton's Third Law, which formalistically describes these interactions.

Most research has focussed on cases in which the bodies are in contact: for instance, a book on a table (Terry et al. 1985; Hestenes et al. 1992; Trumper 1996; Palmer 2001; Bryce and MacMillan 2005), one stone resting on another (Palmer 2001), a man trying to push a box (Brown 1989; Thijs and Bosch 1995), an object connected to a spring placed on a frictionless plane (Park and Han 2002). In contrast, the cases with bodies at a distance are comparatively few, e.g. the interaction between the Earth and a golf ball traveling through the air (Kruger et al. 1990; Hestenes et al. 1992), the magnetic attraction and repulsion between two magnets (Jiménez-Valladares and Perales-Palcios 2001), the Earth and a ball that is dropped from a height (Suzuki 2005), the interactions between two entities (masses, magnets or charged bars) at distance (Kariotoglou et al. 2008). Also, most researchers focus on the investigation of the conceptions of students in cases where the bodies are moving either at a constant speed, e.g. a trolley or a book moving on a table at constant speed (Thijs 1992; Trumper 1996), or at a changing speed, e.g. a bicycle slowing down (Kruger et al. 1990), a student on rollers pushing another (Hestenes et al. 1992; Bao et al. 2002), or even in cases where the bodies are colliding with each other, e.g. a collision between a truck and a car or between two cars (Brown 1989; Hestenes et al. 1992). Considering the above survey, we think that the research is rather limited in the case of two bodies at rest interacting at a distance, as well as in physical contexts other than gravitational ones, e.g. electrostatic, magnetic.

In the research findings, there are similarities concerning the students' difficulties in comprehending Newton's Third Law and the concept of force interaction. To summarize, students find it difficult to comprehend that:

1. Inanimate bodies can exert force, e.g. like a stone or a chair (Finegold and Gorksy 1988; Hestenes et al. 1992).
2. Forces can be exerted on a stationary body, e.g. on a stationary car (Terry et al. 1985; Tao and Gunstone 1999a).
3. Force interaction can be developed between distant bodies (Kolokotronis and Solomonidou 2003).
4. "Terrestrial" as well as celestial bodies can interact with the gravitational force, e.g. they cannot comprehend that the Earth and a stone are objects and it is, therefore, possible for a gravitational interaction to be exercised between them (Küçüközer 2001; Kariotoglou et al. 2005).
5. Interaction is a mutual relationship between two objects, e.g. "*the use of the verb to 'act' associated to a linear causal reasoning leads to see that on one hand A acts on B and B acts on A on the other hand, that is independently*" (Küçüközer 2001).
6. The cause of reaction force, e.g. they think that the upward force of a table on a book comes from air pressure, air molecules and so on (Bryce and MacMillan 2005) or when one body is resting on another, the lower body possesses a passive resistance that "*cannot be regarded as a force*" (Montanero et al. 2002).
7. The placement of the vector of force on the body that receives the force e.g. students place the arrow on the object that exerts the force (Kariotoglou et al. 2005), which

results in identifying the force with an attribute of the object or confusing "*the direction of the force with the direction of the movement*" (Jiménez-Valladares and Perales-Palcios 2001; Kariotoglou et al. 2008).
8. Action and reaction have equal magnitudes, e.g. they think that the body with the greater mass exercises greater force (Hestenes et al. 1992; Bao et al. 2002; Kariotoglou et al. 2008).
9. Last but not least, students' reasoning seems to be highly influenced by context. Students may give answers that agree with the scientific view in one context while, at the same time, their answers may be different than the scientifically accepted ones in another (Montanero et al. 2002; Tao and Gunstone 1999a; Heywood and Parker 2001; Savinainen and Scott 2002b; Kariotoglou et al. 2008). For instance, Heywood and Parker (2001) question which key ideas students and in-service primary teachers have about floating and sinking as well as how these ideas have extended to different contexts such as static structures (for example, an arched bridge). They found that students might comprehend the balanced forces involved in floating but that it is difficult for them to transfer such thinking to other more complex situations, such as an arched bridge.

In recent years, methods of teaching using software have been suggested, with the purpose of confronting the student problems mentioned above. The suggestions that aim at the learning of the Three Laws of Newton seem to focus more on the first two laws (Tao and Gunstone 1999a; Yeo et al. 1999; Pol et al. 2005) rather than the third law. What follows is a presentation in summary form of certain cases which we referred to in the design of our own software.

Finegold and Gorksy (1988; Gorksy and Finegold 1994) developed a computer program including five simulations concerned with forces acting on objects at rest or in motion, e.g. a book resting on a table, a book sliding on a table with or no friction after being propelled by a spring. In each simulation, students (grades 8–12) are asked to choose the vector of forces acting on the object. The vectors of forces have only four directions (horizontally and vertically, from left or right) and two magnitudes for each direction. Next, they check if the given choice of vectors is correct, e.g. can the book move vertically upwards, something that contradicts common sense. The results of this research reveal the special role that simulations play in the teaching–learning process. Students' answers, while they were making the simulated tasks, were both rational and emotional: rational, "*when students could easily reconcile old and new knowledge*"; and emotional "*when old and new knowledge could not be easily reconciled*" (Finegold and Gorksy 1998). Simulations seem to enhance conceptual change strategies during the teaching–learning process.

Kolokotronis and Solomonidou (2003) have developed software, which aims at the construction of the scientific view for the concept of dynamic interaction and Newton's Third Law, for students of primary and high school. Various situations were selected in which forces are exerted in either a vertical or horizontal direction. Authentic situations of interaction between bodies from everyday life were simulated, such as: the Earth and a dog, a woman on scales, and the tug of war game. Most experiments favour processes of cognitive conflict with the challenge of conceptual change as their aim. This research has similarities to that of Finegold and Gorksy (1988; Gorksy and Finegold 1994). For instance, students choose the vectors of forces—which are on the screen—and place them on the body, e.g. on the book balanced on the table. Next, they check if the given choice of vectors is correct. Among the benefits of this exercise is that, in designing software, the researchers took into consideration not only the ideas of students as they are presented in the literature review but also the results of empirical research that they conducted on Greek students and their teachers. Moreover, the simulation of real everyday situations, the chance the students had to test the validity of their conceptions, as well as the enthusiasm they showed while completing the software tasks may all be mentioned as benefits of this software. As Kolokotronis and Solomonidou emphasize, this particular research was focused on the interactions between solid objects, either at a distance or in contact, while not expanding on other interactions, e.g. between liquids in depth.

There is general agreement about the learning results of two research works in which software was developed for the teaching of the first two laws of Newton (Tao and Gunstone 1999a; Yeo et al. 1999). Both showed that students experience difficulties in transferring the knowledge they acquire to new problems and contexts. In particular, Tao and Gunstone (1999a) applied a computer-supported physics unit in order to confront students' alternative conceptions (10th grade) related to Newton's First and Second Laws, e.g. a moving body has a force and its force is gradually used up when it slows down. Computer simulation programs include a motion graph program as well as three other programs, namely, Model Car, Spaceship and Skydiver. Students predict, observe and explain tasks concerned with horizontal linear motion (Model Car), without friction and resistance (Spaceship) or tasks concerned with vertical fall under gravity (Skydiver). Tao and Gunstone use these three different contexts (Model Car, Spaceship and Skydiver) in order to "*enable students to revisit the scientific conceptions in different situations for reflection and consolidation*". From this, research reveals that learning is contextually based and, as a consequence, students need to approach a range of different situations in order to accept the generality of scientific conceptions. Similar problems were recorded by Yeo and his colleagues (1999), who used the intelligent computer-based instructional (ICBI) program, *Freebody*, in order to confront students' inconsistencies in their reasoning about force and motion. Physical situations such as "*a boy having thrown a rock in the air*" are given to high school and university students asking them to draw a free-body diagram on an object, using the mouse. Following that, the software recognises and discusses their drawings, helping them to correct the inconsistencies or contradictions in their ideas. Researchers point out that students "*held conflicting conceptions, both before and after the program*", surmising that students cannot recognise that different situations could be explained by the same Newton Law, either the First or Second.

3 Learning force interactions—Theoretical issues

From the above discussion we may come to two conclusions. Firstly, students attribute to force interactions different characteristics to those attributed by scientists. Second, these characteristics may change from context to context. In line with these issues, the research being developed on conceptual change acknowledges that significant difficulties exist in teaching–learning force interactions and therefore seek a broader theoretical framing in order to interpret these difficulties. diSessa and his colleagues (2004), introduce the terms "contextuality" and "specification" to enhance theoretically and empirically "*how much and what kind of accountability for details in conceptual change must conceptual change researches take on*". According to them (2004), "contextuality" concerns "*the range of contexts in which a concept (meaning, model, theory) applies*", contributes to understanding if students "*have multiple ways of conceptualizing a situation…*", how they "*respond to different situations*" and so on. "Specification" concerns the kind of aspects, which we need in order to specify a particular concept. For the specification of conceptual content five aspects are suggested: existential, ontological, coarse quantitative, compositional and causal. The *existential aspect* answers the question "*to what situations will a subject attribute the existence of a force?*" For instance, students do not accept the existence of force in the case of bodies at rest. The *ontological aspect* concerns the conceptions of students on the nature of force interaction, e.g. the naïve conception of force as a property of an object is well-known (Ioannides and Vosniadou 2002). A significant feature of the nature of force is its vectoral character. It has been established by previous research (see previous unit) that students present various difficulties in perceiving the vectoral character of the force. The *coarse quantitative* aspect specifies the quantitative consideration of the concept of force that students have, e.g. a difference between students and scientists is that the first do not accept the equality of magnitudes of action and reaction. We will not discuss the remaining two aspects, compositional and causal, since they are related to the composition of forces and Newton's Second Law respectively, in other words, they refer to issues not relevant to this paper.

In literature, the term 'contextual coherence' is used to evaluate the extent to which pupils "*can apply a concept or a physical principle in a variety of familiar and novel situations'*", (Savinainen et al. 2005). "Representational coherence" concerns students' capability to use multiple representations correctly, for instance verbal, diagrammatic, graphical. (Savinainen et al. 2005). Based on the above for promoting "contextual coherence", we need to develop appropriate works, in which we focus on the existential aspect of force interactions in various situations in the same phenomenological environment, e.g. gravitational, as well as in different ones, e.g. electrostatic, magnetic. When students recognise dynamic interaction in various contexts, it does not necessarily mean that they have acquired scientific conceptions on the ontological aspect or the coarse quantitative aspect of interactions (diSessa et al. 2004). For instance, students may recognise that a magnet exerts force on a magnetic material, or a rock on another rock, but overall they have failed to structure the conception that this force is the product of interaction and not the quality of a body. When students can handle a variety of representations on force interaction, then we can better comprehend the ontological and the coarse quantitative aspect they have on that concept, e.g. the correct vectoral representation of the force. Therefore, for promoting 'representational coherence', students need to study a variety of representations, e.g. to draw the vectors of force qualitatively, meaning to draw clearly what force is exerted on which body, as well as quantitatively, meaning to ponder on the magnitude of these vectors.

4 The role of educational software

In the conclusions of the literature review, in which the role of software as a means of teaching and learning is analyzed, it is maintained that the use of computers can generate the desired learning outcomes when realized in a learning environment in which students have the ability to interact not only with the software but also between themselves. Empirical research shows that it is not enough for students to merely complete the software labs, since all too frequently they view them as a group of compulsory exercises that will help them learn something they do not know (Tao and Gunstone 1999b). In contrast, learning results are positive in a learning environment in which students work in groups, discuss their views between them, use the software to check them and, then, further discuss their modified views (Jimoyiannis and Komis 2001; Kordaki 2004; Wegerif 2004).

There are many cases which we cannot be studied in real lab experiments in a classroom setting because they are either impossible to conduct, dangerous, too complex, take too long or, in contrast, are too short. In these cases, the role of educational software is essential because, first, the presentation of these physical phenomena is feasible in the software environment (Hennessy et al. 2007); for instance, in our teaching–learning sequence, we can approach the gravitational interaction between a water-melon and an apple, or the electrostatic interaction between two “space” charged spheres. Second, educational software provides opportunities, by reducing the time required, to study these kinds of physical phenomena in a variety of circumstances, e.g. the gravitational interaction between two bodies in space, or on the beach, or in a room, with a variety of representations, e.g. pictures, graphs, vectors (Jimoyiannis and Komis 2001; La Velle et al. 2003). Third, with educational software we can study cases ‘sanitised’ from the real world, in which we can isolate and manipulate variables, e.g. two charged spheres in space whose masses or charges we can change (Jimoyiannis and Komis 2001; Suthermund 2004).

It becomes obvious from the above that educational software plays a unique role in our sequence, because it can essentially aid in promoting “contextual coherence” as well as “representational coherence” for the understanding of force interactions.

5 The education software ‘Newton-3’

Taking into account the problems as outlined in the previous sessions, the following designing principles for the development of our software emerge (Kariotoglou and Spyrtou 2005). Based on our initial conviction that it is necessary for student-teachers to decipher the intimate relation of the concept of interaction with force, we decided to design software in which:

i We take into consideration the empirical results of our research for these two concepts as well as the corresponding nine learning difficulties that derived from the review of the literature review (see Section 2).

ii Contextuality as well as the specification of force interactions are approached with specific tasks. It is, therefore, necessary to include different contexts of force interactions, gravitational and electrostatic, as well as specific tasks in which the existential, ontological and coarse quantitative aspect of specification will be approached. In particular, we consider it essential to include cases in which stationary distant bodies will interact, since our literature review shows that the number of such suggestions is limited (see Section 2). We decided that magnetic interactions are too easy to be studied with real lab experiments.

iii Our students complete the software exercises in groups, in a learning environment of co-operation so as to discuss their views on the relation of interaction with force in depth.

The educational software presented in this work, is a web-based application, designed for the topic of Newton's Third Law. The software covers a series of several cases from gravitational to electrostatic interaction (Kariotoglou and Spyrtou 2005). The application runs on a simple web browser with Macromedia Flash plug-in installed. The main screen looks like a notebook page, and is divided into two main sessions. To the right we have the actual application, called a "Lab". To the left (see Fig. 1) is the text area, which contains brief instructions for "Lab" activity to run. The text is kept to a minimum and briefly describes the tasks that the student should carry out in each "Lab" activity. The user has a choice of a total of 11 different "Lab" activities from among the menu-like buttons at the bottom of the html page. User instructions appear as a pop-up window, on the click of an "instructions" link.

A typical "Lab" stage is shown in Fig. 2. The stage is divided into three parts: the main part is devoted to the visual representation of the interaction addressed in the "Lab" activity. To the right there is a tool-box, and in the bottom part the "expert comments" on the student's actions. A photo-realistic representation of both the background and the interacting bodies is adopted to help the user get a clear view of the problem presented.

Fig. 1 Main screen of the application

Fig. 2 Typical ‘Lab’ stage: the case of the Earth and the Moon

In Fig. 2, the case of the “Earth” and the “Moon” is presented, while the background is set to represent the “Universe”. The user is asked to pick and place the action that one object (the “Earth”) exerts on the other (the “Moon”). The action exerted is represented by a vector (arrow). The arrow—force vector—is initially placed in the “empty space” between the two interacting bodies and the user is prompted to set the vector in the “proper” place. The student can place the force vector by direct manipulation of the arrow representation (drag and rotate). A time indicator located within a schema of an apple-like outline displays the time that has elapsed since the start of “Lab”. It serves as a visual indicator for the students to monitor the time required to make their choice and place the arrow-vector. Then, the students should press the “check” button to receive a comment on their choice.

The application design is fully modular, adaptable and expandable (Fig. 3). Comments and “expert” prompts are not hard coded in the program but they are found in a single external text file, which acts as a source. This enables even an individual instructor without any programming knowledge to adapt and also translate *Newton-3*. The application can easily be extended to other types of interactions (e.g. magnetic interactions), since pictures are also external graphic objects assigned to program internal variables.

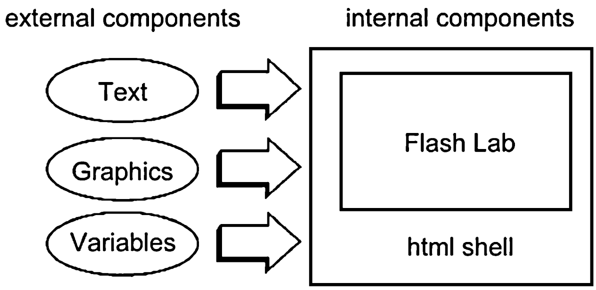

Fig. 3 The structure diagram of the application

5.1 Interactive dialogues

One of the most important parts of this software application is the feature of the pictorial expert that can serve as a virtual "teacher". On the other hand, this feature is used to supply the student with the initial instructions regarding the task in hand and what is to be done. For example:

> *"Let as study the action that the Earth exerts on the Moon. You should place the action (vector) of the Earth on the correct spot."*

On the other hand, every time the program goes through a check on the student's answer (by a click on the "check" button) the system feedback appears in the "expert respond" area. The "responds" are not just a simple indication of error but aim to help the user understand the problem and, at the same time, prompt him towards the right direction of thinking. For example, say the student has placed the tip of the arrow-vector on the surface of the wrong body (i.e. Moon), the "expert" will respond with:

> *"The vector depicts the action of one body (Earth) on the other (Moon). You have placed the tip of the vector on the surface of the Moon. Remember that the vector is applied on the centre of mass of the body that it acts upon. Try again."*

Or, when the student has placed the vector in the correct spot but pointing in the wrong direction/angle, the "expert respond" would be:

> *"The vector depicts the action of one body (Earth) on the other (Moon). You have placed the vector's point of application on the centre of the Moon. Remember that force is a vector and direction is an important element to a vector. Try again."*

5.2 Program feedback and checks

Several cases of possible student answers in placing the arrow-vector are examined. These cases are the sources for a data set in the form of a look-up table, based on known students' alternative conceptions of vector representations, force as a vector, and interactions on Newton's Third Law (Palmer 1997; Hatzikraniotis et al. 2005). The cases examined are:

- i The force-vector is applied on neither of the bodies but on "empty space".
- ii The force-vector is applied on neither of the bodies but is much closer to one, that being the wrong one.
- iii The force-vector is applied on the wrong body.
- iv The force-vector is placed close to the correct body.
- v The base (point of application) of the force-vector is placed on the surface of the correct body.
- vi The tip of the force-vector is placed on the surface of the correct body.
- vii The base of the force-vector is placed somewhere on the correct body but not at the centre of mass.

viii The tip of the force-vector is placed somewhere on the correct body.
ix The tip of the force-vector is placed at the centre of mass.
x The base of the force-vector is placed at the centre of mass, and, in this case, the direction of the force-vector is examined.

6 The application of the software

In the implementation of Teaching–Learning Sequence, we adopted the Initiation-Discussion-Response-Follow-up (IDRF) learning environment (Wegerif 2004). The IDRF corresponds to the interaction of students with the computer, meaning that the computer poses a certain question (Initiates the problem), the students give their ideas to the computer, the computer "answers" (Response) as to whether their ideas are correct and the interaction between them continues in subsequent follow-up questions. The D concerns the discussion that develops, after the question is posed by the computer, between the students, who express their ideas to the other members of their group, compare them, agree or disagree; in other words, make sense of their ideas. The IDRF structure is considered to be a proposition by which the transmission and the constructive aspect of learning are combined in a unified form. The IDRF process "*direct the talk of children in order to meet the goals of a predefined curriculum*" (Wegerif 2004) while, during the D process, students have the time to construct their own meanings.

During the implementation of the sequence according to the IDRF suggestion, students have more time to investigate their ideas than when discussing them with the teacher; they can express them with greater precision to the software than in a dialogue with the teacher, and without fear of teacher's judgement (Finegold and Gorksy 1988; Hennessy et al. 2007). In our sequence, the discussion with the teacher proceeds the IDRF only to help student-teachers express their views to the entire class—while the teacher keeps a neutral position on all views—and follows the IDRF so that possible remaining questions may be explained, and additional explanations given.

Our sequence was implemented to a population (primary and pre-school student-teachers) who are not positively disposed towards physics. In order to help student-teachers become involved with interest and without fear, in the teaching, we took into account the remarks of the literature review on the unique ontological nature that computers seem to possess. Students seem to feel freer to discuss and reflect using educational software than they sometimes feel when talking to their teachers (La Velle et al. 2003; Wegerif 2004).

The implementation of the software is structured in 3 lessons, each lasting 2 h. In Table 1, we can see the content of each lesson, as well as the three aspects (existential, ontological, coarse quantitative aspect) in which these contexts are included.

For the approach of the existential aspect of force interaction, in the first lesson, we introduce gravitational interaction in 5 different "context-labs" of the software and, in the second lesson, we introduce electrostatic interaction in 6 different "context-labs". Therefore, our students have, on the whole, 11 different situations in

Table 1 The content of each lesson related to the three aspects, existential, ontological, coarse quantitative aspect

1st lesson	2nd lesson	3rd lesson
Existential aspect		
Gravitational interaction	Electrostatic interaction	
5 different context-labs	6 different context-labs	
Ontological aspect		
Placement of vector of gravitational force Universal Law of Gravitation	Placement of vector of electrostatic force Newton's Third Law	Similarities/differences of interactions
Coarse quantitative aspect		
The magnitude of gravitational forces	The magnitude of electrostatic forces	Square Distance Law

2 different phenomenological contexts, in which they discover the force interaction between two bodies. The 11 "context-lab" activities are listed below:

1. Gravitational interaction between two celestial bodies: the case of the Earth and Moon.
2. Gravitational interaction between an object of everyday use: a watermelon and the Earth. Both are considered as free in space.
3. Gravitational interaction between two objects of everyday use: a watermelon and an apple, as two free objects in space.
4. Gravitational interaction between two objects of everyday use: a watermelon and an apple, when they are close to the surface of the earth.
5. Gravitational interaction between two objects of everyday use: a watermelon and an apple, when they are inside a room.
6. Electrostatic interaction between two metallic spheres that have the same positive charge but different size.
7. Electrostatic interaction between two metallic spheres that have the same negative charge but different size.
8. Electrostatic interaction between two metallic spheres of the same size and opposite charge of equal value.
9. Electrostatic interaction between two metallic spheres of the same size and opposite charge of unequal value.
10. Electrostatic interaction between two metallic spheres of different size and opposite charge of equal value.
11. Electrostatic interaction between two metallic spheres of different size and opposite charge of unequal value.

The general structure of each "context-lab" is the same as in lab 6, the case of *Electrostatic interaction between two metallic spheres that have the same positive charge but different size*, as described below. Each "Lab" consists of sequential steps, where students are gradually led from the concept of "one body exerts force to the other" to the concept of "mutual action". The "Lab" activity is divided into four sessions; each session once successfully completed follows the previous one. The first two sessions deal with the problem of *one* body acting on the other, while the last two sessions deal with interacting bodies. The essence of "interaction" in the sense of a mutual relationship and a mutual action between two bodies is introduced after students have thoroughly examined the concept of "action". In more detail:

i In the first session (Fig. 4a), the student is asked to place the *action* of one body (right) on the other (left). Much emphasis is placed on the student's understanding of the representation of the action as *force*, and the vectoral characteristics of force.

ii The second session (Fig. 4b) is similar to the first one. The term *reaction* is introduced, as the action of the second body exerted on the first. Again, the main focus is the student's understanding of the characteristics of force as a vector. Students are asked to deal with a similar problem (as in the first session) and this correspondence is believed to help them lay the foundation for the understanding of the mutual relationship between *action* and *reaction*.

iii The third session (Fig. 4c) explores the concept of "mutual relationship". The session summarizes the activities of the previous two sessions in a unified set. The student is asked to place both forces on the two interacting bodies. The concept of *"equal in magnitude but opposite in direction"* is explored.

iv The concept of mutuality is further explored in the final (fourth) session. The session is an interactive simulation (Fig. 4d), where two bodies are shown interacting and the force-vectors appear on each of the bodies. The students are asked to drag one of the interacting bodies all over the screen and observe the two force-arrows, changing in magnitude simultaneously and always pointing one towards the other (opposite directions).

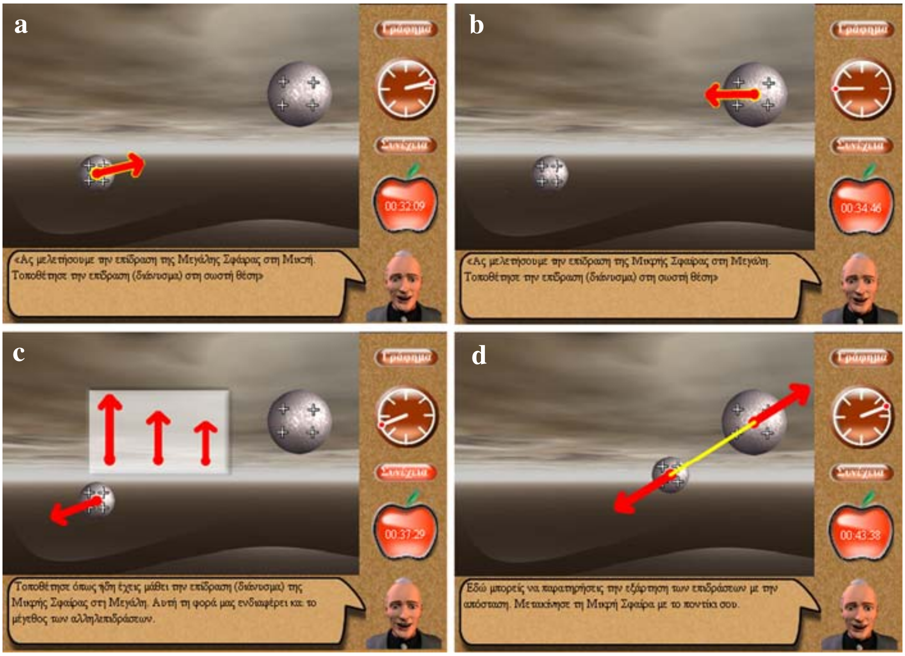

Fig. 4 Action and Reaction in the case of two charged bodies: student tryouts to place the action (**a**) and the reaction (**b**). Action and reaction as mutual interaction: **c** Student is asked to place the reaction on second body and **d** to move one of the bodies and observe the mutual change in action–reaction vectors

In order to help student-teachers comprehend the ontological aspect of force interactions (Table 1), we designed the first two sessions (i and ii) of each "context-lab". Moreover, we approached the ontological aspect in the first lesson by discussing the Universal Law of Gravity in the 5 labs of the software, in other words, that two masses are equally attracted to each other regardless of whether they are in space, e.g. labs 1 and 2, or on the Earth, e.g. labs 3–5. A similar discussion takes place in the second lesson, with the statement of Newton's Third Law, where electrostatic forces are included. We decided to guide our students to acquire a general perception about Newton's Third Law different from the classical one: "to every action there is always an equal reaction", according to the literature (Hellingman 1992; Roach 1992). Our proposal is: when entity A acts on entity B, entity B simultaneously acts on entity A. The interaction between them has the same magnitude and can be either attractive or repulsive. The teaching of the ontological aspect is concluded in the third lesson, as we discuss the similarities as well as the differences between the two kinds of force interaction with student-teachers. For example, they are asked to observe in the software that gravitational interaction is just attractive whereas electrostatic interaction can either be attractive or repulsive.

For the teaching of the coarse quantitative aspect, student-teachers are asked, using the appropriate software instructions (sessions iii and iv), to ascertain, in the first and second lessons, that the lengths of vectors of the two forces (action-reaction) are equal; thus, the magnitudes of forces are equal, regardless of whether the bodies have unequal masses, unequal charges, and are closer or apart from each other. In the third lesson, we focus only on session (iv) of all 11 labs in order to introduce the reverse square distance law for force interactions. Therefore, in our approach, the mutuality of force interactions is approached by the combination of two representations, namely, vectorally and with a formula. We believe that this combination can contribute considerably to the improvement of the ability of student-teachers to use a variety of representations for force interactions, that id say to develop their own "representational coherence" for force interactions.

7 Research design

1. We applied the teaching-learning sequence in 2 groups of 8 primary school and 8 pre-school student-teachers in the first year of their studies in our school of education. Student-teachers were selected on the basis of the answers they gave to a written questionnaire, which was completed by almost all first-year students before the application of the sequence (Kariotoglou et al. 2005). The sample of 16 students consists of the ones who, on one hand, wanted to participate in experimental teaching, and, on the other, offered representative samples in relation to the alternative ideas they had concerning the concept of force interaction.

The process of data collection is as follows (Table 2):

2. One week before the implementation of the software, student-teachers were asked to answer a written questionnaire (Q_A) and after that they explained their views in a semi-structured clinical interview (I_A).

Table 2 The process of data collection

Before the implementation	1st Lesson	2nd Lesson	3rd Lesson	After the implementation
Q_A	Q_1	Q_2	Q_3	Q_B
I_A	W_{S1}	W_{S2}	W_{S3}	I_B
	W_{H1}	W_{H2}	W_{H3}	
Videotape (all lessons); tape-recording (each group during software labs)				

3. At the beginning of each lesson student-teachers individually completed a questionnaire (Q_1, Q_2, Q_3) in order to reveal their initial ideas about the related lesson's content.
4. During their work on software tasks, they filled out a worksheet in groups (W_{S1}, W_{S2}, W_{S3}).
5. After each lesson, they filled out a worksheet at home and brought it to the next lesson for evaluation (W_{H1}, W_{H2}, W_{H3}).
6. A week after the implementation of the software, student-teachers were again asked to answer a written questionnaire (Q_B) and, following that, explain their views in a semi-structured clinical interview (I_B). Questionnaire Q_B contained identical and different questions than $Q_{A.}$
7. Every lesson was videotaped and then transcribed to written text in order to help us describe and interpret students' conceptual development. Moreover, we tape-recorded each group of students while they performed the software labs.

The research questions of our study are:

a) Do student-teachers recognise the force interactions between two physical objects in different contexts? (existential aspect)
b) On which of the two objects is the arrow of the force placed? (ontological aspect)
c) Do student-teachers understand the equality of the magnitudes of the two forces of the interaction? (coarse quantitative aspect)

8 Results and discussion

We present the results of the two groups together because the analysis showed that there were similarities in their answers as well as in their learning development. These results are presented with the three basic research questions always in mind. In our effort to justify the observed changes in the students' learning, we discuss the results of questionnaires Q_A and Q_B, the results of the analysis of the dialogues during the lectures, as well as the results of the worksheets (W_S and W_H).

8.1 Existential aspect

In Table 3, we can see the student-teachers' answers concerning the existence of forces in each of the two interactions (gravitational and electrostatic). These results

Table 3 The existential aspect of force interactions from pre-post questionnaire

Existence of forces	Gravitational		Electrostatic	
	Pre	Post	Pre	Post
Scientific conception	5	15	9	15
1st alternative conception: there is only one force	5	0	5	0
2nd alternative conception there is not exerted force	6	1	2	1
Total	16	16	16	16

are produced by questionnaires Q_A and Q_B (Spyrtou et al. 2007). The questionnaire is constituted of ten situations. Three of the questions deal with gravitational interaction, three look into electrostatic interaction (Kariotoglou et al. 2005) and the remaining four examine magnetic interaction. In each question, there is a system of two entities (masses or charged bars) which interact, e.g. the Earth and the Moon, two wooden cubes, two charged bars, a charged bar and a small piece of paper.

The results concerning the existence of forces are presented in Table 3 and have been produced in the following manner: when the student answers scientifically (existence of two forces) in all three questions concerning gravitational interaction, then we consider him to have a scientific view and classify him in the corresponding category of the table. The remaining students are classified in two alternative categories. Thus, whoever answers even just one question with "no force is exercised" is placed in the second alternative, while individuals who respond to at least one question with "only one force is exercised" are placed in the first alternative. The same applies to electrostatic interactions.

In the first line of Table 3, we see the number of student-teachers who possess the scientific conception concerning the existence of two forces in each interaction. Before the implementation of the software, only 5 and 9 student-teachers respectively identify the existence of two forces in gravitational and electrostatic context. However, even those who identify the existence of two forces are not necessarily in a position to clearly distinguish between these two forces (see below, ontological aspect). After the implementation of our suggestion, we observe that almost all students (15 in the Gravitational part and 15 in electrostatic) give the scientific answer regarding the existence of two forces when two bodies interact.

In the second line of Table 3, we see the number of student-teachers possessing the first—"there is only one force"—alternative conception concerning the existence of two forces for each interaction. Five student-teachers believe that only the Earth exerts force on the apple and not vice versa. Five student-teachers claim that only the charged bar exerts force on a piece of paper and not vice versa. In the third line of Table 3, we see the number of student teachers supporting the second alternative conception concerning the existence of two forces for each interaction, which is "there is no force exerted". Six student-teachers do not recognize the existence of any force between two wooden cubes and two student-teachers do not recognize the existence of any force between the charged bar and the paper before this teaching. One student-teacher holds the same alternative conception in both contexts after this teaching.

It is important to emphasize the surprise that students express while working on the software labs. We impart a representative comment from worksheet (W_{S1}): '*Even stationary bodies that exist in the same space interact between them! Whether they are in a terrestrial environment or in space!*' The following is a typical dialogue between two students transcribed from a tape:

Student-teacher A: '*This means that two bodies interact in the same way on Earth and in space.*'

Student-teacher B: '*Impossible! In space different laws of physics to those on the Earth apply.*'

The above mentioned findings are in agreement with those of the literature review, in the sense that students may recognize force interaction in some cases but not be aware of the more general applicability of the scientific view (Tao and Gunstone 1999a; Heywood and Parker 2001). Furthermore, we consider these findings to be important because they reveal that not only students of primary and secondary school, but first-year university students do not seem to have comprehended the existential aspect of force interactions, despite being taught both gravitational and electrostatic forces within the analytical program of Greek education. In fact, the cases of Earth-apple and charged bar-paper are two of the most common examples of force interactions in the schooling context. The fact that before the implementation of the software the number of students who give a scientific answer regarding electrostatic interaction is greater than the respective number regarding gravitational interaction seems to be derived from their distant memory of the primary "law" "like poles repel, unlike pole attract". But when presented with the case of a charged body and an uncharged one (bar-paper), then their restricted conception of electrostatic interaction becomes apparent. Finally, for the 15 people who answered correctly after the implementation of the software, we can claim that they improved their own existential aspect at least for the two contexts of gravitational and electrostatic force interactions.

8.2 Ontological aspect

The results emerging from questionnaires Q_A and Q_B emerge that are assembled in Table 4, where we can see the student-teacher answers concerning the position of the arrow representing the forces in each interaction (Spyrtou et al. 2007). The results regarding the placement of the arrow, shown in Table 4, have emerged as follows: when the student places the arrow in accordance with the scientific conception in all three questions regarding gravitational interaction, we assume he possesses a scientific conception and classify him in the corresponding category of Table 4 (first line of Table 4). The rest are placed in two alternative classifications. Specifically, those using any other symbol but one single headed arrow (e.g. a double headed arrow), even in just one question, are placed in the category 'Other symbols' (third line of Table 4). The rest, in at least one question, place the arrow on the body that exerts rather than the one accepting the force and are placed in the first alternative conception (second line of Table 4). The same applies to electrostatic interactions.

The results from the summation of the data collected show that all student-teachers seemed to have a confused idea about the nature of force interactions before

Table 4 The ontological aspect of force interactions

Arrow position	Gravitational		Electrostatic	
	Pre	Post	Pre	Post
Scientific conception	4	15	3	14
1st alternative conception	6	0	11	1
Other symbols	6	1	2	1
Total	16	16	16	16

the implementation of our approach as well as during the first two lessons. For example, at the end of the first lesson—after the teaching of gravitational interaction—15 student-teachers write on their worksheet (W_{H1}) that following the relevant software they have comprehended the scientifically accepted representation of the vector of force. However, at the beginning of the second lesson, in the case of electrostatic interaction, the 10 students, who correctly have drawn the vector of force, in questionnaire Q_2, give explanations that do not agree with the scientific conception. One of their representative deductions is: '*…because the small sphere will move in this direction.*' Even though the charged spheres are depicted as stationary on the worksheet and the in software lab, the students imagine the movement that could result from their interaction. In other words, they appear to identify the direction of velocity with that of the vector of force, an opinion which is recorded at length in the literature review (Vosniadou et al. 2001).

In discussions that take place during the teaching, students who hold the first alternative conception develop the reasoning "*because the body gives something*". For example, at the beginning of the first lesson, a student-teacher argues in the Earth-watermelon case: "*I have placed the vector of force on the Earth. It is the Earth that gives force on the watermelon.*" A similar example in the Earth-Moon case: "*The Earth exerts its force on the Moon. Therefore, the vector is placed on the Earth.*" It seems that students conceive the force as an internal attribute of the body that "exerts" its force and thus consider it reasonable to draw the vector on the body that exerts that force (Ioannides and Vosniadou 2002).

Apart from the vectoral characteristic of the force, there are other facts, which reveal that at the beginning of the teaching, students have confused conceptions about the ontological aspect of force interactions. Specifically, none of them refers explicitly to the two different types of force interactions in various situations—even those who stated that two forces are exerted between the two bodies (5 and 9, see Table 3). The questionnaire answers they complete at the beginning of each lesson show that approximately half of the student-teachers (9 in all) cannot distinguish gravitational interactions from electrostatic and magnetic ones. For example, in the first lesson, one writes in his questionnaire (Q_2): '*The watermelon is uncharged, so it cannot exert force on the Earth. On the other hand, the Earth exerts its magnetic force on the watermelon.*' The findings following the completion of the first three lessons demonstrate that student-teachers show an improvement in their conceptions of force interactions. Specifically, after the third lesson, they all emphasize the similarities and differences between the three interactions (W_{H3}). For example:

'*I had the idea that all interactions are either attractive or repulsive. I have now realized that gravitational interaction is only attractive… I have also understood that a charged body can exert force on an uncharged one.*' A student notes: '*Both interactions can act from a distance. Two bodies need not be in contact in order to interact.*'

In conclusion, the results from the written questionnaires as well as from other data resources signify a remarkable increase in scientific conceptions and a corresponding decrease in alternative ones. Furthermore, they reveal that the mistakes made by students in the representation of interactions are not mere drawing mistakes but seem to be connected with the familiar alternative conceptions they have on the understanding of force, "force as a property of a body" or "force and velocity have the same direction". This means that the representation of force with a vector becomes a crucial point for the understanding of the ontological aspect of force interactions.

8.3 Coarse quantitative aspect

In Table 5, the results from questionnaires Q_A and Q_B are shown. When the student answers scientifically (equality of magnitudes) to all three questions about gravitational interaction, then we consider him to have a scientific conception and classify him in the corresponding category of Table 5 (first line). The others are classified in three alternatives as follows: those who do not recognize the existence of forces in at least one of the three questions on gravitational interaction are placed in the category "No force exists" (fourth line of Table 5); those who recognize the existence of a force in at least one of the questions are placed in the category "There is only one force" (third line of Table 5); and the remaining students answer at least one question with: "the larger body exerts the greater force" and are placed in the relevant category of Table 5 (second line). The same applies to electrostatic interactions.

From the worksheets that students complete in each lesson as well as from their discussions while working in the software labs, this alternative conception proves to be particularly strong. Following, we present selected data from the three lessons to demonstrate how our approach makes this problem more explicit for the learners.

Specifically, in the first lesson, when the first two sessions of each lab are completed, all students observe the existence of two forces in the interacting bodies,

Table 5 The coarse quantitative aspect of force interactions

Magnitude of forces	Gravitational		Electrostatic	
	Pre	Post	Pre	Post
Scientific conception	2	15	3	15
Alternative conception: 'the larger body exerts greater force'	3	0	6	0
There is only one force	5	0	5	0
No force exists	6	1	2	1
Total	16	16	16	16

e.g. the force that the Moon exerts on the Earth and the force that the Earth exerts on the Moon. In the third session of the lab, they are asked on whether the forces have equal magnitudes or not. From the findings (worksheet and discussions while working on software exercises) it becomes obvious that the vast majority are surprised by the equality of magnitudes. We offer a representative discussion that took place while students were working on the second software lab, the Earth-watermelon interaction.

Student A: *The effect of the watermelon on the Earth is smaller. So we should take the small vector.*
Student B: *That's wrong! Shouldn't we select the bigger arrow? Now it says (the software teacher) again' 'pay attention to the magnitude".*
Student A: *So it's the middle arrow, which means equal. (They mean equal to the vector of the Earth's force on the watermelon.)*
Student B: So the forces are equal! All this time I was mistaken.

At the end of the first lesson, on the worksheet that they complete at home (W_{H1}), all students write about the equality of magnitudes of the forces that develop between Earth-Moon, Earth-watermelon, and apple-watermelon. Half of them stress that while the masses of the two bodies may be unequal the forces that develop between them are equal. For example: '*It does not matter whether one body has greater mass than the other. These forces are equal.*'

However, at the beginning of the second lesson, when electrostatic interactions are encountered, 13 student-teachers present the alternative conception "*the larger the object, the greater the force exerted*" (questionnaire Q_2). This finding verifies the results of the literature review that the transference of knowledge from one context to another is a very difficult process (Tao and Gunstone 1999a). Most students did not manage to recognize that the equality of magnitudes of two forces may apply beyond the gravitational and electrostatic interaction.

While working on labs 6–8, in the second lesson, students support the written answers they give on the relevant worksheet that the two forces are equal because the amounts of charge are equal. When they move on to the following lab 9 (two spheres with unequal charges), they predict that the magnitudes of forces will be unequal and express their surprise vividly when they discover the equality of magnitudes. For example, a group writes on the relevant worksheet (W_{S2}): "*The measures of forces are equal while the charges are unequal! The charge of the negatively charged sphere is smaller than that of the positively charged one, yet despite all that the measure of forces is equal in contrast to what we expected it to be.*" In the second lesson, we introduce Newton's Third Law (see Table 1). After the end of the second lesson, all students emphasize on the worksheet (W_{H2}), that they have completed at home, how impressed they are by the two forces—action and reaction—having equal magnitudes.

At the beginning of the third lesson (see Table 1), we asked students to express in writing (in questionnaire Q_3) their views on the similarities and differences that they think gravitational and electrostatic forces have. It is of great interest that only 2 students mentioned the equality of action–reaction magnitudes. The reader is reminded that, in the third lesson, the Law of Inverse Square was mathematically introduced. Following the lesson, on their home-worksheets (W_{H3}), 14 student-teachers correctly answer by explaining that the magnitudes of both entities contribute to the calculation of the magnitude of each force and by accurately drawing the two vectors of forces. But 2 of them continue to believe in the related alternative idea. For example, one of them writes about a specific task: "*The negative bar exerts a greater force on the other because it has a larger charge.*" A week after the implementation of the software, these 2 students gave correctly responses to the tasks of the final questionnaire Q_B (Table 5). We are not surprised by the result. It is remarked in the literature review that students are often in two minds between conceptions that may contradict each other (Tao and Gunstone 1999a). It appears that these 2 students did not manage to perceive the general application of the scientifically accepted view about the coarse quantitative aspect of force interactions in different contexts.

The alternative conception "*the larger the object, the greater the force exerted*" is widely recorded at large in the literature review (Watts and Zylberszajn 1981; Hestenes et al. 1992; Bao et al. 2002). We believe that from the implementation of our software the difficulty that student-teachers present in perceiving the equality of action–reaction magnitudes in different contexts (gravitational and electrostatic interactions) as well as in different situations in these two contexts becomes apparent. It also appears that the vectoral representation of forces and the teaching of Newton's Third Law do not suffice but that the quantitative approach of the equality of magnitudes through the Law of Inverse Square is also needed in order to overcome this problem. In conclusion, we consider that, after the implementation of our suggestion, almost all the students quantitatively perceived the equality of forces in gravitational and electrostatic interactions with the Law of Inverse Square.

9 Concluding remarks

In Greek Elementary schools gravitational, electrostatic and magnetic force interactions are taught as well as the effects of the forces (changes in the kinetic state, deformation) the distinction between forces in contact and forces at a distance. Furthermore, the analytic problem includes means of measuring the forces, the concept of friction and, moreover, the factors upon which friction is dependent (5th grade). Even in pre-school education, lessons are recommended in which magnetic force is introduced. Consequently, it is considered essential mainly for elementary school teachers and, to a lesser degree, pre-school teachers to be familiar with the formal aspects of theory about force interactions.

In this paper we have described the design and development of software, which we implemented in the first three lessons of a Teaching–Learning Sequence for primary and pre-school student-teachers. The educational software is a web-based application, designed to introduce the topic of Newton's Third Law. The software covers a sequence of several cases from gravitational to electrostatic interaction and sets a series of 11 "Lab" activities. In each "Lab" students are presented with a problem of interaction and are asked to locate and place the forces. The software is structured on an interactive dialogue-basis, where a pictorial "expert" changes faces and makes comments on the students' response. Each "Lab" consists of subsequent steps, where students are gradually introduced from the concept of "one body exerts force on the other" to the concept of "mutual action". For the design and development of the software, we took into consideration the alternative ideas recorded in the relevant literature review as well as the results of empirical research that we conducted on students from pedagogical departments. Our purpose is to help students develop their contextual as well as their representational coherence about force interaction.

The implementation of software into this concrete teaching–learning sequence has three main characteristics: the idea of contextuality, the specification of the concept of force interaction and the IDRF structure of the teaching–learning environment. We approach the idea of contextuality by providing 11 different situations in two different phenomenological contexts, namely, gravitational and electrostatic. We approach the three aspects of the specification of the concept of force interaction very carefully. Specifically, according to the literature review and the results of our empirical research, the existential aspect relates to the first four difficulties that we mentioned in unit 2 (see numbers 1–4), the ontological aspect concerns the following three difficulties (see numbers 5–7) and the coarse quantitative aspect corresponds to the last difficulty (see number 8). With this in mind, we designed the 11 different lab-situations that address all these learning difficulties.

The teaching approach IDRF that we followed has characteristics of both transfer and construction of knowledge. Transfer of knowledge happens due to the nature of computer-student interaction but also because chunks of the knowledge we negotiated are actual scientific conventions, e.g. the arrow symbol. Construction takes place because we identified alternative ideas emanating from the students that can be modified through group discussion and software interaction. Specifically, the teaching of the placement and magnitude of the arrow that represents the force is a three-step process. In the first and most important step, we answer the question: "on which body is the force exerted?" The answer indicates first the action and then the reaction (sessions 1 and 2). We answer sequentially—separately for action and reaction—so that it becomes clear to the students which body exerts and which accepts the force. In this step, we are not interested in the comparison of magnitudes of forces. In the second step, we negotiate the equality of magnitudes of forces (session 3) using a rather qualitative approach. The completion of the comparison of magnitudes takes place in the third step (session 4) with the negotiation of the Law of Inverse Square ($1/r^2$). By negotiating the law, students are helped to comprehend and, finally, learn the equality of magnitudes, as they observe in the relevant formula that both (usually unequal) quantities, i.e. masses or electrostatic charges, contribute to the calculation of magnitude.

The research results indicate that this implementation was effective. We could support that our student-teachers developed their contextual coherence in a variety of static situations of two contexts, gravitational and electrostatic, because after the implementation of software almost all of them give answers according to the scientific view of the existential aspect of force interaction. We could also support that they developed their representational coherence since we have positive results both in the ontological and coarse quantitative aspect. According to the ontological aspect, they used the vector representation of force correctly and all of them pointed out the similarities as well as the differences between the two interactions (gravitational and electrostatic). According to the coarse quantitative aspect, they correctly used the Law of Inverse Square in order to explain the equality of magnitudes of two forces (action–reaction). Though the use of a pre/post test design may also have facilitated learning, seeing that it is a process of testing, we do not have any evidence of such an effect.

Some interesting points for further clarification have resulted from our research. First, the vectoral representation of force on the body that exerts the force does not seem to be merely a drawing mistake but is connected to two alternative conceptions, namely, ‘‘force as a property of a body’’ or ‘‘force and velocity have the same direction’’, which are known from the relevant literature review (Jiménez-Valladares and Perales-Palcios 2001; Vosniadou et al. 2001). Remarkably, even though we decided that all the bodies in the software labs should be at rest—to avoid the second alternative conception—students imagine the movement that could possibly result from the interaction of the two bodies and, based on that criterion, draw the force of vector on the body that exerts the force. These two alternative conceptions concern the ontological aspect of force interaction and seem to both be able to ‘‘hide’’ simultaneously behind the vector of force. Our research results are not sufficient for us to support that the case of students drawing the vector of force correctly indicates that both these alternative conceptions have been altered.

Secondly, our results show that the difficulty students have in perceiving the equality of magnitudes is essentially countered in the third lesson, when the Law of Inverse Square is introduced. In other words, it seems that the qualitative description of the equality of magnitudes of the two forces using Newton’s Third Law does not suffice, neither does its qualitative representation by the equality of vectors of the two forces. We could suppose that, since the concept of ‘‘equality’’ of magnitudes is quantitative in character, a quantitative approach might be needed for its comprehension; one that could be achieved with the Law of Inverse Square. However, the size of our sample is too small for us to be able to support this hypothesis.

References

Bao, L., Hogg, K., & Zollman, D. (2002). Model analysis of fine structures of student models: an example with Newton’s third law. *American Journal of Physics*, *70*(7), 765–778. doi:10.1119/1.1484152.

Brown, D. (1989). Students’ concept of force: the importance of understanding Newton’s third law. *Physics Education*, *24*(1), 353–358. doi:10.1088/0031-9120/24/6/007.

Bryce, T., & MacMillan, K. (2005). Encouraging conceptual change: the use of bridging analogies in the teaching of action–reaction forces and the ‘at rest’ condition in physics. *International Journal of Science Education*, *27*(6), 737–763. doi:10.1080/09500690500038132.

diSessa, A., Gillespie, N., & Esterly, J. (2004). Coherence versus fragmentation in the development of the concept of force. *Cognitive Science*, *28*(6), 843–900.

Finegold, M., & Gorksy, P. (1988). Learning about forces: simulating the outcomes of pupils’ misconceptions. *Instructional Science*, *17*, 251–261.

Gorksy, P., & Finegold, M. (1994). The role of anomaly and of cognitive dissonance in restructuring concepts of force. *Instructional Science*, *22*, 75–90.

Grimellini-Tomasini, N., Pecori-Balandi, B., Pacca, J. L. A., & Villani, A. (1993). Understanding conservation laws in mechanics: students’ conceptual change in learning about collisions. *Science Education*, *77*(2), 169–189.

Hatzikraniotis, E., Theodorakakos, A., Spyrtou, A., & Kariotoglou, P. (2005). Newton-3: Software for Teaching Force Interactions. In P. G., Michaelides & A. Margetousaki (Eds.), *Proceedings of the 2nd International Conference on Hands on Science, HSci* (pp. 96–102). Rethimno, July.

Hellingman, C. (1992). Newton's third law revisited. *Physics Education*, *27*, 112–115.

Hennessy, S., Wilshart, J., Whitelock, D., Deaney, R., Brawn, R., Velle, L., McFarlane, A., Ruthven, K., & Winterbottom, (2007). Pedagogical approaches for technology-integrated science teaching. *Computers and Education*, *48*, 137–152.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *Physics Teacher*, *30*, 141–158.

Heywood, D., & Parker, J. (2001). Describing the cognitive landscape in learning and teaching about forces. *International Journal of Science Education*, *23*(11), 1177–1199.

Jiménez-Valladares, J., & Perales-Palcios, J. (2001). Graphic representation of force in secondary education: analysis and alternative educational proposals. *Physics Education*, *36*, 227–235.

Jimoyiannis, A., & Komis, V. (2001). Computer simulations in physics teaching and learning: a case study on students' understanding of trajectory motion. *Computers and Education*, *36*, 183–204.

Ioannides, C., & Vosniadou, C. (2002). The beginning meanings of force. *Cognitive Science Quarterly*, *2*, 5–61.

Kariotoglou, P., & Spyrtou, A. (2005). A teaching-learning sequence concerning dynamic interactions: The need for appropriate software. *Στο: Michaelides, P.G., Margetousaki, A., Proceedings of the* 2nd *International Conference on Hands on Science, HSci,* July 13–16, Rethimno, 91–95.

Kariotoglou, P., Spyrtou, A., & Tselfes, V. (2005). Student-teachers; conceptions about gravity interaction. In: R. Pinto et D. Couso (Eds.), *Proceedings of the Fifth International ESERA Conference on Contributions of Research to Enhancing Students' Interest in Learning Science* (pp. 180–183). Barcelona, 28 August–1 September, Spain.

Kariotoglou, P., Spyrtou, A., & Tselfes, V. (2008). How student teachers understand distance force interactions in different contexts. *International Journal of Science and Mathematics Education* (in press).

Kolokotronis, D., & Solomonidou, C. (2003). A step-by-step design and development of an integrated educational software to deal with empirical ideas about mechanical interaction. *Education and Information Technologies*, *8*(3), 229–244.

Kordaki, M. (2004). Challenging prospective computer engineers to design educational software by engaging them in a constructivist learning environment. *Education and Instruction Technologies*, *9* (3), 239–253.

Kruger, C., Summers, M., & Palacio, D. (1990). An investigation of some english primary british teachers' understanding of the concepts force and gravity. *British Educational Research Journal*, *16*(4), 383–397.

Küçüközer, A. (2001). Understanding of the concept of interaction in the framework of a teaching sequence of mechanics. In D. Psillos et al. (Eds.), *Proceedings of the Third International ESERA Conference on Science Education Research in the Knowledge Based Society* Vol. II, (pp. 489–500). Thessaloniki.

La Velle, L., McFarlane, A., & Brawn, R. (2003). Knowledge transformation through ICT in science education: a case study in teacher-driven curriculum development-Case-Study 1. *British Journal of Educational Technology*, *34*(2), 183–199.

Meheut, M., & Psillos, D. (2004). Teaching–learning sequences: aims and tools for science education research. *International Journal of Science Education*, *26*(5), 515–535.

Montanero, M., Suero, M. I., Pérez, A. L., & Pardo, P. J. (2002). Implicit theories of static interactions between two bodies. *Physics Education*, *37*(4), 318–323.

Palmer, D. (1997). The effect of context on students' reasoning about forces. *International Journal of Science Education*, *19*, 681–696.

Palmer, H. D. (2001). Investigating the relationship between students' multiple conceptions of action and reaction in cases of static equilibrium. *Research in Science and Technological Education*, *19*(2), 193–204.

Park, J., & Han, S. (2002). Using deductive reasoning to promote the change of conceptions about force and motion. *International Journal of Science Education*, *24*(6), 593–609.

Pol, H., Harskamp, E., & Suhre, C. (2005). Solving physics problems with the help of computer-assisted instruction. *International Journal of Science Education*, *27*(4), 451–469.

Roach, L. (1992). Demonstrating Newton's Third Law. *The Science Teacher*, *59*(9), 28–31.

Savinainen, A., & Scott, P. (2002a). Using the force concept inventory to monitor student learning and to plan teaching. *Physics Education*, *37*(1), 53–58.

Savinainen, A., & Scott, P. (2002b). The force concept inventory: a tool for monitoring student learning. *Physics Education*, *37*(1), 45–52.

Savinainen, A., Scott, P., & Viiri, J. (2005). Using a bridging representation and social interactions to foster conceptual change: designing and evaluating an instructional sequence for Newton's Third Law. *Science Education*, *89*(2), 175–195.

Spyrtou, A., Zoupidis, A., & Kariotoglou, P. (2007). Teaching and learning force interactions in different contexts. Paper presented at ESERA International Conference, August 21–25, Malmö, Sweden. http://195.178.227.107/ESERA/FMPro?

Suthermund, R. (2004). Designs for learning: ICT and knowledge in the classroom. *Computers and Education*, *43*, 5–16.

Suzuki, M. (2005). Social metaphor mapping of the concept of force “CHI-KA-RA” in Japanese. *International Journal of Science Education*, *27*(15), 1773–1804.

Tao, P., & Gunstone, R. (1999a). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching*, *36*(17), 859–882.

Tao, P., & Gunstone, R. (1999b). Conceptual change in science through collaborative learning at the computer. *International Journal of Science Education*, *21*(1), 39–57.

Terry, C., Jones, G., & Hurford, W. (1985). Children’s conceptual understanding of forces and equilibrium. *Physics Education*, *20*, 162–165.

Thijs, G. (1992). Evaluation of an introductory course on “force” considering students’ preconceptions. *Science Education*, *76*(2), 155–174.

Thijs, G., & Bosch, G. (1995). Cognitive effects of science experiments focusing on students’ preconceptions of force: a comparison of demonstrations and small-group practicals. *International Journal of Science Education*, *7*(3), 311–323.

Trumper, R. (1996). A cross-college age study about physics students’ conceptions of force in pre-service training for high school teachers. *Physics Education*, *31*, 227–236.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction*, *11*, 381–419.

Yeo, S., Loss, R., Zadnik, M., & Treagust, D. (1999). Changing conceptions with an “intelligent tutor". In K. Martin, N. Stanley, & N. Davison (Eds.), *Proceedings of the 8th Annual Teaching Learning Forum, Teaching in the Disciplines/ Learning in Context* (pp. 474–483). The University of Western Australia. February. http://lsn.curtin.edu.au/tlf/tlf1999/yeo.html

Young, H. (1994). Physics—extended version with modern physics, 8th Edition. Addison-Wesley. Greek translation, Copyright by Papazisi, volume A’, 83–85.

Watts, D., & Zylberszajn, A. (1981). A survey of some children’s ideas about force. *Physics Education*, *16*, 360–365.

Wegerif, R. (2004). The role of educational software as a support for teaching and learning conversations. *Computers and Education*, *43*, 179–191.