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*Editors*

# Iterative Design of Teaching-Learning Sequences

## Introducing the Science of Materials in European Schools

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# Contents

# The Evolutionary Refinement Process of a Teaching-Learning Sequence for Introducing Inquiry Aspects and Density as Materials' Property in Floating/Sinking Phenomena

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## 1 Introduction

Considering that TLSs have a discernible characteristic, which is their own gradual research-based evolutionary process (Lijnse 1995; Méheut and Psillos 2004), in this paper, we underline the development and the refinements from the first to the second implementation of an inquiry-oriented TLS focusing on the concept of *density* as a property of materials, in the frame of floating and sinking (F/S) phenomena. Pickering's (1995) theoretical framework and its subsequent adaptations (Kariotoglou et al. 2003; Patsadakis 2003) were used to analyze and describe the refinement process. Pickering's epistemological model includes three main factors affecting the refinement process: (1) the educational factor (e.g., curricula and educational tradition), (2) the material factor (e.g., experimental set-ups and laboratory classrooms) and (3) the scientific factor (e.g., teaching-learning theories such as constructivism and inquiry). From this analysis, we hope to reveal the content of these refinements, the main sources of data that indicated them and the role of each factor to the refinement process and finally to search if there are common characteristics of the refinements that are guided from the same factor.

Furthermore, a theoretical consideration about the dynamic that shapes the development of the TLS was developed. Specifically, there is a lengthy discussion in the science education community concerning the status that characterizes the evolutionary processes of TLSs (Lijnse 1995; Duit 1999; Méheut and Psillos 2004; Kariotoglou et al. 2003; Psillos et al. 2005; Fazio et al. 2008; Tiberghien et al. 2009). A number

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of researchers advocate that it is worth searching for evidence that indicates how and why a tested TLS is one of the best ways of teaching a topic and, as a result, to discuss the *didactical quality* of such a TLS (Lijnse and Klaassen 2004; Fazio et al. 2008). The *Didactical Structure* (Lijnse 1995; Lijnse and Klaassen 2004), the *Model of Educational Reconstruction* (Kattmann and Duit 1996; Duit 2007) and the *Didactical Rhobus* (Méheut and Psillos 2004) are three representative frameworks for elaborating and improving the design of a TLS. Despite the variations of these frameworks and the related interpretations, we could recognize their common focus on the research-based, evolutionary process of TLSs. In particular, these frameworks emphasize (1) the content to be taught (e.g., the elementary science concepts or appropriate teaching materials), (2) the research on learning and teaching (e.g., students' conceptions about physical phenomena and concepts or teaching-learning approaches) and (3) the development and evaluation of the TLSs implementations.

Furthermore, the analysis of designing a TLS extends towards the domain of research into scientific literacy, the crucial role of an educational system in which a TLS is embedded as well as towards the teachers who are disseminating the innovation of a TLS in school (Duit 2007; Besson et al. 2010). In particular, the curriculum, tradition of teaching methods, class organization, existing instructional materials and technical infrastructure are some of the educational system factors which affect the design of a TLS (Kariotoglou et al. 2003; Duit 2007). Essential factors for a TLS's introduction are regarded as (a) teachers' self-efficacy to implement a TLS (e.g., to feel that they enlarge their own knowledge about the topic to be taught) and (b) the close cooperation between teachers and researchers (Besson et al. 2010).

In line with the abovementioned consensus, the related research agenda tend to be oriented towards constructing theoretical backgrounds for designing TLSs (Kariotoglou et al. 2003; Psillos et al. 2004; Tiberghien et al. 2009). The intention of this research is to present theoretical contributions to the TLS design within the field of science education. We focus on an epistemological analysis which is based on Pickering's model (1995). This approach regards scientific practice as a "*changeable 'behavioural model' that unravels through the time*" (Kariotoglou et al. 2003). According to this statement, (1) TLSs are scientific products in the domain of science education and they have a changeable character; (2) a science educator researcher is the *science education* scientist who, through his/her practices, produces a TLS; (3) three factors (educational, material, scientific) constrain the various activities of a TLS development (resistance, accommodation, objective) and the connections between them. Science educators, in order to produce a TLS, accomplish their *objectives* and overcome the specific *resistances* implementing a process of *accommodation* (see Fig. 1).

The *educational* factor is associated with a particular school or classroom and refers to the everyday teaching-learning environments, the educational tradition of a school's district, its students' and teacher's characteristics (i.e., experience, inefficiency, difficulties etc.), the administration of a school and the parents of students. The *material* factor concerns the school's infrastructure, such as experimental setups, technological devices (e.g., PC), simple/everyday materials, laboratory classrooms (e.g., science or PC laboratories). The *scientific* factor is relevant to science education as a scientific activity and not to the traditional concept of science.

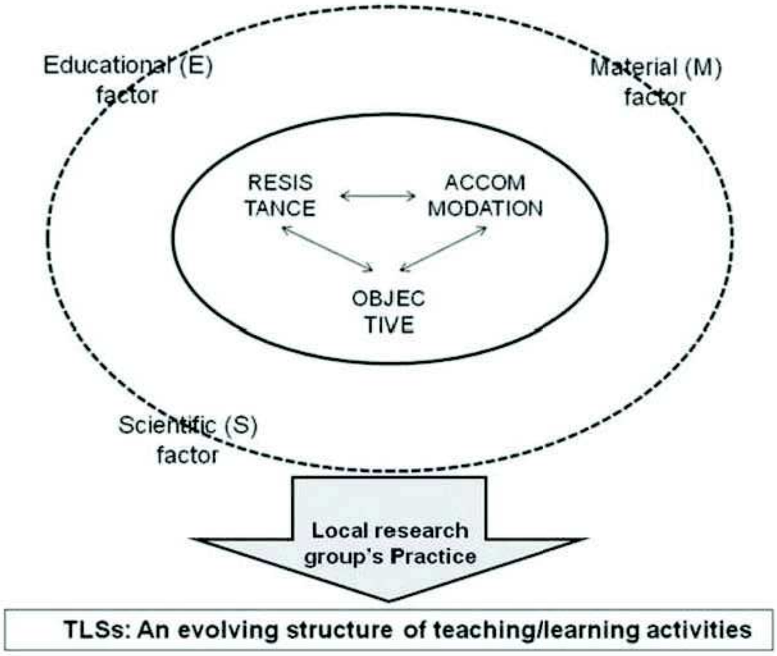



**Fig. 1** The dynamic that shapes scientific practice in the development of a TLS (Kariotoglou et al. 2003)

More specifically, it concerns the literature trends and the dominant teaching-learning theories (e.g., constructivism, inquiry), particular aspects of these theories, such as the negotiation of students' conceptions and the introduction of modeling. The *objectives* pertain to the teaching objectives and expected learning outcomes, such as the learning of a scientific content or a scientific method. *Resistances* concern the difficulties that are confronted in the implementation of the *objectives*, including limited conceptual, procedural and epistemological learning. *Accommodations*, concerning the refinements that aim to overcome the resistances, could include modifications in the knowledge to be taught, the teaching methodology, instructional materials, etc.

From the abovementioned discussion, we believe that *Pickering's model* analysis, on the one hand, specifies the difference between the two areas, namely, science educational research and the area of educational systems, and, on the other hand, links them in a three-pole process, namely, the *objective-resistance-accommodation* process.

## 1.1 Density, A Property for Interpreting F/S Phenomena

Researchers who have studied students' conceptions of density (Smith et al. 1992; Hardy et al. 2006; Wiser and Smith 2008) consider that the difficulty in learning the notion of density is rooted in the fact that students appear to have already developed an alternative conceptual framework about matter and material kind. This framework is composed of perception-based physical quantities in which the raw scientific notions of weight, volume and density coexist.

In parallel, from the abovementioned literature, it is ascertained that F/S phenomena are common among students and, thus, suitable for the teaching of density, especially in primary and junior high school grades. Indeed, students seem to have a strong visualization of these phenomena (Joung 2009), which they explain and describe in terms of perception-based macroscopic natural properties, for example, weight, length and volume (Smith et al. 1992; Kawasaki et al. 2004; Havu 2005). More specifically, students formulate their estimation concerning floating of solid objects in water by taking into account (1) the dimensions of tanks in which floating takes place, (2) the weight of the bodies, (3) the depth of water, (4) the existence of hollows and (5) the shape of the floating object (Fassoulopoulos et al. 2003). Furthermore, other researchers (Perkins and Grotzer 2005) note that students, when interpreting F/S phenomena, use causal linear reasoning, i.e., referring only to an object's property instead of causal relational reasoning, i.e., comparing object and liquid densities in their interpretations. According to Perkins and Grotzer (2005), the shift from linear to relational reasoning in interpreting such phenomena is essential.

According to the abovementioned, the difficulty that students experience in understanding density as a property of material kind is mostly qualitative and conceptual and not quantitative. That is why Smith et al. (1992), followed by other researchers (Kawasaki et al. 2004), introduced the notion of density qualitatively, instead of using the relevant mathematical ratio (mass per unit of volume). In this approach, students were encouraged to develop their own conceptual models in order to interpret F/S phenomena and were prompted to work with a series of conceptual computer simulations.

In summary, there are two important shifts in the conceptual framework of matter and material kind that are considered to be necessary in understanding density as a property of materials: (a) moving from perception-based understanding of physical quantities (weight, volume, density) to a more objective and differentiated set of concepts, grounded in measurement and interrelated in a theory of matter, and (b) moving from causal linear to causal relational reasoning when interpreting F/S phenomena.

### *1.2 Inquiry Orientations, Control of Variables Strategy and Models Perspective*

The realization of inquiry in science classrooms could be differentiated between "inquiry as means", that is, inquiry as an instructional approach or pedagogy, and "inquiry as ends", that is, inquiry as a set of instructional outcomes for students (Abd-El-Khalick et al. 2004). The first one, i.e., "inquiry as means", is recently referred to as Inquiry-Based Science Education (IBSE) in opposition to traditional deductive approaches (EU 2007) or under another perspective as full-inquiry or immersion units (Duschl and Grandy 2008). In both perspectives, learning should happen within a problem-based inquiry process, and inquiry is defined as debating with peers, planning investigations, searching for information, using and constructing models, forming coherent arguments, etc. "Inquiry as ends" is further differentiated into two sets of outcomes, being well documented, that students in grades 5–8 should develop: (1) abilities to do scientific inquiry and (2) understandings about scientific inquiry (Bybee 2006).

Fundamental understandings of scientific "inquiry as ends" in education, among others, are associated with the adoption of control of variables strategy (CVS) elements and the nature and role of models. More specifically, the CVS method (Boudreaux et al. 2008) is used to characterize whether or not a variable influences the behavior of a system. Procedurally, CVS is a method for (a) designing experiments and (b) implementing experiments (Kariotoglou 2002; Toth et al. 2000). Conceptually, CVS is based on the ability to evaluate an experiment as a *good* or *bad* one (well-controlled or not controlled experiment) as well as the ability to draw conclusions based on the evidence of *good* experiments (Toth et al. 2000; Boudreaux et al. 2008). According to literature, students basically experience the following difficulties with scientific reasoning related to CVS: (a) failure to distinguish between expectations and evidence, (b) reluctance to make inferences from data, (c) failure to control variables, (d) failure to realize that a variable must be changed to test for its influence, (e) failure to design experiments for the test of two focal variables (NRC 2000; Boudreaux et al. 2008).

Models, namely, representations of an object, a concept, a process or a phenomenon (Halloun 2004), are also considered as facilitators of conceptual understanding and achievement in school settings, because of their importance in the development of metaconceptual awareness, metacognitive skills and intentional learning (Vosniadou 2010). Learning, using, revising and constructing models are the most important acts of modeling that should be adopted in science classrooms (Justi and Gilbert 2002). Nevertheless, there is some evidence that difficulties in the instruction could arise from students' alternative ideas of models. For example, students that consider models as a precise representation (i.e., a replica) are constrained to understand the concept of scientific model (Treagust et al. 2002) as well as of abstract scientific concepts like density (Wiser and Smith 2008). Besides, it is known that students in primary school mainly hold a recreational view concerning the models (Gilbert 1991; Treagust et al. 2002). That is, students' interpretation of the term scientific model depends on their experiences and personal understandings. Consequently, researchers (Treagust, et al. 2002; Vosniadou 2010) argue that students, apart from acting with models, should develop understandings about their nature and role as well, i.e., that models, at all levels, are analog representations of reality and not their copies, that they serve as a tool and not as exemplar and, finally, that their main role is to explain and predict (Treagust et al. 2002). Furthermore, Petrosino (2003) argues that it is more fruitful to introduce students to modeling practices through models that preserve resemblance, because these models more readily sustain mappings between the model and the world. So, as students learn over a number of cases that resemblance is less fundamental than function, they become increasingly prepared to work with models that do not preserve similarity between the model and the modeled world.

To summarize, it should be noted that both "inquiry as means" and "inquiry as ends" should be important elements of inquiry in contemporary science classrooms. On the one hand, IBSE should be seen as a spectrum of approaches from open inquiry, in which students take the lead in acting and inquiring, to more structured inquiry, in which teachers determine the questions and specific procedures of the investigation (Crawford 2007). On the other hand, inquiry abilities and understandings to be acquired constitute another spectrum, elements of which are both CVS and models.

## 2 The Context of the Study

According to the Greek curriculum, it is proposed that the concept of density be introduced in the fifth grade (10–11 years old) of primary school, as a property of materials. This introduction comprises a limited number of examples including the sinking of a real ship. F/S phenomena are studied neither in the fifth nor in the sixth grade. More specifically, it is proposed that the negotiation of the phenomena/concepts be implemented through a guided discovery approach. In each lesson, students should be asked to implement the following learning approach: brainstorming, hypothesis, experiment, observation, verification or rejection of the hypothesis, drawing a conclusion and generalization. One of the aims referred to in the Greek curriculum is the understanding of this specific scientific method by students. However, the majority of teachers implement traditional deductive teaching-learning practices, followed by experiment demonstrations, while group experimental work is very rare. The innovation, whenever it exists, is confined to some environmental education programs, which are sporadic, and, although encouraged by the official curriculum, no means and motives are given for them to be undertaken. The aftermath of this educational tradition is the limited students' and teachers' experience concerning inquiry and modeling teaching-learning environments.

## 3 Design of the TLS

In this section, we will discuss the major TLS's design principles. An important one was the participative character of its development. A group of researchers and teachers was in charge of designing and developing the TLS. The design principles presented in the next paragraphs were mainly set by the researchers who designed and developed the TLS teaching scenarios. The teachers discussed with the researchers the nature of the TLS activities, their own understanding of the activities, the possible student difficulties that they could figure out, possible changes that they would propose and/or ways of implementing these activities. This process took place over a two-month period before and during the first implementation.

We consider this TLS to be a part of a larger sequence of TLSs, designed to bring about a restructuring of student frameworks for thinking about matter and material kind. This TLS focuses on the concept of *density*: (a) in a qualitative way, i.e., as a property of materials, instead of the quantitative approach of mathematical ratio, and (b) in the frame of F/S phenomena of several objects (both/either homogeneous and/or composite) in everyday life, e.g., that of a ship. Studying F/S phenomena revealed that the negotiation with the variables affecting these phenomena becomes an important teaching issue. Having in mind that students should be helped to understand the variables that influence the F/S phenomena, CVS is assumed to be an appropriate instructional tool to achieve it. Because of the limited students' inquiry experiences, it was decided that the CVS method should firstly be demonstrated by the teacher and afterwards applied by the students in a two-step and strictly guided way.

In addition, a technological-problem scenario was developed, which is based on the intention to salvage the *Sea Diamond* shipwreck. This shipwreck received wide media coverage in April 2007 in Greece. We assume that this scenario is an authentic context in which technological and scientific issues coexist. Furthermore, this real technological problem is the vehicle to design trans-disciplinary activities trying to create the path from technological to scientific inquiries and vice versa, aiming at the interweaving of scientific and technological knowledge. We assumed that the use of authentic contexts in which technological and scientific issues coexist would enhance elementary students' interest in science learning. We based this belief on literature, arguing that the integration of technology with science teaching-learning (1) promotes active learning, (2) helps to improve academic performance and students' attitudes towards science and (3) reinforces positive interaction between teachers and students, providing the latter with opportunities to engage in authentic inquiry processes that scientists actually carry out (Waight and Abd-El-Khalick 2007; Benett et al. 2007). The hope is that the technological contexts will motivate students and make them feel more positive about science by helping them see that *science is everywhere*.

Adopting the IBSE approach, the aim was to give students the opportunity to (a) work in groups realizing real and simulated F/S experiments in order to interpret them or to find solutions to technological problems such as the salvaging of a ship, (b) use and understand CVS reasoning, (c) search for information about the properties of new materials, (d) learn and use a visual model of density in order to develop causal relational reasoning in interpreting F/S phenomena, (e) communicate their understandings in their group and in class. In order to enhance the abovementioned approach, we designed and developed, from scratch, a software (Spyrtou et al. 2008) having at least the following features: (a) playful character with profound interactive elements; (b) semi-open approach, which allows experimenting in a controlled environment; and (c) separation in *rooms*, which will follow the development of teaching.

*CVS* and *nature and role of models* elements were the inquiry abilities and understandings that students were expected to acquire (for details, see Sect. 4). Our primary assumption was that by involving students in a discussion about these two main epistemological aspects of scientific inquiry, they could really enhance their own understanding about them.

## 4 Development of the TLS

The TLS consists of five units, each of which lasts for 80 min. Hereafter, we will describe the units of the first implementation (Table 1). In the first unit, the students are introduced to the technological problem of the salvage of the *Sea Diamond*'s shipwreck through a video which includes a description of the accident and a discussion about its environmental consequences. Furthermore, the students are familiarized with F/S phenomena through several activities such as real experiments working in a predict-observe-explore (POE) approach. Following on, students discuss and try to predict, under the teacher's guidance, the variables that possibly affect F/S. In the end, the teacher enounces the scientific method used in order to test if a variable affects a phenomenon, that is, CVS method. The teacher, following the steps of the method, tests if the shape of an object could affect the F/S of the object.

In the second unit, the students, working in groups, follow the POE approach in a simulated environment, testing several variables according to structured worksheets. These are guiding students in an inquiry procedure, using CVS method by following three steps: (a) to keep constant all the other variables except for tested variable, (b) to experiment at least twice in order to compare the results and (c) to

**Table 1** The content in each unit of the TLS, in the first implementation

| Unit | Content |
|---|---|
| First | The shape of an object does not affect its F/S in water |
| | The crucial steps of the CVS method |
| Second | The variables that affect F/S of an object are both the kind of material of the object and the kind of liquid |
| | The weight of an object or the width of a tank does not affect its F/S in a tank |
| | The crucial steps of the CVS method |
| Third | Object-water *dots-per-cube criterion* for F/S |
| Fourth | Density can be represented by *dot crowdedness* model for each homogeneous material |
| | Density of a composite object lies between the densities of the two materials |
| | Object-liquid *density's criterion* for F/S |
| | Study of natural and artificial materials' properties |
| | Basic features of the nature and role of models |
| Fifth | *Density's criterion* used as a predicting tool in a series of technological F/S situations |


**Fig. 2** The visual *dot crowdedness* model of several materials

draw a conclusion according to the observations. In these inquiries, the focal variable and the method that students should apply are given, in the sense that their observations are guided. In addition, they communicate their groups' conclusions in the class.

In the third unit, the students are introduced to a precursor visual model of density as a property of materials, the *dot crowdedness* model (Smith et al. 1992, Fig. 2). Firstly, the students are called to propose their ideas about how to represent the *heavier-lighter* relation between three cubes of the same volume but of different material. After this discussion, the teacher proposes the *dot crowdedness* model as another possible representation for the *heavier-lighter* relation. As a next step, they are called to predict the F/S of several objects in several liquids. Our aim is to lead students to realize the necessity for a criterion in order to confront the difficulty of predicting the result of the phenomenon. Using simulated environments, students are expected to acquire a causal relational reasoning (Perkins and Grotzer 2005) in order to explain and predict F/S phenomena for homogenous objects. More specifically, students are expected to acquire and use the object-water *dots-per-cube criterion*, that is, *if dots-per-cube of an object are fewer than the same-size dots-per-cube of water, then the object will float in the water* and *if dots-per-cube of an object are more than the same-size dots-per-cube of water, then the object will sink in the water*.

In the fourth unit, instead of the concept *dots-per-cube* of a material, the concept *density* of a material is also introduced. As a consequence, students conclude the object-water *density's criterion*: *if an object's density is smaller than water's density, then the object will float in the water* and *if an object's density is greater than water's density, then the object will sink in the water*. They are also prompted to work in groups in order to generalize the object-liquid *density's criterion* for F/S (see Sect. 7.4.2). Furthermore, students are negotiating situations of F/S of two-material composite objects, for instance, a bottle filled with air or a bottle filled with water. Our aim is for the students to understand that the density of a composite object, which consists of two materials, lies between the densities of the two materials. Hence, they are supposed to extend the use of the *density's criterion* to composite objects as well, and so come closer to the technological world, in order to confront authentic technological problems in the next unit. In addition, students collect information about several natural and artificial materials and discuss their density as well as their use and the possible environmental problems they create. Finally, they are introduced to the concept of *model* and its features through a discussion about the models of ships and the models of density that they already used during the previous units. Furthermore, they negotiate about the features of two heliocentric models, a picture and a concrete model, that a teacher has brought into the class. During this discussion, the focus is on basic features of the nature of models, such as (a) a model is a representation of a target; (b) a model is not a copy of a target; (c) a target could be represented by more than one model; (d) the role or purpose of a model is to describe, explain or predict a phenomenon; and (e) a model is not a recreational or instructional medium (Treagust et al. 2002; Gilbert 1991).

In the fifth unit, students have the opportunity to work in groups in a simulated environment and investigate the F/S of the *Sea Diamond* cruise ship, in order to argue about its salvage. Students are also confronting the technological problem of salvaging, in a real setting, a model of a clay statue and an iron ship model which are both immersed in tanks filled with water. Students are negotiating these problems in a technological frame, that is, they are prompted to take into account features such as the possible risks and costs of the enterprise.

## 5 Implementations of the TLS

The first implementation was conducted during November and December 2007 in a primary school of Florina, Greece, with 12 fifth grade students (10–11 years old). The primary teacher of the first implementation holds a master's degree in ICT in education and has 9 years of teaching experience, the last 2 of which were exclusively dedicated to teaching science to fifth and sixth grade students. After the refinement process, a second implementation was conducted, during March and April 2008, by another teacher in another Florina primary school, with 41 fifth grade students (two classes). This teacher had 23 years of teaching experience including 8 years as a science mentor to pre-service students in the Department of Primary School Education of Florina.

The first implementation took place during normal daily courses. We reduced the number of students for technical reasons, because it was difficult to videotape the implementation due to the small size of the class. The second implementation took place during normal daily courses, but in this case, the classroom was large enough so the whole class could be videotaped.

Furthermore, because of its innovative nature, permission to videotape the intervention was requested from all educational authorities (consultants, headmasters, teachers, parents and students).

## 6 Research Methodology

The main concern of this paper is related to the disclosure and the classification of the TLS refinements from the first to the second implementation. The participants who were involved in this process were (a) the students, (b) the teachers, (c) the four science education researchers of the local group (researchers) and (d) the expert panel of the project (experts).

So, the research questions of this endeavor are the following:

1. Which were the refinements that took place between the first and second implementation of the TLS and to which content do they relate?
2. Which were the main sources of data that contributed to the refinement procedure?
3. Which of the three factors of Pickering's model guided the local research group to proceed to these refinements?
4. Are there common characteristics among the refinements that are guided from the same Pickering factor?

In order to answer the aforementioned research questions, we elaborated the following first implementation's sources of data: (a) researchers' classroom notes (researchers' notes), (b) experts' and teachers' suggestions, (c) students' worksheets, pre- and post-questionnaires (given to the students one week before and one week after the intervention of the TLS, respectively), video recordings.

TLS's refinement process began just after the completion of the first implementation. This process took place during several meetings of the local research group. Each of the participants, though, contributed in a different way and to varying degrees. The researchers, for example, had the main responsibility for the design and redesign of the teaching scenarios taking into account teachers' suggestions. In addition, they followed the implementation of each unit taking notes about the difficulties that either students or teachers had during the lessons. The experts contributed as distant consultants based on the teaching scenarios and the descriptions of the difficulties given by the researchers. The teacher's role, during both the development and the refinement of the teaching scenarios, was mainly advisory, and their suggestions were mainly focused on the difficulties they or the students confronted during the first implementation, making suggestions to overcome them. In addition, in order to establish the significance of researchers' notes or teachers' suggestions, these were crosschecked and associated with specific parts of the students' worksheets, pre- and post-questionnaires or/and teaching video recordings. Therefore, we consider researchers' notes as well as experts' and teachers' suggestions as the primary data sources in the refinement process, while students' worksheets, pre- and post-questionnaires and teaching videos were taken as secondary data sources. The analysis of all these data was performed by the researchers. Nevertheless, each refinement came of through a consensus among all the members of the local research group.

After the second implementation of the TLS, the local research group identified these refinements comparing the two TLSs (first and second implementations). We analyzed each of the refinements following *Pickering's model* (see the Introduction). In our case, there is a TLS innovation which has several *objectives*. The analysis of the abovementioned data provided the *resistances* that influenced and directed the researchers towards specific *accommodations*. Having in mind that Pickering's model interprets scientific production in general, we consider that in our case, it can be used to interpret the evolutionary design and development of a TLS and, more specifically, the process of its refinement, in the sense of a cyclical process of recon-

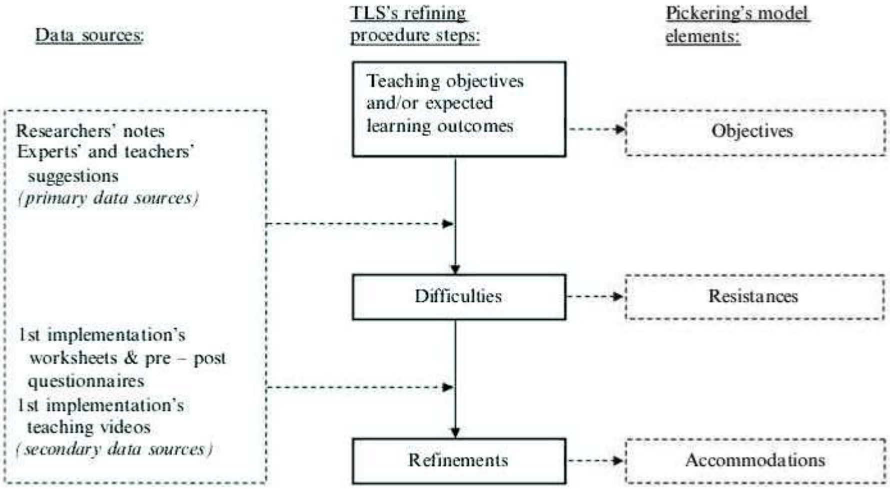



**Fig. 3** TLS's refining process flow chart from the first to the second implementation

sideration. We consider that our refinements correspond to Pickering's *accommodations*. In addition, we consider that the difficulties each participant of this project confronted correspond to Pickering's *resistances*. Finally, teaching objectives and expected learning outcomes correspond to Pickering's *objectives*. The abovementioned analysis following Pickering's model was performed by two members of the local research group independently, reaching 80 % consensus initially. However, all disagreements were solved after discussion between the researchers.

The TLS's refining process in relation to the elements of Pickering's model is illustrated in Fig. 3.

The presentation of the results, i.e., the refinements, follows the respective content of the TLS, that is, (a) reasoning concerning F/S phenomena and (b) density as a property of materials, which are considered as declarative knowledge, (c) CVS method and (d) the nature and role of models as well as model use, which are considered as both procedural and epistemological knowledge.

## 7 Results

In total, fifteen refinements of the TLS took place following the *objective, resistance, accommodation* structure (see Tables 3, 5 and 6). In addition, each refinement was associated (a) to the Pickering factor(s) that mainly guided this accommodation and (b) to the data sources, both primary and secondary, that influenced them. Due to lack of space, only representative refinements of each category will be analytically described. Throughout this evolutionary process, one, two or even all three factors (educational, scientific or material) could be involved, having though different degrees of influence. We consider that the main factor that guides a refinement is (a) the educational factor if the origins of the refinement are teachers' experience or/and students' difficulties, (b) the scientific factor if the roots or the origins of the refinement are literature trends or/and dominant teaching-learning theories and (c) the material factor if the root or the origin of the refinement is, for example, school infrastructure.

## 7.1 *Reasoning Concerning F/S Phenomena*

Two refinements have been made concerning F/S: (a) a connection between real and simulated experiment interpretations and (b) a reduction in the time devoted to the familiarization phase. The first refinement is described analytically in the following section, while the second is presented in Table 3.

### 7.1.1 F/S, Connection between Real and Simulated Experiments Interpretations

*Objective* One of the intended goals of the TLS is the use of the concept of density in the explanations given by students about the F/S phenomena in a relational way, i.e., by comparing the density of the object with the density of the liquid (Perkins and Grotzer 2005). A moderate expected learning outcome could be the reference to the material of the object (Smith et al. 1992).

*Resistance* The resistance was initially triggered by the experts' suggestion of a better balance between the real and the simulated experiments concerning the negotiation of the F/S phenomena of the TLS because of the students' young age. It was considered difficult for the students to grasp the relation and analogy between simulations and real situations. This difficulty was established by the results produced from pre- and post-questionnaires of the first implementation, concerning the explanations given by students when asked about F/S phenomena. There are questionnaire tasks which negotiate everyday environment situations (e.g., task A, "A ball made of plasticine is sunk in a tank of water. Could you make it float? How?"), as well as simulated situations (e.g., task B, giving them the opportunity to use the *dot crowdedness* model in order to decide if an object will float or sink). Based on the results of these two indicative tasks and especially the post ones (Table 2), we argue that the students give answers closer to the expected learning outcome when they confront simulated rather than real situations.

The comparison of the abovementioned results permits us to assume that the students find it difficult to apply to real phenomena what they have learned in a simulated environment. We thought that one way to overcome this difficulty could have been to increase the comparatively smaller amount of real, in relation to the simulated, experiments being processed.

**Table 2** Categories of student's explanations of F/S phenomena

| | Real experiments – Task A | | Simulated experiments – Task B | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| Compare the density of the object to the density of the liquid or refer to the material of the object | 1[a] | 3 | – | 10 |
| Refer to the weight of the object or teleological answers | 11 | 9 | – | 2 |

[a]Number of students expressing the particular explanation

*Accommodation* Due to the abovementioned reasons, we proceeded to the following changes: (a) the number of the real experiments was increased from eight to ten, and the simulated ones were reduced from 16 to 15; (b) three of the activities that, in the first implementation, were performed by the teacher, in the second implementation, were performed by groups of students; and (c) students were prompted to associate their explanations given in simulated experiments with those given in the real ones. The latter aimed to increase students' active participation in real experiments, in expectation of a consequent enhancement of their explanations of F/S phenomena in real situations. Although this accommodation was initiated by the experts, it was considered that the educational factor has mainly guided this refinement, as the main issue was students' difficulties and how to overcome them. On the other hand, in a secondary manner, the refinement was considered to also have been guided by the scientific factor, because the teaching method was changed from demonstration to group work, following science education literature trends.

## 7.2 *Density*

### 7.2.1 Density, Emphasis given to the Distinction between Homogeneous and Composite Objects

*Objective* Another intended goal of the TLS is for students to use the visual model of density in order to explain and predict F/S phenomena of both homogeneous and composite objects. More specifically, the students initially are called to negotiate the F/S of homogeneous objects, like cubes or spheres made of one material, for example, wood or plastic, using the *dots crowdedness* model and the object-liquid densities comparison criterion. Next, they are called to apply the same criterion to composite objects like a bottle made of glass or an iron-made model of a ship filled with air or water.

*Resistance* It appeared, according to the researcher's notes, that in order to understand the concept of density of an object, the students should make clear the distinction between the concepts of homogeneous and composite objects (because of their age, we only used two composite parts). During the first implementation, this discussion took place at the end of the TLS and specifically at the beginning of the fifth unit (Table 1). The resistance occurred because most of the students could use the *dot crowdedness* model in a causal relational reasoning in order to predict and explain the F/S of homogeneous objects, but they found it difficult to do the same for composite objects, e.g., an iron model ship filled with air or water, even though the teachers prompted them to do so. The following excerpt from classroom video recordings is indicative:

*Student A: (tries to use density in order to explain the iron ship floating). This ship is made of… it has air inside and the air has less density than the iron and the water… the ship has air inside and the air holds the iron up.*
*Student B: because air floats on water and that's why the ship floats.*
*Teacher: Yes, the ship is made of iron and has air inside.*
*Student C: It is like a life-jacket.*
*Student D: Buoyancy is created. Because this has air inside, like student C correctly said, it is like a life-jacket, and because it has air inside it floats…*

So, the students' explanations turned into causal linear reasoning instead of the causal relational, with the main variable influencing F/S being the existence of air in the object.

**Table 3** Pickering's model concerning F/S and density refinements

| Objective | Resistance | Accommodation | Factor | Data sources |
|---|---|---|---|---|
| 7.1.1. Explaining and predicting F/S phenomena for homogeneous objects | Less efficiency in interpreting real than simulated experiments | Connection between real and simulated experiments interpretations | E, S[a] | Experts' suggestions |
| | | From demonstration to group experiments | | Pre – and post-questionnaires (analyzed by the researchers) |
| 7.1.2. Familiarization with F/S phenomena | Much time was devoted to this objective | Reduction of the time devoted to the students' familiarization activities, in favor of the introduction of aspects of the nature and role of models | E | Teachers suggestions |
| | | | | Students' worksheets |
| 7.2.1. Explaining and predicting F/S phenomena for composite objects using the dot crowdedness model | Limited knowledge in using density of composite materials in F/S | Emphasis given to the distinction between homogeneous and composite objects | E | Researchers' notes |
| | | Immediate approach to the visual dot crowdedness model during the relevant discussions | | Videotaped lessons |

[a]*E* Educational, *M* Material, *S* Scientific

*Accommodation* In the second implementation, the discussions that aimed at the use of the visual model of density for the explanation of the F/S phenomena of homogeneous and composite objects were presented as follows: (a) the concept of homogeneous objects was introduced and discussed during the first unit, and the concept of the composite objects, during the fourth unit and (b) the students were prompted to use the *dot crowdedness* model in their explanations of composite objects' F/S phenomena during the fourth and fifth units.

Consequently, it was considered that the educational factor has mainly guided this refinement since it occurred due to student difficulties.

## 7.3 *Inquiry Skills – Control of Variables Strategy (CVS)*

Six refinements have been recognized concerning inquiry skills, with five of them being relevant to the CVS: (a) from demo and guided to more open inquiry approach, (b) emphasis on drawing a conclusion procedure, (c) changes in the order of the focal variables, (d) two tests instead of three and (e) changes in teaching materials used to reveal variables of F/S phenomena, while the sixth refinement concerns searching for information in texts: (f) changes in visual material. The first three refinements are discussed in detail in the following sections, while the rest are presented in Table 5.

### 7.3.1 CVS, From Demo and Guided, to More Open Inquiry Approach

*Objective* This refinement refers to the degree of guidance, hence the teaching method, according to which the students tested the variables that probably affect the F/S of an object in a liquid (see Sect. 4, development of the TLS, units 1 and 2). We thought that students needed this significant guidance to apply the method because they are not familiar with similar inquiries. We also assumed that the students would acquire the method, just using it in F/S phenomena, in the way described in Sect. 4.

*Resistance* The experts made the provocative suggestion of turning to an open instead of guided inquiry approach. In parallel, it was clear that the students confronted difficulties in acquiring the method (see Sect. 7.3.2). However, guided by the inquiry paradigm and following expert suggestion, we insisted on the acquisition of the reasoning of the CVS method adopting a more open inquiry approach.

*Accommodation* As a result, in the second implementation, the method aimed at the gradual increase of students' active participation, i.e., the gradual increase of the degree of *openness* of the inquiry procedure. At first, the teacher demonstrated the CVS method, and particularly, she tested the variable *weight* of the object. Next, the students tested the variable *width* of the tank, in groups, by using structured worksheets, in which the appropriate method is clearly given. Then they tested the variable *kind* of the liquid, for which they were asked to design the experiment they were to carry out. Finally, in the last level of inquiry *openness*, the students were asked to design and implement an experiment or experiments in order to test two variables: *kind* of the object's material and *shape* of the object, without any other guidance.

The determining factor that led the research group to a more open inquiry approach was expert suggestions. Despite the students' difficulties in acquiring CVS method, which should lead to a more guided approach, this decision was obviously affected by inquiry literature trends. Consequently, it was assumed that it was mainly the scientific factor that guided this refinement.

### 7.3.2 CVS, Emphasis on the Drawing a Conclusion Procedure

*Objective* A main element of the CVS is drawing a conclusion procedure. In the first implementation, it was expected that the students would acquire this procedure just by participating in guided experimental activities.

*Resistance* Nevertheless, there was evidence which emerged from different data collection tools that highlighted the fact that the students experienced difficulty in understanding the rationale of the method. The first clue comes from the researchers' notes during the third unit: "at the beginning of the lesson the teacher poses a review question about which variables eventually affect the F/S of an object. The students at first mention all the variables that they had tested in the first two lessons and answer that all these variables affect the F/S phenomena." The observation is enforced by videotaped transcriptions analysis.

Moreover, results from the pre- and post-questionnaires (Table 4) showed that the students had great difficulty in understanding the drawing a conclusion procedure and especially the importance of evidence in this procedure.

*Accommodation* As a result, we decided to teach the drawing a conclusion procedure in an explicit way, following the suggestions of the relevant literature, which indicates that the importance of the extra teaching on this part of scientific reasoning is still an open field for further investigation (Boudreaux et al. 2008; Toth et al. 2000). Hence, a representation (Fig. 4) of the drawing a conclusion procedure, like the rationale *If... then..., while if... then....*, was explicitly presented to the students.

**Table 4** Students' understanding of the drawing a conclusion procedure

| | Pre | Post |
|---|---|---|
| Correct description of CVS | 0 | 0 |
| Partially correct description of CVS | 1 | 2 |
| Expression of the inference instead of the CVS | 7 | 9 |
| Incoherence of description | 4 | 1 |

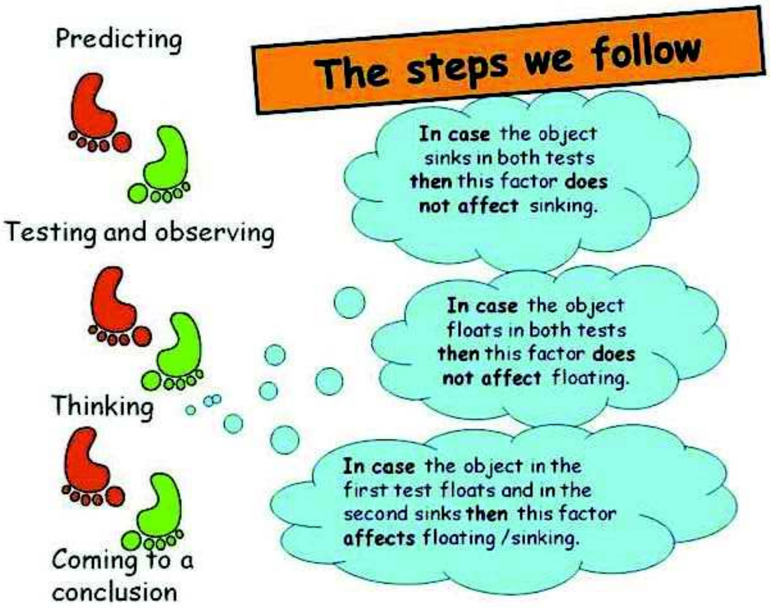



**Fig. 4** A representation of the drawing a conclusion procedure, emphasizing "thinking" step

Moreover, the teacher was guided by the research group to give more time to the students to participate in the relevant discussions and thus to present and argue their opinions on the CVS method, and especially on the drawing a conclusion procedure, so that they could finally "identify the difference between what they know (because someone told them) and what they understand" (Boudreaux et al. 2008).

The *accommodation* was considered to be guided by the educational factor because the refinement's aim was to help students overcome their aforementioned difficulties.

### 7.3.3 CVS, Changes in the Order of the Focal Variables

*Objective* In this case, the objective is the same as the previous one. In the first implementation, the variables that possibly affect F/S were tested in the following order: object's shape, object's weight, narrow/wide tank, object's material, kind of liquid.

*Resistance* According to the researchers' notes, the students found it difficult to understand that differently shaped objects which are made of the same material can have the same weight. The following excerpt from classroom video recordings is indicative:

*Teacher: What will be different?*
*Student A: The shape and weight.*
*Teacher: The weight. Why?*
*Student A: Not the weight.*
*Student B: and the material.*
*Student A: The material is the same.*
*Teacher: The material is the same. The shape though, won't it surely be different?*
*Students: Yes.*

Moreover, even though this activity aimed at testing whether the shape of the object affects the F/S, some students claimed that we could draw a conclusion about the object's weight effect on the phenomenon. We think that this difficulty emerged for two reasons: (a) the explanation that weight is responsible for the F/S of an object is one of the most common and powerful alternative ideas of the students (Fassoulopoulos et al. 2003), and (b) when we test whether an object's shape affects its F/S, keeping its volume constant, dependent variables come into the picture (weight, mass, density), which in this age range are usually undifferentiated (Wiser and Smith 2008). In such cases, even older students find it extremely hard to implement the CVS method (Boudreaux et al. 2008).

*Accommodation* For the above reasons, the order in which we test the variables has been changed. The first variable that was set to be tested is the weight of the object through an experimental demonstration by the teacher. The next two variables (tank's width, kind of liquid), which are tested by the students, are independent of the other possible variables that relate to the phenomenon. Finally, the students have to test two variables (object's material, object's shape).

We assume that in this way, it is easier to understand not only the method's steps (Fig. 4) but also the importance of observation in drawing a conclusion; in other words, to understand the underlying rationale of the method. In short, we propose that when CVS method is introduced to the students, the first variables that the students themselves will test should be independent variables.

The didactical transformation in the framework of this refinement was made in order to help students acquire CVS method and its application as well as the variables that affect F/S, overcoming the aforementioned difficulties. Thus, it was considered that the *accommodation* here was mainly guided by the educational factor.

## 7.4 Models and Modeling

Six refinements have been recognized concerning models and modeling: (a) the gradual introduction of models, (b) changes in the activity for the generalization of the rule for predicting F/S, (c) emphasis on the same size of the cubes, (d) change in the air cube, (e) change in the way of approaching the technological modeling and (f) emphasis on the difference between a target and its model. The first two refinements are described analytically, while the rest are presented in Table 6.

**Table 5** Pickering's model concerning inquiry skills and CVS refinements

| Objective | Resistance | Accommodation | Factor | Data sources |
|---|---|---|---|---|
| 7.3.1. Learning elements of CVS | Limited learning of the CVS method | From demo (1 variable (var.)) and guided teaching and learning approach (2 var.) to more open inquiry (2 var.) (gradually) | S[a] | Experts' suggestions<br>Videotaped lessons |
| 7.3.2. Describing the way that we draw a conclusion in the frame of CVS | Students could not describe clearly the way that they proceeded to a conclusion | Explicit emphasis on the drawing a conclusion procedure, with discussion aiming at recognizing the role of evidence | E | Researchers' notes |
| | | Changes in the teaching model that we use for the introduction of the CVS | | Videotaped lessons<br>Pre- and post-questionnaires |
| 7.3.3. Describing the way to test a variable using CVS | Students have difficulties in describing the CVS steps when the focal variable is dependent on others | Change in the order of the focal variables that possibly affect F/S phenomena | E | Researchers' notes<br>Videotaped lessons |
| 7.3.4. Describing the way to test a variable using CVS | Students considered six tests needed for the test of each variable instead of two as minimum | Reduction of the number of tests from three to two (the minimum required) | E | Researchers' notes |
| | | Explicit separation of the two phenomena (F/S) | | Videotaped lessons |
| 7.3.5. Distinguishing possible logical variables that could affect the F/S phenomenon | Students have difficulties in the distinction between possible logical variables that could affect the F/S phenomenon | Changes in teaching materials of the tasks that aim at the revelation and distinction of the variables that possibly affect F/S phenomena | E | Researchers' notes<br>Teacher's suggestions<br>Videotaped lessons |
| 7.3.6. Searching for and writing down information | Students did not know where to focus during searching for information | Given topics to search for, e.g., environmental consequences | E | Researchers' notes |
| | | From pdf file to simulated Internet website | | |

[a]*E* Educational, *M* Material, *S* Scientific

**Table 6** Pickering's model concerning models and modeling refinements

| Objective | Resistance | Accommodation | Factor | Data sources |
|---|---|---|---|---|
| 7.4.1. Learn aspects of nature and the role of models | Limited learning of this content | From a mere model-centered approach to a model-centered approach that emphasizes aspects of the nature and the role of models | E, S[a] | Researchers' notes |
| | | Gradual introduction of models from concrete to more abstract, with discussion aiming at metaconceptual awareness | | Pre- and post-questionnaires |
| 7.4.2. Generalize the rule for predicting F/S phenomena | Limited understanding of the role of the same volume of the cube in the *dots-per-cube* visual model of density and the distance between models and reality | The *dots-per-cube* models were replaced by real-looking objects, of different volume and shape | E | Researchers' notes and teachers' suggestions |
| | | | | Students' Worksheets |
| 7.4.3. Learn the dot crowdedness model, learn aspects of modeling | Difficulty in comprehending what it means to construct a model that would describe the *heavier-lighter* material relation | Emphasize the fact that although the cubes are of the same size/volume they do not have the same weight | E | Researchers' notes |
| 7.4.4. Acquire the concept of density as a property of materials | It strengthened students' idea that air is weightless | The cube of air makes a difference when it is put on the one side of the balance, to indicate the fact that even air has weight | E | Researchers' notes |
| Construct the object-water *dots-per-cube* rule for predicting F/S phenomena | | | | Videotaped lessons |
| 7.4.5. Solve a technological problem (salvage of a sunken object) using the object-water *dots-per-cube* rule | Students look for the correct solution | Broadening of the concept of correct technological solution under prerequisites (e.g., risk, cost, etc.) | E | Researchers' notes |
| 7.4.6. Pass from the technological to the scientific world | Difficulties in abstracting from concrete situation | Change in the worksheets emphasizing the difference between a target and its model in an F/S phenomenon | E | Researchers' notes |
| | | | | Students' worksheets |

[a]*E* Educational, *M* Material, *S* Scientific

### 7.4.1 Models, Gradual Introduction of Models

*Objective* One of the TLS's aims is for the students to understand aspects of the nature and the role of models, using real and simulated environments (see Sect. 4).

*Resistance* According to the researchers' notes and the results from the pre- and post-questionnaires of the first implementation, only 25 % of the students could write a sentence with the word "model" showing that they understand model as a representation and not as a reality (see task 3, Fig. 6).

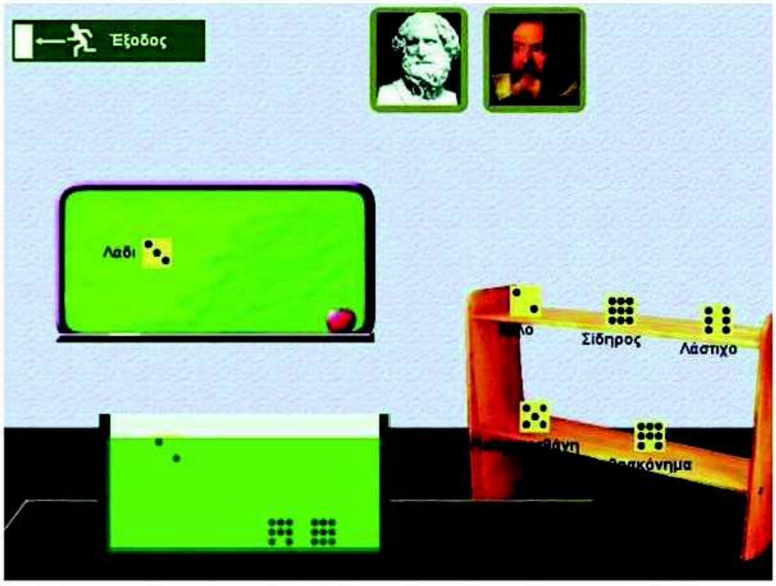
*Accommodation* In the second implementation, the students used enough of the total given time to discuss the nature and role of models. In addition, there was a gradual introduction to elements of the nature of models. So, in the first unit, the students discussed the nature and role of an object's models (ship models), which are more easily acceptable to students of this age. Next, in the third unit, they discussed the characteristics of the visual models of density, while in the fourth unit, they discussed the causal models that the students presented to explain and/or predict F/S phenomena. In the last unit of the implementation, students carried out discussions about the models that they worked with in the five units, aiming at students' metaconceptual awareness. As shown above, there was a shift to a model-centered approach that focuses on aspects of the nature and role of models (Treagust et al. 2002) – an approach in which the students do not only use models but also talk about them. What is more is that the introduction to models is gradual: from material models to more abstract ones.

We argue that this accommodation was guided mainly by the educational factor because it came up as a response to students' difficulties and, secondarily, by the scientific factor because it was influenced by the scientific literacy demand, which is an element of the inquiry paradigm.

### 7.4.2 Models, Changes in the Activity for the Generalization of the Rule for Predicting F/S

*Objective* One of the TLS's aims is the generalization of the object-water *density* criterion (see Sect. 4) to a rule that could cover all liquids. For the achievement of this aim, in the first implementation, the students work in a simulated environment (Fig. 5, Screenshot 1), in which there are *dots-per-cube* models of several materials and a tank with oil. They are asked to propose a way to check if the criterion with which they ended up for the case of water can be applied to other liquids, such as oil.

*Resistance* According to the researchers' observations, the students found it difficult to propose a way to check the application of the object-water *density* criterion to more liquids. The students just realized all the possible trials they could do, without having any specific strategy in their minds. For example, in the worksheets, one of the groups proposes: "The iron sinks in oil, the carbon fiber sinks in oil, the glycerin sinks in oil, the rubber sinks in oil, the polyurethane sinks in oil, the wood doesn't sink".




Screenshot 1


Screenshot 2

**Fig. 5** Change in the simulated environment

*Accommodation* The abovementioned observations guided us to make several changes in the software, for the second implementation (Fig. 5, Screenshot 2). At first, we replaced the *dots-per-cube* models with more real-looking objects of different volume and shape. For the sake of symmetry, we used glycerin instead of oil, since of the five materials given, only wood floated on oil, while in glycerin, two of them sank and the rest floated. Moreover, apart from the liquid's *dots-per-cube* model on the blackboard (Screenshot 1), students could see and use the five objects' material *dots-per-cube* models as well (Screenshot 2). We thought that these changes would make it easier for the students to understand, on the one hand, the fixed volume of all cubes and, on the other hand, the difference between the world of models (e.g., *dots-per-cube* models on the blackboard) and the world of experiences (e.g., real-looking objects on the shelf).

We argue that the *accommodation* in this case was guided mainly by the educational factor in order to eliminate students' difficulties.

## 7.5 Indicative Learning Results From the First and the Second Implementations

In order to answer the question concerning whether the refinements were effective, some indicative learning results will be presented. Specifically, the results are from four individual tasks, each one concerning one of the four different content areas of the TLS. The tasks concerning density, models and F/S are included in the written questionnaire, while the task concerning CVS elements understanding is from an interview questionnaire because it was considered to be too difficult a subject for assessment by written questions.

Task 1, which concerns F/S reasoning, was asking the students the change they would make to the system of a ball made of plasticine, being sunk in a tank with water, so that the ball would float on the water. Reference to the comparison of materials' densities or to the material is considered to be the expected learning outcome. In the first implementation, 25 % of the students acquired the expected level of knowledge, while in the second implementation, this increased to 66 % of the students (see Fig. 6). Task 2, which concerns understanding of density as materials' property, was asking students to write a sentence including the words density and material. In this case, the increase was from 41 to 63 % of the students. Task 3, which concerns understanding of models as representations of a target, asked students to write a sentence with the word "model." In this task, there is also an increase from 25 to 56 % of the students. Task 4, which concerns understanding of the draw a conclusion procedure of the CVS, asked students to describe the way that they would come to a conclusion after they had described and hypothetically tested if the shape of an object influences its floating or sinking in a liquid. The students that could adequately describe the procedure of drawing a conclusion also increased in this case from 33 to 64 %. In general, there is an increase in the students who acquired the content which has been taught in the second implementation in comparison to that of the first implementation of TLS.

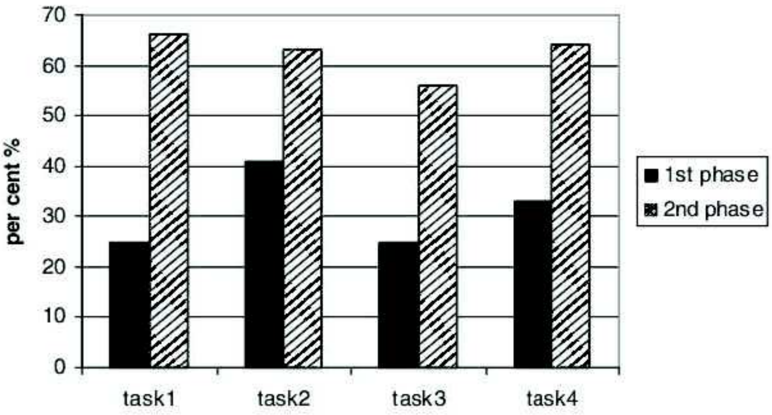



**Fig. 6** First and second implementation post results in tasks 1, 2, 3 and 4

Apart from the learning outcomes' results, which indicate the efficiency of the refinements of the TLS, the researchers' notes during the second implementation can also be utilized to enhance this efficiency. According to the researchers' notes, the resistances that appeared during the first implementation were significantly less intense in the second implementation. For example, it is recorded that the discussions in the second implementation that were aiming at the distinction between the concepts of homogeneous and composite objects have helped the students to realize more easily the tasks concerning F/S phenomena of composite objects, i.e., the F/S of a bottle or a ship filled with air or water. Furthermore, both teachers and researchers certify that the students acquired and applied the CVS method more easily due to the gradual degree of *openness* of the inquiry approach. Another example of the success of a refinement is that in the second implementation, the students easily accepted the fact that air has weight, so they could use the cube of air in the same way as with the cubes of other materials, and this was the result of the refinement 7.4.4 presented in Table 6.

## 8 Discussion and Conclusions

We can discuss the 15 refinements made from the first to the second implementation in four different ways, by changing the criterion according to which they will be described and sorted, answering respectively the four research questions that are described in the research methodology section.

These criteria are (a) the content to which the refinements correspond, (b) the data sources which bring out the need for change, (c) the factor that affected and guided each refinement and (d) the common characteristics among the refinements that are guided from the same Pickering factor.

As we begin to describe and sort the refinements according to criterion (a), we observe that most of them refer to the procedural and epistemological knowledge; six, to the CVS method; and six, to the nature and the role of models. Far fewer are the refinements which concern the conceptual content of science; two, to the interpretation and prediction of F/S; and one, to the understanding of the concept of density. We assume that this happens for two reasons: firstly, because the project's innovative characteristics refer mainly to the emphasis on both epistemological and procedural knowledge, as described in Sects. 3 and 4, and secondly, it is well documented that both teachers (Crawford 2007), even if they are experienced in teaching science, as well as students (Boudreaux et al. 2008; Treagust et al. 2002), find it difficult to adapt to such innovations.

Taking into account criterion (b), i.e., the data sources which bring out the need to change, we observe that most of the refinements were influenced by two or more data sources, enforcing the validity of this analysis in the sense of data triangulation. An interesting finding is that the main data source was the local group researchers' notes (12 out of 15 cases). The researchers' notes are important not only because of their great quantity but also because they refer to the innovative elements of the content, i.e., to the nature and the role of models as well as to the characteristics of the CVS method. In addition, teachers who do not have the experience and the appropriate background could only play a secondary and advisory role (Duit 2007), especially when they are nurtured in a centrally guided educational tradition, as is the case in Greece. This is perhaps the reason that the teachers' intervention in these refinements is limited in two cases (7.1.2 and 7.3.5). Nevertheless, the teachers' contribution was important, since they participated in the evolutionary development of the scenarios and the teaching materials, by commenting on the type and the content of the activities and considering the possibility of them being carried out by the students.

The learning results, as shown in the questionnaires, the worksheets and the video recordings were also important, yet secondary, data sources (11 out of 15 cases). For example, the refinement related to the connection between students' real and simulated experiment interpretations was guided, in a secondary way, by the analysis of students' questionnaires (case 7.1.1).

Experts' suggestions were significant in two out of 15 cases. The small number of refinements is reasonable, considering the nature (advisory) and the function (from a distance) of the experts' role. The first refinement refers to the abovementioned case (7.1.1), while the second refinement refers to the *openness* of the students' inquiry activities (case 7.3.1).

As far as criterion (c) is concerned, i.e., the factor that affected and guided each refinement, we observe that the refinements that are mainly guided by educational factors (E) are 12 out of the 15, while there are two out of the 15 that are mainly guided by educational factors and in parallel, in a secondary though significant way by scientific factors as well (Tables 3, 5 and 6). Although the Greek national curriculum proposes a kind of discovery teaching method, the majority of teachers follow a more traditional teaching method, which is based mainly on the transmission of knowledge, followed by some demonstration experiments. The particular TLS adopts the inquiry teaching method within a constructivist framework. The effort to implement such an innovative project in such a traditional system necessitated many accommodations and modifications, guided by the E factors. Indeed, E factors concern mainly students' difficulties because the students were the researchers' main observation subject. However, the teachers confronted several difficulties as well even though they were assumed to be experienced and well-trained. Teachers' difficulties concerned epistemological and procedural knowledge and especially the nature and role of models, both concerning the necessity of teaching this content and the possibility that the students of this age could acquire this kind of knowledge.

Three out of the 15 refinements were guided by scientific factors (S), one of them in a significant way and the other two in a secondary way. However, these refinements are more essential, and we could call them *pylons*, because they refer to basic design principles of the TLS, influencing all units of the TLS and not only one activity. We also noticed that there are no refinements mainly guided by the material factor (M). We consider that the reason that no refinement was guided by the material factors is that the local group had the appropriate funds. We should also notice that the refinements concern accommodations that relate to (a) the content, (b) the teaching and learning approach of each activity, (c) the materials and the software used or (d) its duration, confirming the relevant literature (Méheut and Psillos 2004). Moreover, the refinements focus both on "inquiry as means" and on "inquiry as ends" (Abd-El-Khalick et al. 2004), through a gradual introduction of concepts and procedures from guided to open (Bybee 2006) and from concrete to abstract (Petrosino 2003).

Considering criterion (d), we notice that there are significant differences between the refinements that were guided by scientific factors (either mainly or secondarily) and those that were guided by educational factors. On the one hand, the refinements guided by scientific factors have a *holistic-open* character while the refinements guided by educational factors have a *local-guided* character.

More specifically, the refinements guided by scientific factors (cases 7.1.1, 7.3.1 and 7.4.1) (a) affect the TLS as a whole, i.e., the accommodation concerns many activities through all five units of the TLS; (b) are relevant to the IBSE (EU 2007) context, i.e., the main researchers' concern is to follow the principles of inquiry paradigm; and (c) promote increasing openness in students' learning methods, i.e., students are expected to construct the expected scientific knowledge through their own intervention and active participation in the learning procedure. Consequently, we call these refinements *holistic-open*, and they could be interpreted by the evolutionary process of acquiring and implementing IBSE teaching and learning methods by the researchers. For example, in case 7.3.1, the accommodation chosen by the researchers was *holistic-open*, in the sense that despite the difficulties the students experienced in understanding and implementing the CVS method, it was decided to select a teaching-learning approach that presents a gradual increase of *openness* to the type and extent of investigation made by the students themselves, following the recent literature trends (NRC 2000; EU 2007).

On the other hand, the refinements guided by educational factors are (a) local and limited to a certain activity of a unit of the TLS, (b) mainly relevant to students' difficulties, (c) guided in the sense that sometimes, there is a specific change in the materials used during the implementation without any change in the openness of students' learning methods, and it is proposed that the new scientific knowledge should be introduced implicitly (cases 7.1.2, 7.3.3, 7.3.4, 7.3.5, 7.4.2, 7.4.4 and 7.4.6), while on other occasions, it is proposed that the new scientific knowledge should be introduced explicitly (cases 7.2.1, 7.3.2, 7.3.6, 7.4.3 and 7.4.5). Consequently, we call these refinements *local-guided (local-guided implicit* and *local-guided explicit)*, and it is expected that they will help students to overcome their difficulties. An example of a *local-guided implicit* refinement is case 7.3.3 where the scientific goal is the learning of elements of the CVS method. The resistance was students' difficulties in applying the CVS steps when the variable is dependent on others. The accommodation chosen to overcome the abovementioned resistance is *local-guided implicit* in the sense that it aims in facilitating implicitly the acquisition of the expected scientific knowledge by the change in the order of the focal variables that possibly affect F/S phenomena. An example of a *local-guided explicit* refinement is case 7.3.2 where the scientific goal is learning the elements of the CVS method. The resistance was students' difficulty in understanding the draw a conclusion procedure. Hence, the accommodation chosen to overcome the above resistance is *local-guided explicit*, in the sense that it aims to make a clear introduction of the rationale hidden behind the CVS method, concerning the role that the observations made during an experiment play in the drawing a conclusion procedure (Fig. 7).

Summarizing the abovementioned discussion, the following suggestions can be made for future extension:

- The refinements are differentiated from each other according to the factors that guide them. The educational factor guides *local-guided* refinements, while the scientific factor guides *holistic–open* refinements, i.e., in the first case, the refinements are necessary in order to deal with the students' educational needs, while in the second, to adjust the TLS to the new scientific trends.
- When one has to design a teaching-learning innovative intervention, very close to the conditions of a regular class and which contains a variety of goals that pertain to scientific content, then a relevant variety of accommodations is necessary. On the contrary, in the case of a teaching-learning intervention with purely research characteristics, being therefore more controllable, the accommodations are usually fewer.

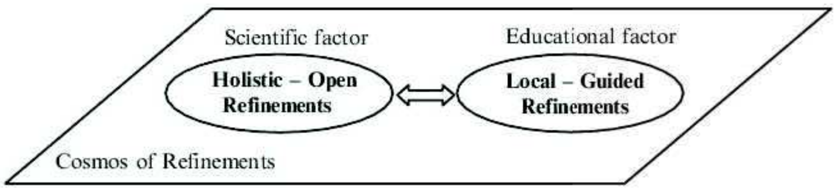



**Fig. 7** The differentiation of TLS refinements according to the factors that guide them

- When an innovative intervention is designed and developed in the context of a traditional educational system, then the refinements and proposals for the necessary accommodations, to overcome certain resistances, are made to a greater degree and depth by the researchers. An important role – but to a smaller degree – belongs to teachers and, finally, to the external observers and evaluators.
- During the design and development of this TLS, the research group made an effort to merge, on the one hand, science-oriented tradition characteristics such as paying attention to teaching practice and emphasis on science content issues in designing new TLSs and, on the other hand, student-oriented tradition characteristics such as giving emphasis to the students' needs, interests and learning processes (Duit 2007).

Moreover, although they are not direct results of the present study, the following extension remarks can be made:

- As the design and development of a TLS are not a *one-shot* procedure but an evolutionary process (Méheut and Psillos 2004), several suggestions for refinements could be revealed after the second implementation as well. These refinements concern, however, different subjects from the refinements implemented after the first implementation.
- Although there were several discussions between the teachers and the researchers, we still have doubts as to whether they really agreed to the explicit introduction of the nature and the role of models to primary school students. As a result, teachers' education in relation to the innovative characteristics of the project and especially in relation to the nature and role of models is a crucial point for future programs.
- As revealed from classroom videos and students' interviews analysis, teachers did not adequately emphasize the importance of the fact that the size of the different materials' cubes of the *dot crowdedness* model was the same. That was a key point in order to help students understand the model, and special emphasis should be given to this in the future.

The last two points indicate into a major degree the need for teachers' PCK improvement, in line with a transition from central-guided educational systems to educational systems that give greater initiative to the teacher (Duit 2007).

## 9 Recommendations

According to the issues discussed in the abovementioned sections, several recommendations can be made for research groups that could possibly begin to carry out similar, developmental type research.

- When a project is innovative, e.g., aiming at introducing new concepts and/or procedures such as nature and role of models and CVS method, especially with primary school children, then a more suitable teaching approach is one that introduces students gradually, i.e., from guided to more open and from the concrete to more abstract, to these new concepts and procedures.

- In the case where the main focus in a TLS's teaching and learning process is (a) inquiry "as ends" and (b) elements of epistemological knowledge such as the nature and role of models in science education, these should be explicitly taught in the form of discrete steps.
- It appeared that the scheme *technological problem – scientific investigation and return to the problem to find a solution*, e.g., through the teaching scenario of the SD's shipwreck salvage – motivates students to study the scientific dimension of a problem in the context of an authentic and real problem-solving situation rather than facing learning as an end in itself.
- Even though the ICT environments are extremely helpful for us to gain time when we apply procedural knowledge in experiments, the connection between the real and simulated experiments is necessary at young ages, in order (a) to avoid the confusion of the real world as we understand it through our experiences, with the model world, and (b) to enhance students' interpretations of real context phenomena in a similar way to simulated ones.

As far as the compilation of a future curriculum for the Greek school is concerned and therefore for any other similar (traditional) one, we could suggest the following: (a) taking as given that students are interested in materials that constitute several new technological products that they deal with in their everyday life, the introduction of materials' science and especially their properties in the curriculum would increase students' interest and participation, and (b) the introduction of difficult scientific concepts, such as density, in a qualitative way, i.e., as materials' properties (wherever this is possible), would decrease the conceptual load for the primary school students.

Last but not least, we consider that an innovation in education needs teachers that are not only adequately educated and trained in relation to the innovative parts of the TLS but persuaded as well concerning the necessity of the existence of these innovative parts in the TLS.

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