

Editorial Manager(tm) for Education and Information Technologies
Manuscript Draft

Manuscript Number: EAIT-88R1

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

Article Type: Manuscript

Keywords: educational software; force interactions; Newton's Third Law; student teachers education; alternative conceptions

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

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4 **Educational software for improving learning aspects of Newton’s Third Law for student**
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9 **Abstract**

10 In this paper, we present the design, development, implementation and evaluation of
11 educational software "Newton-3", aiming at the learning of Newton’s Third Law by student –
12 teachers who are not Physics majors. We describe the theoretical issues of our teaching
13 approach and the various software tasks that we designed in order to promote students’
14 understanding. Specifically, the software is designed for the teaching of gravitational and
15 electrostatic interactions between two distant bodies at rest. It is a web-based application and
16 runs on a simple web browser with Macromedia Flash plug-in installed. The development of
17 software and its integration into teaching-learning
18 sequence is based on three main characteristics: the range of contexts in which the
19 concept of force interaction applies, in the specification of the concept,
20 and in an appropriate teaching learning environment (IDRF). We trialled the software on two
21 groups of 8 primary school and 8 pre-school student-teachers, for 3 teaching periods, in the
22 School of Education of our University. The research results indicate that the implementation
23 was effective as the majority of the teacher-students improved their own knowledge
24 concerning the existence and representation of gravitational and electrostatic interactions. An
25 interesting result reveals that student-teachers have difficulty in perceiving the equality of
26 magnitudes of action and reaction forces. This problem seems to be overcome after the
27 teaching of the Inverse square law.
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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 Zylbersztain 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 Gorsky 1988; Gorsky 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

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4 developed educational software. In this paper, we focus on that part of the research which
5 concerns the development, implementation and evaluation of the software.
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9 **2. Force interactions – An instructional problem**

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11 In the following, we present the findings from the literature review that we took into
12 consideration to design and develop the software. We sought the situations in physics which
13 the relevant literature review has dealt with, as well as students' special difficulties in
14 comprehending force interaction and Newton's Third Law, which formalistically describes
15 these interactions.
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19 Most research has focussed on cases in which the bodies are in contact: for instance, a
20 book on a table (Terry et al. 1985; Hestenes et al. 1992; Trumper 1996; Palmer 2001; Bryce
21 and MacMillan 2005), one stone resting on another (Palmer 2001), a man trying to push a
22 box (Brown 1989; Thijs and Bosch 1995), an object connected to a spring placed on a
23 frictionless plane (Park and Han 2002). In contrast, the cases with bodies at a distance are
24 comparatively few, e.g. the interaction between the Earth and a golf ball traveling through the
25 air (Kruger et al. 1990; Hestenes et al. 1992), the magnetic attraction and repulsion between
26 two magnets (Jiménez-Valladares and Perales-Palacios 2001), the Earth and a ball that is
27 dropped from a height (Suzuki 2005), the interactions between two entities (masses, magnets
28 or charged bars) at distance (Kariotoglou, Spyrtou and Tselfes, 2008). Also, most researchers
29 focus on the investigation of the conceptions of students in cases where the bodies are
30 moving either at a constant speed, e.g. a trolley or a book moving on a table at constant speed
31 (Thijs 1992; Trumper 1996), or at a changing speed, e.g. a bicycle slowing down (Kruger et
32 al. 1990), a student on rollers pushing another (Hestenes et al. 1992; Bao et al. 2002), or even
33 in cases where the bodies are colliding with each other, e.g. a collision between a truck and a
34 car or between two cars (Brown 1989; Hestenes et al. 1992). Considering the above survey,
35 we think that the research is rather limited in the case of two bodies at rest interacting at a
36 distance, as well as in physical contexts other than gravitational ones, e.g. electrostatic,
37 magnetic.
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41 In the research findings, there are similarities concerning the students' difficulties in
42 comprehending Newton's Third Law and the concept of force interaction. To summarize,
43 students find it difficult to comprehend that:
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- 46 1. Inanimate bodies can exert force, e.g. like a stone or a chair (Finegold and Gorsky
47 1988; Hestenes et al. 1992).
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4 2. Forces can be exerted on a stationary body, e.g. on a stationary car (Terry et al. 1985;
5 Tao and Gunstone 1999a).
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7 3. Force interaction can be developed between distant bodies (Kolokotronis and
8 Solomonidou 2003).
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10 4. “Terrestrial” as well as celestial bodies can interact with the gravitational force, e.g.
11 they cannot comprehend that the Earth and a stone are objects and it is, therefore, possible for
12 a gravitational interaction to be exercised between them (Küçüközer 2001; Kariotoglou,
13 Spyrtou and Tselfes 2005).
- 14
15 5. Interaction is a mutual relationship between two objects, e.g. “*the use of the verb to*
16 *‘act’ associated to a linear causal reasoning leads to see that on one hand A acts on B and B*
17 *acts on A on the other hand, that is independently*” (Küçüközer 2001).
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19 6. The cause of reaction force, e.g. they think that the upward force of a table on a book
20 comes from air pressure, air molecules and so on (Bruce and MacMillan 2005) or when one
21 body is resting on another, the lower body possesses a passive resistance that “*cannot be*
22 *regarded as a force*” (Montanero et al. 2002).
- 23
24 7. The placement of the vector of force on the body that receives the force e.g. students
25 place the arrow on the object that exerts the force (names of authors, 2005), which results in
26 identifying the force with an attribute of the object or confusing “*the direction of the force*
27 *with the direction of the movement*” (Jiménez-Valladares and Perales-Palacios 2001;
28 Kariotoglou et al. 2008).
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30 8. Action and reaction have equal magnitudes, e.g. they think that the body with the
31 greater mass exercises greater force (Hestenes et al. 1992; Bao et al. 2002; Kariotoglou et
32 al. 2008).
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34 9. Last but not least, students’ reasoning seems to be highly influenced by context.
35 Students may give answers that agree with the scientific view in one context while, at the
36 same time, their answers may be different than the scientifically accepted ones in another
37 (Montanero et al. 2002; Tao and Gunstone 1999a; Heywood and Parker 2001; Savinainen and
38 Scott 2002b; Kariotoglou et al. 2008). For instance, Heywood and Parker (2001) question
39 which key ideas students and in-service primary teachers have about floating and sinking as
40 well as how these ideas have extended to different contexts such as static structures (for
41 example, an arched bridge). They found that students might comprehend the balanced forces
42 involved in floating but that it is difficult for them to transfer such thinking to other more
43 complex situations, such as an arched bridge.
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4 In recent years, methods of teaching using software have been suggested, with the
5 purpose of confronting the student problems mentioned above. The suggestions that aim at
6 the learning of the Three Laws of Newton seem to focus more on the first two laws (Tao and
7 Gunstone 1999a; Yeo et al. 1999; Pol et al. 2005) rather than the third law. What follows is a
8 presentation in summary form of certain cases which we referred to in the design of our own
9 software.
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14 Finegold and Gorsky (1988, 1994) developed a computer program including five
15 simulations concerned with forces acting on objects at rest or in motion, e.g. a book resting
16 on a table, a book sliding on a table with or no friction after being propelled by a spring. In
17 each simulation, students (grades 8-12) are asked to choose the vector of forces acting on the
18 object. The vectors of forces have only four directions (horizontally and vertically, from left
19 or right) and two magnitudes for each direction. Next, they check if the given choice of
20 vectors is correct, e.g. can the book move vertically upwards, something that contradicts
21 common sense. The results of this research reveal the special role that simulations play in the
22 teaching-learning process. Students' answers, while they were making the simulated tasks,
23 were both rational and emotional: rational, "*when students could easily reconcile old and new*
24 *knowledge*"; and emotional "*when old and new knowledge could not be easily reconciled*"
25 (Finegold and Gorsky 1994). Simulations seem to enhance conceptual change strategies
26 during the teaching-learning process.
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36 Kolokotronis and Solomonidou (2003) have developed software, which aims at the
37 construction of the scientific view for the concept of dynamic interaction and Newton's Third
38 Law, for students of primary and high school. Various situations were selected in which
39 forces are exerted in either a vertical or horizontal direction. Authentic situations of
40 interaction between bodies from everyday life were simulated, such as: the Earth and a dog, a
41 woman on scales, and the tug of war game. Most experiments favour processes of cognitive
42 conflict with the challenge of conceptual change as their aim. This research has similarities to
43 that of Finegold and Gorsky (1988, 1994). For instance, students choose the vectors of forces
44 – which are on the screen – and place them on the body, e.g. on the book balanced on the
45 table. Next, they check if the given choice of vectors is correct. Among the benefits of this
46 exercise is that, in designing software, the researchers took into consideration not only the
47 ideas of students as they are presented in the literature review but also the results of
48 empirical research that they conducted on Greek students and their teachers. Moreover, the
49 simulation of real everyday situations, the chance the students had to test the validity of their
50 conceptions, as well as the enthusiasm they showed while completing the software tasks may
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4 all be mentioned as benefits of this software. As Kolokotronis and Solomonidou emphasize,
5 this particular research was focused on the interactions between solid objects, either at a
6 distance or in contact, while not expanding on other interactions, e.g. between liquids in
7 depth.
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11 There is general agreement about the learning results of two research works in which
12 software was developed for the teaching of the first two laws of Newton (Tao and Gunstone
13 1999a; Yeo et al. 1999). Both showed that students experience difficulties in transferring the
14 knowledge they acquire to new problems and contexts. In particular, Tao and Gunstone
15 (1999a) applied a computer-supported physics unit in order to confront students' alternative
16 conceptions (10th grade) related to Newton's First and Second Laws, e.g. a moving body has
17 a force and its force is gradually used up when it slows down. Computer simulation programs
18 include a motion graph program as well as three other programs, namely, Model Car,
19 Spaceship and Skydiver. Students predict, observe and explain tasks concerned with
20 horizontal linear motion (Model Car), without friction and resistance (Spaceship) or tasks
21 concerned with vertical fall under gravity (Skydiver). Tao and Gunstone use these three
22 different contexts (Model Car, Spaceship and Skydiver) in order to "*enable students to revisit*
23 *the scientific conceptions in different situations for reflection and consolidation*". From this,
24 research reveals that learning is contextually based and, as a consequence, students need to
25 approach a range of different situations in order to accept the generality of scientific
26 conceptions. Similar problems were recorded by Yeo and his colleagues (1999), who used the
27 intelligent computer-based instructional (ICBI) program, *Freebody*, in order to confront
28 students' inconsistencies in their reasoning about force and motion. Physical situations such
29 as "*a boy having thrown a rock in the air*" are given to high school and university students
30 asking them to draw a free-body diagram on an object, using the mouse. Following that, the
31 software recognises and discusses their drawings, helping them to correct the inconsistencies
32 or contradictions in their ideas. Researchers point out that students "*held conflicting*
33 *conceptions, both before and after the program*", surmising that students cannot recognise
34 that different situations could be explained by the same Newton Law, either the First or
35 Second.
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53 54 55 56 **3. Learning Force Interactions – Theoretical Issues**

57 From the above discussion we may come to two conclusions. Firstly, students
58 attribute to force interactions different characteristics to those attributed by scientists. Second,
59 these characteristics may change from context to context. In line with these issues, the
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4 research being developed on conceptual change acknowledges that significant difficulties
5 exist in teaching-learning force interactions and therefore seek a broader theoretical framing
6 in order to interpret these difficulties. diSessa and his colleagues (2004), introduce the terms
7 “contextuality” and “specification” to enhance theoretically and empirically “*how much*
8 *and what kind of accountability for details in conceptual change must conceptual change*
9 *researches take on*”. According to them (2004), “contextuality” concerns “*the range of*
10 *contexts in which a concept (meaning, model, theory) applies*”, contributes to understanding
11 if students “*have multiple ways of conceptualizing a situation...*”, how they “*respond to*
12 *different situations*” and so on. “Specification” concerns the kind of aspects, which we need
13 in order to specify a particular concept. For the specification of conceptual content five
14 aspects are suggested: existential, ontological, coarse quantitative, compositional and causal.
15 The existential aspect answers the question “*to what situations will a subject attribute the*
16 *existence of a force?*” For instance, students do not accept the existence of force in the case
17 of bodies at rest. The ontological aspect concerns the conceptions of students on the nature of
18 force interaction, e.g. the naïve conception of force as a property of an object is well-known
19 (Ioannides and Vosniadou 2002). A significant feature of the nature of force is its vectoral
20 character. It has been established by previous research (see previous unit) that students
21 present various difficulties in perceiving the vectoral character of the force. The coarse
22 quantitative aspect specifies the quantitative consideration of the concept of force that
23 students have, e.g. a difference between students and scientists is that the first do not accept
24 the equality of magnitudes of action and reaction. We will not discuss the remaining two
25 aspects, compositional and causal, since they are related to the composition of forces and
26 Newton’s Second Law respectively, in other words, they refer to issues not relevant to this
27 paper.
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45 In literature, the term ‘contextual coherence’ is used to evaluate the extent to which
46 pupils “*can apply a concept or a physical principle in a variety of familiar and novel*
47 *situations*”, (Savinainen et al. 2005). “Representational coherence” concerns students’
48 capability to use multiple representations correctly, for instance verbal, diagrammatic,
49 graphical. (Savinainen et al. 2005). Based on the above for promoting “contextual
50 coherence”, we need to develop appropriate works, in which we focus on the existential
51 aspect of force interactions in various situations in the same phenomenological environment,
52 e.g. gravitational, as well as in different ones, e.g. electrostatic, magnetic. When students
53 recognise dynamic interaction in various contexts, it does not necessarily mean that they have
54 acquired scientific conceptions on the ontological aspect or the coarse quantitative aspect of
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4 interactions (diSessa et al. 2004). For instance, students may recognise that a magnet exerts
5 force on a magnetic material, or a rock on another rock, but overall they have failed to
6 structure the conception that this force is the product of interaction and not the quality of a
7 body. When students can handle a variety of representations on force interaction, then we can
8 better comprehend the ontological and the coarse quantitative aspect they have on that
9 concept, e.g. the correct vectoral representation of the force. Therefore, for promoting
10 ‘representational coherence’, students need to study a variety of representations, e.g. to draw
11 the vectors of force qualitatively, meaning to draw clearly what force is exerted on which
12 body, as well as quantitatively, meaning to ponder on the magnitude of these vectors.
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21 **4. The role of educational software**

22 In the conclusions of the literature review, in which the role of software as a means of
23 teaching and learning is analyzed, it is maintained that the use of computers can generate the
24 desired learning outcomes when realized in a learning environment in which students have
25 the ability to interact not only with the software but also between themselves. Empirical
26 research shows that it is not enough for students to merely complete the software labs, since
27 all too frequently they view them as a group of compulsory exercises that will help them
28 learn something they do not know (Tao and Gunstone 1999b). In contrast, learning results are
29 positive in a learning environment in which students work in groups, discuss their views
30 between them, use the software to check them and, then, further discuss their modified views
31 (Jimoyiannis and Komis 2001; Kordaki 2004; Wegerif 2004).
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40 There are many cases which we cannot be studied in real lab experiments in a
41 classroom setting because they are either impossible to conduct, dangerous, too complex,
42 take too long or, in contrast, are too short. In these cases, the role of educational software is
43 essential because, first, the presentation of these physical phenomena is feasible in the
44 software environment (Hennesy et al. 2007); for instance, in our teaching-learning sequence,
45 we can approach the gravitational interaction between a water-melon and an apple, or the
46 electrostatic interaction between two “space” charged spheres. Second, educational software
47 provides opportunities, by reducing the time required, to study these kinds of physical
48 phenomena in a variety of circumstances, e.g. the gravitational interaction between two
49 bodies in space, or on the beach, or in a room, with a variety of representations, e.g. pictures,
50 graphs, vectors (Jimoyiannis and Komis 2001; La Velle et al. 2003). Third, with educational
51 software we can study cases ‘sanitised’ from the real world, in which we can isolate and
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4 manipulate variables, e.g. two charged spheres in space whose masses or charges we can
5 change (Jimoyiannis and Komis 2001; Suthermund 2004).
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7 It becomes obvious from the above that educational software plays a unique role in
8 our sequence, because it can essentially aid in promoting “contextual coherence” as well as
9 “representational coherence” for the understanding of force interactions.
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12 13 14 **5. The education software ‘Newton-3’**

15 Taking into account the problems as outlined in the previous sessions, the following
16 designing principles for the development of our software emerge (Kariotoglou and Spyrtou
17 2005). Based on our initial conviction that it is necessary for student-teachers to decipher the
18 intimate relation of the concept of interaction with force, we decided to design software in
19 which:
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- 24 i. We take into consideration the empirical results of our research for these two
25 concepts as well as the corresponding nine learning difficulties that derived from
26 the review of the literature review (see section 2).
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- 28 ii. Contextuality as well as the specification of force interactions are approached with
29 specific tasks. It is, therefore, necessary to include different contexts of force
30 interactions, gravitational and electrostatic, as well as specific tasks in which the
31 existential, ontological and coarse quantitative aspect of specification will be
32 approached. In particular, we consider it essential to include cases in which
33 stationary distant bodies will interact, since our literature review shows that the
34 number of such suggestions is limited (see section 2). We decided that magnetic
35 interactions are too easy to be studied with real lab experiments.
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- 38 iii. Our students complete the software exercises in groups, in a learning environment
39 of co-operation so as to discuss their views on the relation of interaction with
40 force in depth.
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50 The educational software presented in this work, is a web-based application, designed
51 for the topic of Newton’s Third Law. The software covers a series of several cases from
52 gravitational to electrostatic interaction (Kariotoglou and Spyrtou 2005). The application runs
53 on a simple web browser with Macromedia Flash plug-in installed. The main screen looks
54 like a notebook page, and is divided into two main sessions. To the right we have the actual
55 application, called a “Lab”. To the left (see Fig. 1) is the text area, which contains brief
56 instructions for “Lab” activity to run. The text is kept to a minimum and briefly describes
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4 the tasks that the student should carry out in each “Lab” activity. The user has a choice of a
5 total of eleven different “Lab” activities from among the menu-like buttons at the bottom of
6 the html page. User instructions appear as a pop-up window, on the click of an
7 “instructions” link.
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12 “Figure 1. Main screen of the application.”
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16 A typical “Lab” stage is shown in Figure 2. The stage is divided into three parts: the
17 main part is devoted to the visual representation of the interaction addressed in the “Lab”
18 activity. To the right there is a tool-box, and in the bottom part the “expert comments” on
19 the student’s actions. A photo-realistic representation of both the background and the
20 interacting bodies is adopted to help the user get a clear view of the problem presented.
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26 “Figure 2. Typical ‘Lab’ stage: the case of the Earth and the Moon.”
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30 In Figure 2, the case of the “Earth” and the “Moon” is presented, while the
31 background is set to represent the “Universe”. The user is asked to pick and place the action
32 that one object (the “Earth”) exerts on the other (the “Moon”). The action exerted is
33 represented by a vector (arrow). The arrow – force vector – is initially placed in the “empty
34 space” between the two interacting bodies and the user is prompted to set the vector in the
35 “proper” place. The student can place the force vector by direct manipulation of the arrow
36 representation (drag and rotate). A time indicator located within a schema of an apple-like
37 outline displays the time that has elapsed since the start of “Lab”. It serves as a visual
38 indicator for the students to monitor the time required to make their choice and place the
39 arrow-vector. Then, the students should press the “check” button to receive a comment on
40 their choice.
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50 “Figure 3. The structure diagram of the application.”
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54 The application design is fully modular, adaptable and expandable (Fig.3). Comments and
55 “expert” prompts are not hard coded in the program but they are found in a single external
56 text file, which acts as a source. This enables even an individual instructor without any
57 programming knowledge to adapt and also translate *Newton-3*. The application can easily be
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4 extended to other types of interactions (e.g. magnetic interactions), since pictures are also
5 external graphic objects assigned to program internal variables.
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8 9 Interactive dialogues

10 One of the most important parts of this software application is the feature of the
11 pictorial expert that can serve as a virtual “teacher”. On the other hand, this feature is used to
12 supply the student with the initial instructions regarding the task in hand and what is to be
13 done. For example:
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17 *“Let us study the action that the Earth exerts on the Moon. You should place the*
18 *action (vector) of the Earth on the correct spot.”*
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21 On the other hand, every time the program goes through a check on the student's answer
22 (by a click on the “check” button) the system feedback appears in the “expert respond” area.
23 The “responds” are not just a simple indication of error but aim to help the user understand
24 the problem and, at the same time, prompt him towards the right direction of thinking. For
25 example, say the student has placed the tip of the arrow-vector on the surface of the wrong
26 body (i.e. Moon), the “expert” will respond with:
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31 *“The vector depicts the action of one body (Earth) on the other (Moon). You have*
32 *placed the tip of the vector on the surface of the Moon. Remember that the vector is*
33 *applied on the centre of mass of the body that it acts upon. Try again.”*
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36 Or, when the student has placed the vector in the correct spot but pointing in the wrong
37 direction/angle, the “expert respond” would be:
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40 *“The vector depicts the action of one body (Earth) on the other (Moon). You have*
41 *placed the vector's point of application on the centre of the Moon. Remember that*
42 *force is a vector and direction is an important element to a vector. Try again.”*
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45 46 47 Program feedback and checks

48 Several cases of possible student answers in placing the arrow-vector are examined. These
49 cases are the sources for a data set in the form of a look-up table, based on known students’
50 alternative conceptions of vector representations, force as a vector, and interactions on
51 Newton’s Third Law (Palmer 1997; Hatzikraniotis, Theodorakakos, Spyrtou, and Kariotoglou
52 2005). The cases examined are:
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57 i. The force-vector is applied on neither of the bodies but on “empty space”.
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59 ii. The force-vector is applied on neither of the bodies but is much closer to one, that
60 being the wrong one.
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- 4 iii. The force-vector is applied on the wrong body.
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- 6 iv. The force-vector is placed close to the correct body.
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- 8 v. The base (point of application) of the force-vector is placed on the surface of the
- 9 correct body.
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- 11 vi. The tip of the force-vector is placed on the surface of the correct body.
- 12
- 13 vii. The base of the force-vector is placed somewhere on the correct body but not at the
- 14 centre of mass.
- 15
- 16 viii. The tip of the force-vector is placed somewhere on the correct body.
- 17
- 18 ix. The tip of the force-vector is placed at the centre of mass.
- 19
- 20 x. The base of the force-vector is placed at the centre of mass, and, in this case, the
- 21 direction of the force-vector is examined.
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24 **6. The application of the software**

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26 In the implementation of Teaching-Learning Sequence, we adopted the Initiation-
27 Discussion-Response-Follow-up (IDRF) learning environment (Wegerif 2004). The IDRF
28 corresponds to the interaction of students with the computer, meaning that the computer
29 poses a certain question (Initiates the problem), the students give their ideas to the computer,
30 the computer “answers” (Response) as to whether their ideas are correct and the interaction
31 between them continues in subsequent follow-up questions. The D concerns the discussion
32 that develops, after the question is posed by the computer, between the students, who express
33 their ideas to the other members of their group, compare them, agree or disagree; in other
34 words, make sense of their ideas. The IDRF structure is considered to be a proposition by
35 which the transmission and the constructive aspect of learning are combined in a unified
36 form. The IDRF process “*direct the talk of children in order to meet the goals of a*
37 *predefined curriculum*” (Wegerif 2004) while, during the D process, students have the time
38 to construct their own meanings.
39

40
41 During the implementation of the sequence according to the IDRF suggestion,
42 students have more time to investigate their ideas than when discussing them with the
43 teacher; they can express them with greater precision to the software than in a dialogue with
44 the teacher, and without fear of teacher’s judgement (Finegold and Gorsky 1988; Henessy et
45 al. 2007). In our sequence, the discussion with the teacher proceeds the IDRF only to help
46 student-teachers express their views to the entire class – while the teacher keeps a neutral
47 position on all views – and follows the IDRF so that possible remaining questions may be
48 explained, and additional explanations given.
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4 Our sequence was implemented to a population (primary and pre-school student-
5 teachers) who are not positively disposed towards physics. In order to help student-teachers
6 become involved with interest and without fear, in the teaching, we took into account the
7 remarks of the literature review on the unique ontological nature that computers seem to
8 possess. Students seem to feel freer to discuss and reflect using educational software than
9 they sometimes feel when talking to their teachers (La Velle et al. 2003; Wegerif 2004).
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14 The implementation of the software is structured in 3 lessons, each lasting 2 hours. In
15 table 1, we can see the content of each lesson, as well as the three aspects (existential,
16 ontological, coarse quantitative aspect) in which these contexts are included.
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21 **Table 1** The content of each lesson related to the three aspects: existential, ontological,
22 coarse quantitative aspect
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26 For the approach of the existential aspect of force interaction, in the first lesson, we
27 introduce gravitational interaction in 5 different “context-labs” of the software and, in the
28 second lesson, we introduce electrostatic interaction in 6 different “context-labs”. Therefore,
29 our students have, on the whole, 11 different situations in 2 different phenomenological
30 contexts, in which they discover the force interaction between two bodies. The eleven
31 “context-lab” activities are listed below:
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- 36 1. Gravitational interaction between two celestial bodies: the case of the Earth and
37 Moon.
- 38 2. Gravitational interaction between an object of everyday use: a watermelon and the
39 Earth. Both are considered as free in space.
- 40 3. Gravitational interaction between two objects of everyday use: a watermelon and an
41 apple, as two free objects in space.
- 42 4. Gravitational interaction between two objects of everyday use: a watermelon and an
43 apple, when they are close to the surface of the earth.
- 44 5. Gravitational interaction between two objects of everyday use: a watermelon and an
45 apple, when they are inside a room.
- 46 6. Electrostatic interaction between two metallic spheres that have the same positive
47 charge but different size.
- 48 7. Electrostatic interaction between two metallic spheres that have the same negative
49 charge but different size.
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- 4 8. Electrostatic interaction between two metallic spheres of the same size and opposite
- 5 charge of equal value.
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- 7 9. Electrostatic interaction between two metallic spheres of the same size and opposite
- 8 charge of unequal value.
- 9
- 10 10. Electrostatic interaction between two metallic spheres of different size and opposite
- 11 charge of equal value.
- 12
- 13 11. Electrostatic interaction between two metallic spheres of different size and opposite
- 14 charge of unequal value.
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19 “Figure 4. Action and Reaction in the case of two charged bodies: student tries to place (a)

20 the action; (b) the reaction; (c) action and reaction as mutual interaction; and (d) to move one

21 of the bodies and observe the mutual change in action-reaction vectors.”

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26 The general structure of each “context-lab” is the same as in lab 6, the case of

27 *Electrostatic interaction between two metallic spheres that have the same positive charge but*

28 *different size*, as described below. Each “Lab” consists of sequential steps, where students are

29 gradually led from the concept of “one body exerts force to the other” to the concept of

30 “mutual action”. The “Lab” activity is divided into four sessions; each session once

31 successfully completed follows the previous one. The first two sessions deal with the problem

32 of one body acting on the other, while the last two sessions deal with interacting bodies. The

33 essence of “interaction” in the sense of a mutual relationship and a mutual action between

34 two bodies is introduced after students have thoroughly examined the concept of “action”. In

35 more detail:

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43 i. In the first session (Fig. 4a), the student is asked to place the action of one body

44 (right) on the other (left). Much emphasis is placed on the student’s understanding of the

45 representation of the action as force, and the vectoral characteristics of force.

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48 ii. The second session (Fig. 4b) is similar to the first one. The term reaction is

49 introduced, as the action of the second body exerted on the first. Again, the main focus is the

50 student’s understanding of the characteristics of force as a vector. Students are asked to deal

51 with a similar problem (as in the first session) and this correspondence is believed to help

52 them lay the foundation for the understanding of the mutual relationship between action and

53 reaction.

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58 iii. The third session (Fig. 4c) explores the concept of “mutual relationship”. The session

59 summarizes the activities of the previous two sessions in a unified set. The student is asked to

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4 place both forces on the two interacting bodies. The concept of “*equal in magnitude but*
5 *opposite in direction*” is explored.
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8 iv. The concept of mutuality is further explored in the final (fourth) session. The session
9 is an interactive simulation (Fig. 4d), where two bodies are shown interacting and the force-
10 vectors appear on each of the bodies. The students are asked to drag one of the interacting
11 bodies all over the screen and observe the two force-arrows, changing in magnitude
12 simultaneously and always pointing one towards the other (opposite directions).
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16 In order to help student-teachers comprehend the ontological aspect of force
17 interactions (Table 1), we designed the first two sessions (i and ii) of each “context-lab”.
18 Moreover, we approached the ontological aspect in the first lesson by discussing the
19 Universal Law of Gravity in the 5 labs of the software, in other words, that two masses are
20 equally attracted to each other regardless of whether they are in space, e.g. labs 1 and 2, or on
21 the Earth, e.g. labs 3-5. A similar discussion takes place in the second lesson, with the
22 statement of Newton’s Third Law, where electrostatic forces are included. We decided to
23 guide our students to acquire a general perception about Newton’s Third Law different from
24 the classical one: “to every action there is always an equal reaction”, according to the
25 literature (Hellingman 1992; Roach 1992). Our proposal is: when entity A acts on entity B,
26 entity B simultaneously acts on entity A. The interaction between them has the same
27 magnitude and can be either attractive or repulsive. The teaching of the ontological aspect is
28 concluded in the third lesson, as we discuss the similarities as well as the differences between
29 the two kinds of force interaction with student-teachers. For example, they are asked to
30 observe in the software that gravitational interaction is just attractive whereas electrostatic
31 interaction can either be attractive or repulsive.
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35 For the teaching of the coarse quantitative aspect, student-teachers are asked, using
36 the appropriate software instructions (sessions iii and iv), to ascertain, in the first and second
37 lessons, that the lengths of vectors of the two forces (action-reaction) are equal; thus, the
38 magnitudes of forces are equal, regardless of whether the bodies have unequal masses,
39 unequal charges, and are closer or apart from each other. In the third lesson, we focus only on
40 session (iv) of all 11 labs in order to introduce the reverse square distance law for force
41 interactions. Therefore, in our approach, the mutuality of force interactions is approached by
42 the combination of two representations, namely, vectorally and with a formula. We believe
43 that this combination can contribute considerably to the improvement of the ability of
44 student-teachers to use a variety of representations for force interactions, that is to say to
45 develop their own “representational coherence” for force interactions.
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4 **7. Research design**
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- 6 a) We applied the teaching-learning sequence in 2 groups of 8 primary school and 8
7 pre-school student-teachers in the first year of their studies in our school of
8 education. Student-teachers were selected on the basis of the answers they gave to a
9 written questionnaire, which was completed by almost all first-year students before
10 the application of the sequence (Kariotoglou, Spyrtou and Tselfes 2005). The
11 sample of 16 students consists of the ones who, on one hand, wanted to participate
12 in experimental teaching, and, on the other, offered representative samples in
13 relation to the alternative ideas they had concerning the concept of force
14 interaction.
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21 The process of data collection is as follows (table 2):
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- 23 b) One week before the implementation of the software, student-teachers were asked
24 to answer a written questionnaire (Q_A) and after that they explained their views in a
25 semi-structured clinical interview (I_A).
26
27 c) At the beginning of each lesson student-teachers individually completed a
28 questionnaire (Q_1, Q_2, Q_3) in order to reveal their initial ideas about the related
29 lesson's content.
30
31 d) During their work on software tasks, they filled out a worksheet in groups ($W_{S1},$
32 W_{S2}, W_{S3}).
33
34 e) After each lesson, they filled out a worksheet at home and brought it to the next
35 lesson for evaluation (W_{H1}, W_{H2}, W_{H3}).
36
37 f) A week after the implementation of the software, student-teachers were again asked
38 to answer a written questionnaire (Q_B) and, following that, explain their views in a
39 semi-structured clinical interview (I_B). Questionnaire Q_B contained identical and
40 different questions than Q_A .
41
42 g) Every lesson was videotaped and then transcribed to written text in order to help us
43 describe and interpret students' conceptual development. Moreover, we tape-
44 recorded each group of students while they performed the software labs.
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53 **Table 2** The process of data collection
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57 The research questions of our study are:
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- 59 a) Do student-teachers recognise the force interactions between two physical objects in
60 different contexts? (existential aspect)
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4 b) On which of the two objects is the arrow of the force placed? (ontological aspect)
5
6 c) Do student-teachers understand the equality of the magnitudes of the two forces of the
7
8 interaction? (coarse quantitative aspect)
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10 **8. Results and Discussion**

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12 We present the results of the two groups together because the analysis showed that
13
14 there were similarities in their answers as well as in their learning development. These results
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16 are presented with the three basic research questions always in mind. In our effort to justify
17
18 the observed changes in the students' learning, we discuss the results of questionnaires Q_A
19
20 and Q_B, the results of the analysis of the dialogues during the lectures, as well as the results of
21
22 the worksheets (W_S and W_H).
23

24 **Existential aspect**

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26 In table 3, we can see the student-teachers' answers concerning the existence of forces
27
28 in each of the two interactions (gravitational and electrostatic). These results are produced by
29
30 questionnaires Q_A and Q_B (Spyrtou, Zoupidis and Kariotoglou 2007). The questionnaire is
31
32 constituted of ten situations. Three of the questions deal with gravitational interaction, three
33
34 look into electrostatic interaction (Kariotoglou, Spyrtou and Tselfes 2005) and the remaining
35
36 four examine magnetic interaction. In each question, there is a system of two entities (masses
37
38 or charged bars) which interact, e.g. the Earth and the Moon, two wooden cubes, two charged
39
40 bars, a charged bar and a small piece of paper.

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42 The results concerning the existence of forces are presented in table 3 and have been
43
44 produced in the following manner: when the student answers scientifically (existence of two
45
46 forces) in all three questions concerning gravitational interaction, then we consider him to
47
48 have a scientific view and classify him in the corresponding category of the table. The
49
50 remaining students are classified in two alternative categories. Thus, whoever answers even
51
52 just one question with "no force is exercised" is placed in the second alternative, while
53
54 individuals who respond to at least one question with "only one force is exercised" are
55
56 placed in the first alternative. The same applies to electrostatic interactions.

57
58 In the first line of table 3, we see the number of student-teachers who possess the
59
60 scientific conception concerning the existence of two forces in each interaction. Before the
61
62 implementation of the software, only 5 and 9 student-teachers respectively identify the
63
64 existence of two forces in gravitational and electrostatic context. However, even those who
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66 identify the existence of two forces are not necessarily in a position to clearly distinguish

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4 between these two forces (see below, ontological aspect). After the implementation of our
5 suggestion, we observe that almost all students (15 in the Gravitational part and 15 in
6 electrostatic) give the scientific answer regarding the existence of two forces when two
7 bodies interact.
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11 In the second line of table 3, we see the number of student-teachers possessing the
12 first -“there is only one force”- alternative conception concerning the existence of two forces
13 for each interaction. Five student-teachers believe that only the Earth exerts force on the
14 apple and not vice versa. Five student-teachers claim that only the charged bar exerts force on
15 a piece of paper and not vice versa. In the third line of table 3, we see the number of student
16 teachers supporting the second alternative conception concerning the existence of two forces
17 for each interaction, which is “there is no force exerted”. Six student-teachers do not
18 recognize the existence of any force between two wooden cubes and two student-teachers do
19 not recognize the existence of any force between the charged bar and the paper before this
20 teaching. One student-teacher holds the same alternative conception in both contexts after
21 this teaching.
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31 **Table 3.** The existential aspect of force interactions from pre-post questionnaire
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35 It is important to emphasize the surprise that students express while working on the
36 software labs. We impart a representative comment from worksheet (W_{S1}): ‘*Even stationary*
37 *bodies that exist in the same space interact between them! Whether they are in a terrestrial*
38 *environment or in space!*’ The following is a typical dialogue between two students
39 transcribed from a tape:
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43 Student-teacher A: ‘*This means that two bodies interact in the same way on Earth and in*
44 *space.*’
45

46
47 Student-teacher B: ‘*Impossible! In space different laws of physics to those on the Earth*
48 *apply.*’
49

50
51 The above mentioned findings are in agreement with those of the literature review, in
52 the sense that students may recognize force interaction in some cases but not be aware of the
53 more general applicability of the scientific view (Tao and Gunstone 1999a; Heywood and
54 Parker 2001). Furthermore, we consider these findings to be important because they reveal
55 that not only students of primary and secondary school, but first-year university students do
56 not seem to have comprehended the existential aspect of force interactions, despite being
57 taught both gravitational and electrostatic forces within the analytical program of Greek
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4 education. In fact, the cases of Earth-apple and charged bar-paper are two of the most
5 common examples of force interactions in the schooling context. The fact that before the
6 implementation of the software the number of students who give a scientific answer
7 regarding electrostatic interaction is greater than the respective number regarding
8 gravitational interaction seems to be derived from their distant memory of the primary “law”
9 “like poles repel, unlike pole attract”. But when presented with the case of a charged body
10 and an uncharged one (bar-paper), then their restricted conception of electrostatic interaction
11 becomes apparent. Finally, for the fifteen people who answered correctly after the
12 implementation of the software, we can claim that they improved their own existential aspect
13 at least for the two contexts of gravitational and electrostatic force interactions.
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22 **Ontological aspect**

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24 The results emerging from questionnaires Q_A and Q_B emerge that are assembled in
25 table 4, where we can see the student-teacher answers concerning the position of the arrow
26 representing the forces in each interaction (Spyrtou, Zoupidis and Kariotoglou 2007). The
27 results regarding the placement of the arrow, shown in table 4, have emerged as follows:
28 when the student places the arrow in accordance with the scientific conception in all three
29 questions regarding gravitational interaction, we assume he possesses a scientific conception
30 and classify him in the corresponding category of table 4 (first line of table 4). The rest are
31 placed in two alternative classifications. Specifically, those using any other symbol but one
32 single headed arrow (e.g. a double headed arrow), even in just one question, are placed in the
33 category ‘Other symbols’ (third line of table 4). The rest, in at least one question, place the
34 arrow on the body that exerts rather than the one accepting the force and are placed in the
35 first alternative conception (second line of table 4). The same applies to electrostatic
36 interactions.
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47 The results from the summation of the data collected show that all student-teachers
48 seemed to have a confused idea about the nature of force interactions before the
49 implementation of our approach as well as during the first two lessons. For example, at the
50 end of the first lesson – after the teaching of gravitational interaction – 15 student-teachers
51 write on their worksheet (W_{H1}) that following the relevant software they have comprehended
52 the scientifically accepted representation of the vector of force. However, at the beginning of
53 the second lesson, in the case of electrostatic interaction, the 10 students, who correctly have
54 drawn the vector of force, in questionnaire Q_2 , give explanations that do not agree with the
55 scientific conception. One of their representative deductions is: ‘...because the small sphere
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4 *will move in this direction.* Even though the charged spheres are depicted as stationary on the
5 worksheet and the in software lab, the students imagine the movement that could result from
6 their interaction. In other words, they appear to identify the direction of velocity with that of
7 the vector of force, an opinion which is recorded at length in the literature review (Vosniadou
8 et al. 2001).
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14 **Table 4** The ontological aspect of force interactions
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18 In discussions that take place during the teaching, students who hold the first
19 alternative conception develop the reasoning “*because the body gives something*”. For
20 example, at the beginning of the first lesson, a student-teacher argues in the Earth-
21 watermelon case: “*I have placed the vector of force on the Earth. It is the Earth that gives*
22 *force on the watermelon.*” A similar example in the Earth-Moon case: “*The Earth exerts its*
23 *force on the Moon. Therefore, the vector is placed on the Earth.*” It seems that students
24 conceive the force as an internal attribute of the body that “exerts” its force and thus
25 consider it reasonable to draw the vector on the body that exerts that force (Ioannides and
26 Vosniadou 2002).
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33 Apart from the vectoral characteristic of the force, there are other facts, which reveal
34 that at the beginning of the teaching, students have confused conceptions about the
35 ontological aspect of force interactions. Specifically, none of them refers explicitly to the two
36 different types of force interactions in various situations -even those who stated that two
37 forces are exerted between the two bodies (5 and 9, see table 3). The questionnaire answers
38 they complete at the beginning of each lesson show that approximately half of the student-
39 teachers (9 in all) cannot distinguish gravitational interactions from electrostatic and
40 magnetic ones. For example, in the first lesson, one writes in his questionnaire (Q₂): ‘*The*
41 *watermelon is uncharged, so it cannot exert force on the Earth. On the other hand, the Earth*
42 *exerts its magnetic force on the watermelon.*’ The findings following the completion of the
43 first three lessons demonstrate that student-teachers show an improvement in their
44 conceptions of force interactions. Specifically, after the third lesson, they all emphasize the
45 similarities and differences between the three interactions (W_{H3}). For example: ‘*I had the*
46 *idea that all interactions are either attractive or repulsive. I have now realized that*
47 *gravitational interaction is only attractive... I have also understood that a charged body can*
48 *exert force on an uncharged one.*’ A student notes: ‘*Both interactions can act from a*
49 *distance. Two bodies need not be in contact in order to interact.*’
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4 In conclusion, the results from the written questionnaires as well as from other data
5 resources signify a remarkable increase in scientific conceptions and a corresponding
6 decrease in alternative ones. Furthermore, they reveal that the mistakes made by students in
7 the representation of interactions are not mere drawing mistakes but seem to be connected
8 with the familiar alternative conceptions they have on the understanding of force, “force as a
9 property of a body” or “force and velocity have the same direction”. This means that the
10 representation of force with a vector becomes a crucial point for the understanding of the
11 ontological aspect of force interactions.
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19 **Coarse quantitative aspect**

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

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44 From the worksheets that students complete in each lesson as well as from their
45 discussions while working in the software labs, this alternative conception proves to be
46 particularly strong. Following, we present selected data from the three lessons to demonstrate
47 how our approach makes this problem more explicit for the learners.
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51 Specifically, in the first lesson, when the first two sessions of each lab are completed,
52 all students observe the existence of two forces in the interacting bodies, e.g. the force that
53 the Moon exerts on the Earth and the force that the Earth exerts on the Moon. In the third
54 session of the lab, they are asked on whether the forces have equal magnitudes or not. From
55 the findings (worksheet and discussions while working on software exercises) it becomes
56 obvious that the vast majority are surprised by the equality of magnitudes. We offer a
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4 representative discussion that took place while students were working on the second software
5 lab, the Earth-watermelon interaction.

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7 Student A: *The effect of the watermelon on the Earth is smaller. So we should take the small*
8 *vector.*

9
10 Student B: *That's wrong! Shouldn't we select the bigger arrow? Now it says (the software*
11 *teacher) again' 'pay attention to the magnitude'.*

12
13 Student A: *So it's the middle arrow, which means equal. (They mean equal to the vector of*
14 *the Earth's force on the watermelon.)*

15
16 Student B: *So the forces are equal! All this time I was mistaken.*

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

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

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

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4 At the beginning of the third lesson (see table 1), we asked students to express in
5 writing (in questionnaire Q₃) their views on the similarities and differences that they think
6 gravitational and electrostatic forces have. It is of great interest that only 2 students
7 mentioned the equality of action-reaction magnitudes. The reader is reminded that, in the
8 third lesson, the Law of Inverse Square was mathematically introduced. Following the
9 lesson, on their home-worksheets (W_{H3}), 14 student-teachers correctly answer by explaining
10 that the magnitudes of both entities contribute to the calculation of the magnitude of each
11 force and by accurately drawing the two vectors of forces. But 2 of them continue to believe
12 in the related alternative idea. For example, one of them writes about a specific task: “*The*
13 *negative bar exerts a greater force on the other because it has a larger charge.*” A week after
14 the implementation of the software, these 2 students gave correctly responses to the tasks of
15 the final questionnaire Q_B (table 5). We are not surprised by the result. It is remarked in the
16 literature review that students are often in two minds between conceptions that may
17 contradict each other (Tao and Gunstone 1999a). It appears that these 2 students did not
18 manage to perceive the general application of the scientifically accepted view about the
19 coarse quantitative aspect of force interactions in different contexts.
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31 The alternative conception “*the larger the object, the greater the force exerted*” is
32 widely recorded at large in the literature review (Watts and Zylbersztain 1981; Hestenes et al.
33 1992; Bao et al. 2002). We believe that from the implementation of our software the
34 difficulty that student-teachers present in perceiving the equality of action-reaction
35 magnitudes in different contexts (gravitational and electrostatic interactions) as well as in
36 different situations in these two contexts becomes apparent. It also appears that the vectoral
37 representation of forces and the teaching of Newton’s Third Law do not suffice but that the
38 quantitative approach of the equality of magnitudes through the Law of Inverse Square is also
39 needed in order to overcome this problem. In conclusion, we consider that, after the
40 implementation of our suggestion, almost all the students quantitatively perceived the
41 equality of forces in gravitational and electrostatic interactions with the Law of Inverse
42 Square.
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53 **9. Concluding remarks**

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57 In Greek Elementary schools gravitational, electrostatic and magnetic force
58 interactions are taught as well as the effects of the forces (changes in the kinetic state,
59 deformation) the distinction between forces in contact and forces at a distance. Furthermore,
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4 the analytic problem includes means of measuring the forces, the concept of friction and,
5 moreover, the factors upon which friction is dependent (5th grade). Even in pre-school
6 education, lessons are recommended in which magnetic force is introduced. Consequently, it
7 is considered essential mainly for elementary school teachers and, to a lesser degree, pre-
8 school teachers to be familiar with the formal aspects of theory about force interactions.
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12 In this paper we have described the design and development of software, which we
13 implemented in the first three lessons of a Teaching-Learning Sequence for primary and pre-
14 school student-teachers. The educational software is a web-based application, designed to
15 introduce the topic of Newton's Third Law. The software covers a sequence of several cases
16 from gravitational to electrostatic interaction and sets a series of eleven "Lab" activities. In
17 each "Lab" students are presented with a problem of interaction and are asked to locate and
18 place the forces. The software is structured on an interactive dialogue-basis, where a pictorial
19 "expert" changes faces and makes comments on the students' response. Each "Lab" consists
20 of subsequent steps, where students are gradually introduced from the concept of "one body
21 exerts force on the other" to the concept of "mutual action". For the design and development
22 of the software, we took into consideration the alternative ideas recorded in the relevant
23 literature review as well as the results of empirical research that we conducted on students
24 from pedagogical departments. Our purpose is to help students develop their contextual as
25 well as their representational coherence about force interaction.
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36 The implementation of software into this concrete teaching-learning sequence has
37 three main characteristics: the idea of contextuality, the specification of the concept of force
38 interaction and the IDRF structure of the teaching-learning environment. We approach the
39 idea of contextuality by providing eleven different situations in two different
40 phenomenological contexts, namely, gravitational and electrostatic. We approach the three
41 aspects of the specification of the concept of force interaction very carefully. Specifically,
42 according to the literature review and the results of our empirical research, the existential
43 aspect relates to the first four difficulties that we mentioned in unit 2 (see numbers 1-4), the
44 ontological aspect concerns the following three difficulties (see numbers 5-7) and the coarse
45 quantitative aspect corresponds to the last difficulty (see number 8). With this in mind, we
46 designed the eleven different lab-situations that address all these learning difficulties.
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55 The teaching approach IDRF that we followed has characteristics of both transfer and
56 construction of knowledge. Transfer of knowledge happens due to the nature of computer-
57 student interaction but also because chunks of the knowledge we negotiated are actual
58 scientific conventions, e.g. the arrow symbol. Construction takes place because we identified
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4 alternative ideas emanating from the students that can be modified through group discussion
5 and software interaction. Specifically, the teaching of the placement and magnitude of the
6 arrow that represents the force is a three-step process. In the first and most important step, we
7 answer the question: “on which body is the force exerted?” The answer indicates first the
8 action and then the reaction (sessions 1 and 2). We answer sequentially – separately for
9 action and reaction – so that it becomes clear to the students which body exerts and which
10 accepts the force. In this step, we are not interested in the comparison of magnitudes of
11 forces. In the second step, we negotiate the equality of magnitudes of forces (session 3) using
12 a rather qualitative approach. The completion of the comparison of magnitudes takes place in
13 the third step (session 4) with the negotiation of the Law of Inverse Square ($1/r^2$). By
14 negotiating the law, students are helped to comprehend and, finally, learn the equality of
15 magnitudes, as they observe in the relevant formula that both (usually unequal) quantities, i.e.
16 masses or electrostatic charges, contribute to the calculation of magnitude.
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26 The research results indicate that this implementation was effective. We could support
27 that our student-teachers developed their contextual coherence in a variety of static situations
28 of two contexts, gravitational and electrostatic, because after the implementation of software
29 almost all of them give answers according to the scientific view of the existential aspect of
30 force interaction. We could also support that they developed their representational coherence
31 since we have positive results both in the ontological and coarse quantitative aspect.
32 According to the ontological aspect, they used the vector representation of force correctly and
33 all of them pointed out the similarities as well as the differences between the two interactions
34 (gravitational and electrostatic). According to the coarse quantitative aspect, they correctly
35 used the Law of Inverse Square in order to explain the equality of magnitudes of two forces
36 (action-reaction). Though the use of a pre/post test design may also have facilitated learning,
37 seeing that it is a process of testing, we do not have any evidence of such an effect.
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47 Some interesting points for further clarification have resulted from our research. First,
48 the vectoral representation of force on the body that exerts the force does not seem to be
49 merely a drawing mistake but is connected to two alternative conceptions, namely, “force as
50 a property of a body” or “force and velocity have the same direction”, which are known
51 from the relevant literature review (Jiménez-Valladares and Perales-Palacios 2001;
52 Vosniadou et al. 2001). Remarkably, even though we decided that all the bodies in the
53 software labs should be at rest – to avoid the second alternative conception – students
54 imagine the movement that could possibly result from the interaction of the two bodies and,
55 based on that criterion, draw the force of vector on the body that exerts the force. These two
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4 alternative conceptions concern the ontological aspect of force interaction and seem to both
5 be able to “hide” simultaneously behind the vector of force. Our research results are not
6 sufficient for us to support that the case of students drawing the vector of force correctly
7 indicates that both these alternative conceptions have been altered.
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10 Secondly, our results show that the difficulty students have in perceiving the equality
11 of magnitudes is essentially countered in the third lesson, when the Law of Inverse Square is
12 introduced. In other words, it seems that the qualitative description of the equality of
13 magnitudes of the two forces using Newton’s Third Law does not suffice, neither does its
14 qualitative representation by the equality of vectors of the two forces. We could suppose that,
15 since the concept of “equality” of magnitudes is quantitative in character, a quantitative
16 approach might be needed for its comprehension; one that could be achieved with the Law of
17 Inverse Square. However, the size of our sample is too small for us to be able to support this
18 hypothesis.
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Figure 1. Main screen of the application.

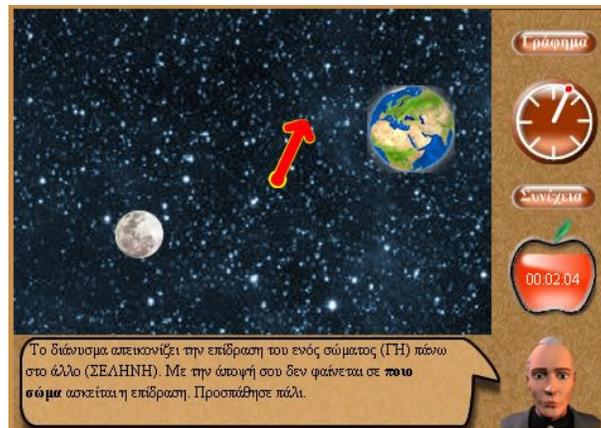


Figure 2. Typical 'Lab' stage: the case of the Earth and the Moon.

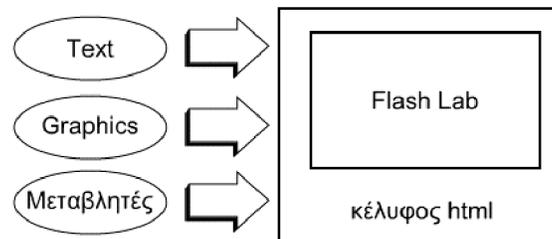


Figure 3. The structure diagram of the application.

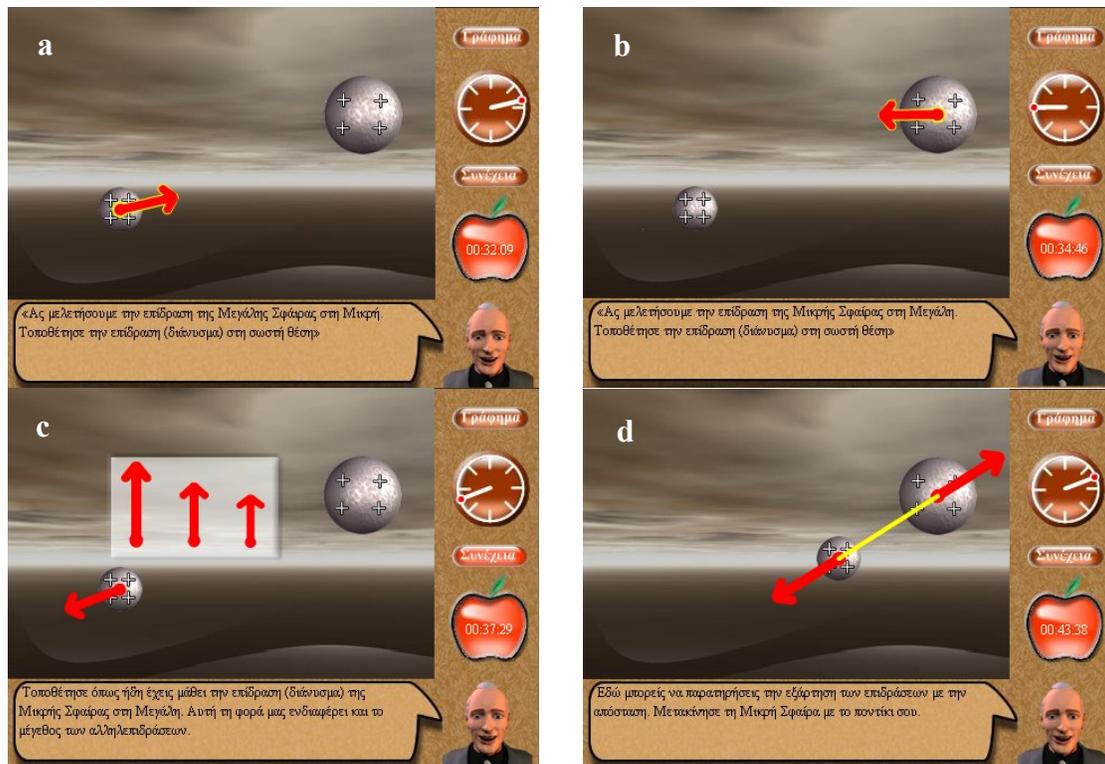


Figure 4. Action and Reaction in the case of two charged bodies: student tryouts to place the action (a) and the reaction (b). Action and reaction as mutual interaction: (c) Student is asked to place the reaction on second body and (d) to move one of the bodies and observe the mutual change in action-reaction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

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

1 st lesson	2 nd lesson	3 rd lesson
Existential aspect		
Gravitational Interaction 5 different context-labs	Electrostatic Interaction 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

Table 2 The process of data collection

Before the implementation	1 st Lesson	2 nd Lesson	3 rd Lesson	After the implementation
Q _A I _A	Q ₁ W _{S1} W _{H1}	Q ₂ W _{S2} W _{H2}	Q ₃ W _{S3} W _{H3}	Q _B I _B

Videotape (all lessons)
Tape-recording (each group during software labs)

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
1 st alternative conception: there is only one force	5	0	5	0
2 nd alternative conception there is not exerted force	6	1	2	1
Total	16	16	16	16

Table 4 The ontological aspect of force interactions

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

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

Dear Editor,

What follows is our response to the comments of the two reviewers.

Dear Reviewer 1,

Thank you very much for your constructive comments and remarks. Our responses to your remarks are as follows:

Issue 1: I would suggest that the article needs to be read and corrected by a native English speaker who has specialist knowledge of Physics. The useful content of the article is somewhat hidden by this lack clarity.

We carried out your suggestion.

Issue 2 & 3: The title and the abstract failed to give an insight into the content and the scope of the article. The use of the terms "contextuality" and "specification" in the title is confusing and I suspect that I would not be alone in being unfamiliar with these terms. The use of the quotations emphasises their specialist nature - the simple use of the word context would be sufficient to transmit most of the meaning for the former term. Their meaning is explained in the abstract and in the body of the article but I suspect that potential readers would be put off by their use in the title. Overall the abstract could be significantly simplified and consequently would better reflect the useful content of the article.

We changed the title and simplified the abstract in accordance with your recommendations.

Issue 3: The following points relate to the abstract but are typical of the problems relating to grammar, the clarity of expression, the use of specialist terms and the use of appropriate vocabulary in the rest of the article (p. 1):

**On line 15 the use of the term "elements" does not contribute to the understanding of the term "specification".*

**Line 26: "to approach" seems the wrong term here.*

** Line 29 - "and" instead of comma*

** Line 31 - "trialled" seems more appropriate than "applied"*

** Line 36 - Grammar and word choice needs examining - "sequence(s)" also "characteristics"*

** Line 41 - comma use*

** Line 46 - "equality of magnitudes of forces" is unclear and even misleading. The full "equality of magnitudes of action and reaction forces" is required to transmit full meaning.*

**Line 48 - There is a translation problem with the "Law of Inverse Square". This is almost always referred to as "Inverse square law".*

We amended all the specified points with the assistance of a native speaker of English.

Issue 4. The keywords also fail to reflect the full usefulness of the article. I suspect that few people would search with the terms "contextuality" and "specification". Additional Physics terms might include Newton's Laws, Force diagrams, Gravitation etc. It might also be useful to include further ICT keywords.

Done.

Issue 5a: Regarding the research methodology the article has two main references to research conducted by the authors. On pages 6 and 7 there is a summary of some previous research completed by the authors. It reads as if this is part of the research being reported in this article and not as a summary of previous findings - this is rather unclear.

You are right. It concerns a preceding stage of our research, to be published in another journal. We incorporated the chief/basic/essential/primary findings of our research in the relevant/pertinent literature review.

Issue 5b: The summary is useful and relevant overall but the following points require further consideration:

**page 6, line 47 perhaps should be research project
*page 7, line 29 "bibliography" is probably referring to the "literature review". (there are other uses of this term elsewhere in the text, e.g. page 9 lines 47 and 57).
page 7, line 28 needs clarification.

Done.

Issue 6a: The research which forms the basis of this article is described in pages 10 to 17. The description of the software is clear and examples are usefully provided. The translation could be clearer on page 11 lines 37 and 38. Sixteen participants used the software and this is a reasonable number in the light of the amount of data collected from each participant.

Done.

Issue 6b: Furthermore, the use of a pre/post test design is appropriate here, although it would have been useful to see this method critiqued as the process of testing may also have facilitated learning

We agree with your observation. See in the concluding remarks the pertinent sentence: "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."

Issue 7: Points to note:

**page 10, line 57 - "...placed in the "empty..."?
*page 12, line 12 - need to check apostrophe.
page 12, line 45 - the use of the word "implementation" needs considering.

Done.

Issue 8: The results are discussed on pages 17 - 24. The description of the results is lengthy, for example, on page 18 lines 14 to 46 there is little in the text that cannot be deduced from Table 3. Instead of giving full explanations of all the tables the results from one table could be explained and the reader would then have the tools to understand the other tables

With your instructions in mind, we maintained in analytic/itemised/detailed form the presentation of results of the existential aspect (table 3), while presenting concisely the results from tables 4 and 5.

Issue 9: The careful analysis of typical alternative conceptions associated with Newton's Third Law is especially useful and so is the application of the diSessa et al. (2004) theoretical framework. However, there is some work to be done before the terms existential, ontological and coarse quantitative are adequately and succinctly explained.

We gave further explanations/elucidation concerning the terms existential, ontological and coarse quantitative. This may be observed in the first paragraph of section 3.

Issue 10: The software is well conceived and is designed to be used within an Initiation-Discussion-Response-Follow-up (IDRF) learning environment. This is in line with current thinking on the use of discourse to improve learning. Therefore, the article does critically examine important issues and provides a way of examining the teaching and learning of this Physics concept. It would have been useful to have had further explanation of why this use of an ICT based pedagogy would be preferable to other pedagogies. The literature used by the authors is adequately up to date.

In section 4, in the first paragraph, we refer to two ICT based pedagogies and explain that we have taken into account the literature review which maintains that the discussion between the students and the interaction with the computer produces a more positive learning result than the pedagogy upon which the teaching is based, that is, mainly the interaction between students and only software.

In addition, in the second paragraph we explain why we did not implement a real lab based pedagogy. That is to say, we explain why it is essential/necessary to use software for the particular material we teach in our series/sequence of lessons/labs. We stress that with the pedagogy that we use, the students have the opportunity to practise in situations where it is not possible for real experiments to be undertaken, and in a variety of cases, where they can isolate and manipulate variables.

Moreover, in section 6 we emphasize more particularly that, with IDRF pedagogy, the students have more time to think about their ideas than when discussing them with the teacher. Indeed, since we are dealing with students who are not positively disposed towards physics, we consider that IDRF pedagogy may enable them to acquire greater self-confidence, that is to say, by giving them time to express and exchange their ideas with each other; and 'discuss' those ideas with the computer.

Finally, we stress the 3rd paragraph of section 9 because IDRF pedagogy, the way that we have implemented it, contributes both to the transfer (of knowledge) and the construction of knowledge.

Based on the above, we maintain that we have adequately/sufficiently/competently supported the choice of this particular/specific pedagogy in comparison to/relative to those in which either real experiments are used, or students work individually at a computer, or we have a classic/standard traditional transfer of knowledge from a teacher's lecture.

Issue 11: On the whole the referencing follows the Harvard System, however, the names of journal are not italicised and there are a couple of instances where there is only one space

between the references. There is one incorrect journal name - page 28, line 4 -Teacher not Teachers.

Done.

Thank you for your attention.

Yours sincerely

The authors

Dear Reviewer 2,

Thank you very much for your constructive comments and remarks. Our responses to your remarks are as follows:

Issue1: The title and abstract, however, do not really give an adequate view of what the paper is about - they need to be more informative. I'd suggest a title along the lines of 'Educational software for improving an aspect of physics knowledge for primary school student teachers'. The abstract should make more mention of the research that has been done and its results. Likewise with the keywords that should include words like physics, primary school teachers and Newton's Laws to give a better idea of what is included in the paper.

We changed the title and simplified the abstract in accordance with your recommendations.

Issue2: the paper describes two research activities, a survey and a pre/post test use of the software, but does not describe the purpose of these clearly enough. They should be outlined in the abstract or the Introduction, and their purpose made more clear. The methodology seems sound and the results interesting. (It is a little depressing to see that the science knowledge of primary school student teachers is so poor in Greece along with many other countries.) In summary, I would like to see the research better explained than it currently is.

You are right. It concerns a preceding stage of our research, to be published in another journal. We incorporated the chief/basic/essential/primary findings of our research in the relevant/pertinent literature review.

Issue3: Firstly the English expression needs some work as in many places it is awkward or clumsy. I will give some examples of problems I have found in the first few pages. On page 2, line 9 'In specific, the idea ...' would be better expressed as 'Specifically, the idea ...'. In a number of places the authors use the term 'researches' for several pieces of research instead of the word 'research'. Still on page 2, between lines 31 and 45 is one very long sentence. Page 3, line 11: 'In following ...' would be better expressed as 'In the following ...'. In line 33 'Also, most researches focus on ...' should be 'Also, most researchers focus on ...'. In line 50: 'In the findings of research ...' would be better as 'In the research findings ...' and so on. The paper really needs to be edited by a native (or fluent) English speaker.

We amended all the specified points as well as the whole abstract with the help of a native speaker of English.

Issue4: Another thing I would like to see in the revised article is some background on the Greek education system, specifically, why do primary school teachers really need to know all about Newton's third law. Is this something that is taught in primary schools? (- it is not in my country).

We replied to this remark in section 9 of the abstract.

Issue5: The article several times mentions the term 'coarse quantitative'. This is a term I have not come across before, what does it mean? (Quantitative is of course a standard term).

We adopted this term as introduced by diSessa and his colleagues (DiSessa, Gillespie, Esterly, 2004). In section 3, paragraph 1 we gave additional explanations.

Issue6: Also it would be interesting to know a little of the background of the student teachers. Did they study science at school? What is their attitude to science? Are they studying science in their teaching training under protest because it is something they do not like? Do they see it as important? (If they do have a poor attitude to science I could also question whether teaching about Newton's third law is the best way to improve this. Perhaps the authors could also spend some time justifying this.)

In Greek secondary education all students are taught science. For example, 15 year olds in the first year of their Lyceum studies are instructed about forces. Students in university Departments of Pedagogy are taught science subjects as well as Science Education.

Generally speaking, student teachers are not positively disposed towards the Natural Sciences. For this reason, the sample that we chose satisfied two requirements, one of which was that they wished to follow this teaching-learning sequence because they realized we had/provided a special learning environment. (see section 7, paragraph 1).

Thank you for your attention.

Yours sincerely

The authors

11.09.08