Explicitly linking simulated with real experiments for conceptual understanding of floating/sinking phenomena

Anastasios Zoupidis, Anna Spyrtou, Dimitris Pnevmatikos, Petros Kariotoglou
azoupidis@uowm.gr, aspirtou@uowm.gr, dpnevmat@uowm.gr, pkariotog@uowm.gr

School of Education, University of Western Macedonia, Greece

Abstract

In the present paper, we have examined the impact of explicit linkage between simulated (i.e., virtual) and real (i.e., physical) experimental settings in order to scaffold conceptual understanding, in the case of floating and sinking (F/S) phenomena explanations. This research is part of a research-based curriculum project and has been implemented evolutionarily. The first implementation took place in a science classroom of 12 fifth graders while the refined second that emphasized explicitly linking students' explanations of real with simulated F/S phenomena took place in two science classrooms of 41 fifth graders in total. We report and discuss the results of five research tasks included in a questionnaire developed to record students' explanations concerning F/S phenomena. Findings showed that explicit instruction linking simulated and real activities of F/S phenomena was beneficial for students even as long as seven months after the intervention.

Keywords: analogical encoding, conceptual understanding, floating/sinking, simulated and real experiments

Introduction

Students, especially in primary and junior high school grades, confront difficulties understanding the concept of density and explaining floating and sinking (F/S) phenomena (Wiser & Smith, 2008). In parallel, there has been an increasing interest in ICT integration in science classroom practice (Mishra & Koehler, 2006; Jimoyannis, 2010; Psillos & Paraskevas, 2017) and more specifically in the effective use of simulation software (Spyrtou, Hatzikraniotis & Kariotoglou, 2009; Moore, Herzog & Perkins, 2013; Michaloudis & Hatzikraniotis, 2017).

More specifically, there is an increasing interest in the role of explicit linking -in addition to combining- the use of simulated and real experimental settings in order to scaffold conceptual understanding (Jaakkola, Nurmi & Lehtinen, 2010; Jaakkola, Nurmi & Veermans, 2011). The present paper aimed to investigate this consideration in the case of students' explanations concerning F/S phenomena.

In the following section, a substantial literature review will be presented about the main issues of the study, that is: students' ideas and difficulties in understanding and explaining F/S phenomena (e.g., Smith, Snir & Grosslight, 1992), combining simulated and real experimental settings in science education (e.g., Wang & Tseng, 2018) and analogical encoding approach (e.g., Kurtz, Miao & Gentner, 2001), thus, adopting the method of comparing two instances of a principle which is an intended learning outcome, as a powerful means of promoting learning.

Literature Review

F/S phenomena

It is ascertained that F/S phenomena are common among students, and, thus, suitable for the teaching of density (Smith et al., 1992; Havu-Nuutinen, 2005). Indeed, students seem to have a strong visualization of these phenomena (Joung, 2009). Specifically, students explain and describe F/S phenomena regarding perception-based macroscopic natural properties, for example, weight, length, and volume (Smith et al., 1992; Kawasaki, Herrenkohl & Yeary, 2004; Havu-Nuutinen, 2005). Besides, researchers who have studied students' conceptions of density (Smith et al., 1992; Hardy, Jonen, Moeller & Stern, 2006; Wiser & Smith, 2008) consider that the difficulty in learning the notion of density is rooted exactly in an already developed conceptual framework (Vosniadou, Vamvakoussi & Skopeliti, 2008). This framework is composed of perception-based physical quantities in which the raw scientific notions of weight, volume and density coexist undifferentiated. Specifically, students formulate their estimation concerning floating of solid objects in water by considering: (i) the dimensions of tanks in which floating occurs, (ii) the weight of the bodies, (iii) the shape of the floating object, (iv) the existence of hollows, and (v) the depth of water (Fassoulopoulos, Kariotoglou & Koumaras, 2003).

According to the above, the difficulty that students experience in understanding density as a property of material kind is more qualitative and conceptual than quantitative. Therefore, students' understanding of measurement and models could allow them to conceive weight and volume as objective and extensive properties, differentiate weight and density concepts and produce interpretations on F/S phenomena in a more coherent and abstract explanatory framework (Wiser & Smith, 2008). In parallel, computer models that can help in the visualization of density are considered (Smith et al., 1992). 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 appropriate mathematical ratio (mass per unit of volume). Through this approach, students were encouraged to develop their conceptual models in order to interpret F/S phenomena and were prompted to work with a series of conceptual computer simulations.

Furthermore, other researchers (Perkins & 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. Perkins and Grotzer (2005) provided students with activities designed to reveal the underlying causal structure of a concept or a phenomenon, such as density and F/S phenomena, and also initiated discussions concerning the nature of causality. It appeared that their intervention improved students' ability to reason about topics about which they typically have misconceptions. However, it was hard for them to move from a linear to a relational model in explaining F/S phenomena.

In conclusion, there are two significant shifts in the conceptual framework of matter and material kind that are considered to be necessary for understanding density as a property of materials. The first one is moving from perception-based understanding of physical quantities (i.e., weight, volume, density) to a more objective and differentiated set of concepts, based upon measurement and interrelated in a theory of matter. The second one is moving from causal linear to causal relational reasoning when interpreting F/S phenomena.

Combining simulated and real experimental settings

Recently, there has been an increasing interest in ICT integration in science classroom practice (Jimoyannis, 2010; Psillos & Paraskevas, 2017). This integration effort is developed in the framework of the Technological Pedagogical Content Knowledge (TPACK) model which does not consider its three key elements in isolation, but instead emphasizes the connections and the complex relationships system they define (Mishra & Koehler, 2006). Among the wide range of effective educational environments and applications available for science education, simulated experimental settings offer a great variety of affordances for both students and teachers (Moore et al., 2013; Michaloudis & Hatzikraniotis, 2017). However, simulations should evolve and be combined with innovative methodologies and pedagogical strategies in order to be effective in understanding physics phenomena (Michaloudis & Hatzikraniotis, 2017). In this framework (TPACK), the combination of simulated with real experimental settings is perceived as an important methodological aspect of the way that simulations could be used in science education. Besides, Zacharia and Anderson (2003) focusing on the role of combining the use of real and simulated experimental settings argued that the scientific literature lacked studies that investigate the impact of the combination of the two methods on students' conceptual understanding of science. More recently, Wang and Tseng (2018) argued that although several studies investigate various combinations and sequences of simulated and real laboratory activities across different content areas of science, few of the studies focus on elementary level. Meanwhile, Zacharia (2007) concluded from his research that the combination of real and simulated experiments was more effective than the use of real experiments alone. In a recent survey studying physical and simulated laboratories, de Jong, Linn and Zacharia (2013) conclude, among others (e.g., Wang & Tseng, 2018), that combination of physical and simulated laboratories offers advantages that neither of them can fully achieve separately.

In line with this trend, Jaakkola et al. (2011) experimental study aimed at comparing learning outcomes in the domain of electricity, of elementary school students working only in a simulation environment with outcomes of those working in a simulation in parallel with real circuitry environment. In addition, the study aimed at exploring how learning outcomes in these environments are influenced by implicit (only procedural guidance) and explicit (procedural guidance, focus on the aspects of the circuits that are necessary for a theoretical understanding of electric circuits and make comparisons between different circuits) instruction. The results demonstrated that students could gain a better understanding when, in conjunction, they used the simulation and the real circuits than if they had available only a computer simulation. This effect was evident even when the simulation was supported with explicit instruction. Surprisingly, when the students used the simulation and the real circuits in parallel, the explicit instruction did not seem to appreciably enhance their understanding of electric circuits compared to the implicit instruction. In conclusion, this research supported the idea that combining the use of simulated external representations with concrete (i.e., physical) external representations -such as scaffolding for conceptual understanding of electric circuits- is more efficient than if the students have only the simulated representations available. On the contrary, explicit instruction could improve students' conceptual understanding of electrical circuits considerably only in the case of the simulation environment (Jaakkola et al., 2010; 2011).

Analogical encoding approach

Furthermore, researchers who adopt an analogical encoding approach (Kurtz et al., 2001; Gentner, Loewenstein & Thompson, 2003; Mason & Tornatora, 2014), claim that comparing two instances of a principle which is an intended learning outcome is a powerful means of promoting learning, even for novices. This claim theoretically supports the presented in the previous section idea of combining simulated and real experimental settings (Jaakkola et al., 2010; 2011). For instance, in the case of Kurtz et al.'s (2001) research, two scenarios concerning heat flow scientific phenomenon are presented together to the students. A pancake being cooked on a gas stove griddle is presented in conjunction with a scenario depicting hot coffee with a metal bar in it that has an ice cube at the end. The two scenarios share a common relational principle: heat flows from a source to an object through a conductor, producing an effect (cooked pancake and melted ice cube). The joint presentation of the two cases of heat flow phenomena and the instructions for case comparisons were the two conditions that supported students' understanding of the common relational principle interpreting the phenomena. Gentner et al. (2003) also showed that promoting comparisons between two complementary cases can help students realize the common principles shared by the cases, and thus result in a more abstract understanding of the phenomena.

Howe, Rodgers, and Tolmie (1990) found that when 8 – 12-year-old children conducted F/S experiments in small groups, the group members showed improved understanding regarding F/S phenomena only when the groups discussed how the evidence should be interpreted. On the contrary, when groups held similar ideas and discussion was therefore precluded, conceptual understanding did not show any improvement. Furthermore, Howe, Devine, and Taylor Tavares (2013) claim that for some areas of science, the conceptions that students invoke when interpreting phenomena represent only a proportion of their wholly conceptual knowledge. So, they suggested a strategy that involves engaging tacit understanding through tasks that require discrimination -through comparison-between natural and non-natural events, expecting improvement in the conceptual knowledge that is displayed when reasoning. More specifically, Howe et al. (2013) examined the importance of using simulated experimentation to guide science learning using an age group of 8 – 12-year-old children. The topic selected was patterns of motion when objects fall after being dropped from some height. The results showed that the students who worked in the simulated environment made significant progress in the conceptual understanding, underpinning predictions, while progress was limited concerning explanations of the phenomena.

Mason and Tornatora (2014) designed and implemented an intervention concerning scientific phenomena of heat flow and change of matter. They assumed that analogical encoding through mutual alignment of teaching scenarios is an efficient way to enhance students' mapping processes. The research provided evidence that the extraction of a common relational structure for a deeper understanding of a scientific phenomenon in primary and lower secondary school students can be best sustained in the classroom by providing joint presentations of two cases of a scientific phenomenon. In addition, and contrary to the research findings of Jaakkola et al. (2011), Mason and Tornatora (2014) provided evidence that a brief though explicit prompt to compare two cases of a scientific phenomenon is also a constructive condition for a deeper understanding of the phenomenon.

Research question

Summing up the literature review, analogical encoding could be effective, even quite early in learning, when learners lack knowledge of an appropriate base domain (Kurtz et al., 2001). In other words, combining two instances of the same principle or phenomenon (e.g., simulated and real experimental settings) could function as scaffolding towards conceptual understanding. However, there are divergent opinions concerning the necessity or the effectiveness of explicit instruction for comparison of those two instances (Jaakkola et al., 2011; Mason & Tornatora, 2014).

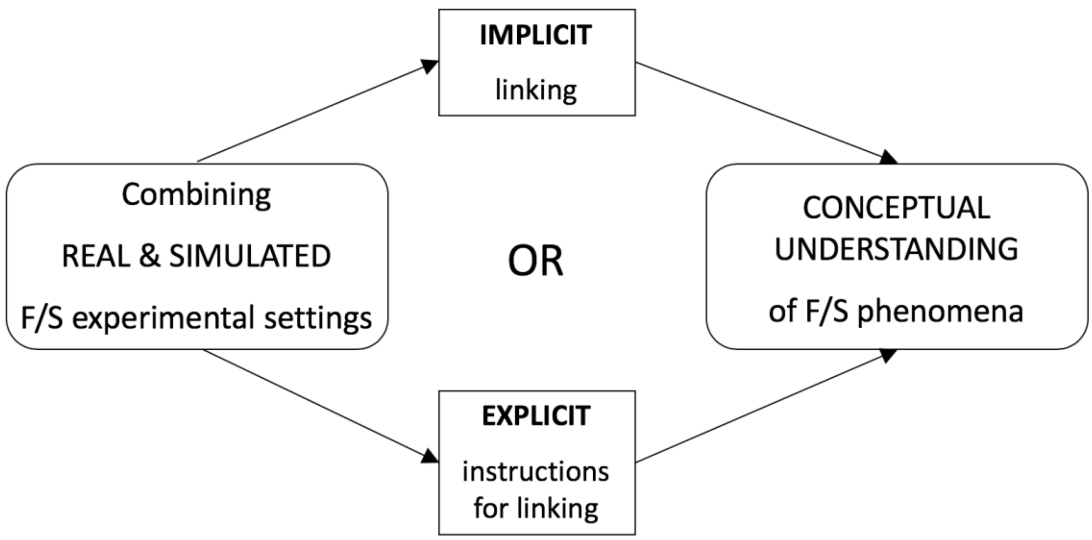

Figure 1. Implicit linking (only procedural guidance) or explicit instruction (procedural guidance and focus on the visual 'dots-in-a-box' model) for linking the reasoning of simulated and real experimental settings

Consequently, there is an open question as to whether implicit linking between two instances of a phenomenon (e.g., simulated and real experimental settings) is sufficient or explicit instruction for linking them is necessary to enable phenomena and relevant concepts to be better understood. This research aimed to investigate whether an explicit instruction for linking the reasoning of simulated and real experimental settings can enhance conceptual understanding of FS phenomena. Thus, the discussion (Jaakkola et al., 2011; Mason & Tornatora, 2014) that could further be enriched by this study could be expressed by the following research question (Figure 1): do explicit instruction for linking the reasoning of simulated and real experimental settings help students to improve their explanations in F/S phenomena?

Research context

In this study, part of a broader research-based curriculum project, we were keen to help students improve their explanations in F/S phenomena and acquire procedural and epistemological understanding related to the control of variables strategy and the nature and role of models. For this purpose, a five-unit Teaching Learning Sequence (TLS) on density as a materials property (Spyrtou, Zoupidis & Kariotoglou, 2008) has been developed. A TLS is a medium-level curriculum unit package, which includes well-researched teaching-learning activities empirically adapted to student reasoning (Méheut & Psillos, 2004; Psillos & Kariotoglou, 2016). The density TLS was implemented, refined under the light of the data collected, and implemented the second time in another group of the same age range. For the sake of brevity and in order to focus on this study's research question, the TLS will be described focusing only on F/S phenomena activities and excluding the description of the activities that aimed at procedural and epistemological understandings, which are analytically described in previous studies (Spyrtou et al., 2008; Zoupidis et al., 2010; 2012; 2016; Zoupidis, Spyrtou, Malandrakis & Kariotoglou, 2016).

During the first implementation of the TLS, in the first unit, students were acquainted with F/S phenomena and the relevant concepts through specific activities. For instance, students followed a video of the salvage of the shipwrecked Sea Diamond cruise ship, which included a description of the accident and a discussion about its environmental consequences. Students were also involved in relevant real experiments, using a Predict-Observe-Explore (POE) approach (White & Gunstone, 1992) in order to engender individual students' predictions.

In the second unit, the students, working in groups, followed the POE approach in a combination of real and simulated experiments in order to pinpoint and check possible variables that involve F/S, for instance, the kind of liquid and the weight of an object or the object's material. So, our initial aim was for the students to understand that the F/S of an object is influenced by the material of the object and the material of the liquid.

In the third unit, the students were introduced to a visual model of density as a property of material, namely the 'dots-in-a-box' model (Smith et al., 1992) shown in Figure 2. Each box represents a standard unit of volume, each dot a weight unit, with the number of dots per box corresponding to the density. Using density's visual model in respective simulated experiments, we expected that the students would acquire causal relational reasoning (Perkins & Grotzer, 2005) to explain and predict the F/S phenomena of homogeneous objects of different volume, such as wooden or iron cubes in water. In other words, the students were supposed to understand that the F/S of an object in a liquid can be interpreted by comparing the density of the object with the density of the liquid.

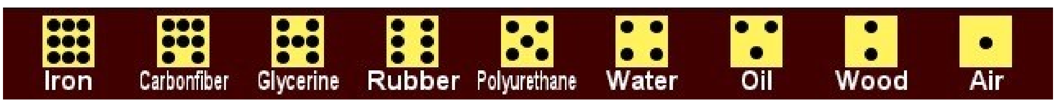

Figure 2. The visual 'dots-in-a-box' model of several materials

In the fourth unit, students were once again introduced to a combination of real and simulated experiments. First, in a simulated environment, they were asked to provide explanations of the F/S of several homogeneous objects in glycerine instead of water. These explanations were expected to follow the causal relational reasoning, i.e., comparing the object's and glycerine's densities. Second, in a real environment, students negotiated situations of F/S of two-material composite objects, for instance, a glass bottle or an iron ship filled initially with air and then with water. They were expected to use the visual model to intepret the F/S of these composite objects. In so doing, we also aimed to help students understand that the density of a two-material composite object lies between the densities of these two materials.

Finally, in the fifth unit, students had the opportunity to work in groups both in a real and simulated environment so as to investigate the F/S of the Sea Diamond cruise ship and argue about its salvage. Overall, real and simulated experiments were combined in three of the five units of the TLS, specifically the second, fourth, and fifth.

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 & Grotzer, 2005). A moderate expected learning outcome could be the reference to the material of the object (Smith et al., 1992). Based on the results produced mainly from pre and post questionnaires of the first implementation (see below in the 'results' section) we proceeded with several refinements of the TLS (Zoupidis, Spyrtou, Malandrakis & Kariotoglou, 2016).

Concerning the refinement of the TLS that we focus on in this paper, we noticed that the students gave answers closer to the expected learning outcome about F/S phenomena when they confronted simulated rather than real situations in the pre and post questionnaire tasks. We assumed that students' difficulty was greater in the real than in the simulated environments because in the latter the variables affecting the phenomena are usually eliminated, so the context is more guided than in the respective real ones (Howe et al., 2013). Also, the visual 'dots-in-a-box' model has been included in all the simulated environments, possibly acting as scaffolding for student explanations. Moreover, inspired by relevant literature (Jaakkola et al., 2010; Mason & Tornatora, 2014), we assumed that the students found it challenging to use causal relational reasoning when interpreting F/S phenomena because there was no linkage between simulated and real experimental settings.

As a consequence, during the second implementation, students were prompted to associate their explanations given in simulated experiments with those provided in the real ones. So, although the experiments are the same in both implementations, only in the second implementation students were reminded to use the visual 'dots-in-a-box' model (Figure 2) in order to interpret the F/S of real homogeneous or composite objects. Specifically, the visual model was projected on the whiteboard during this particular activity, serving as a reminder and a link between simulated and real experiments. Furthermore, the teacher, to help students when necessary, pointed out the existence of the model on the whiteboard and prompted for the use of the model in students' explanations. Indicatively, we quote part of a discussion concerning the floating of an iron scale model of a ship:

> Teacher: *Why does the ship floats, kids? Why does an object float in a liquid? John!*
>
> John: *Because of the air in it.*
>
> Teacher: *Let us think again about it! Why does it float? How would we explain it if we used density (showing to the 'dots-in-a-box' model on the whiteboard), the rule that we used in the simulated experiments?*
>
> Helen: *When the object is not so dense inside?*
>
> Teacher: *John, do you want to continue your thought?*
>
> John: *When it's (the object's) density is smaller than water's density.*

Teacher: *Which means that this ship, in relation to water, has bigger or smaller density?*

John and Helen: *Smaller!*

These discussions aimed to make the abstract concept of density more visible and increase students' active participation in real experiments, in expectation of a consequent enhancement of their explanations towards the scientific ones.

In summary, both implementations had the characteristic of combining real and simulated experiments in line with the results of the relevant literature (Kurtz et al., 2001) which showed a positive effect of this combination on the understanding of scientific concepts. However, only in the second implementation was there an explicit instruction for the students to link their explanations of F/S phenomena in a real environment with those in a simulated environment.

Research method

Participants

The first implementation took place in one science classroom of 12 (six of each gender) fifth graders (10-11 years old) while the second one occurred in two science classrooms of 41 (26 male, 15 female) fifth graders in total. The implementations were conducted by the regular science teachers of the classes, who cooperated with the research group in developing the TLS implementation.

Data collection

Data were collected from multiple sources for both implementations (e.g., questionnaires, interviews, researchers' notes). However, for the purpose of this paper, five research tasks from the questionnaire, relevant to F/S phenomena explanations and suitable in evaluating the impact of linking simulated with real experimental settings, are presented (see Appendix). The tasks were adapted from different previous studies (Havu-Nuutinen, 2005; Perkins & Grotzer, 2005; Smith et al., 1992) and modified by the researchers according to the implemented TLS. The questionnaire was answered by all the students at three-time points: before, then one week and finally seven months after TLS's implementation (Pre, Post, and Post post -from now on Ppost- respectively in Tables 1, 2, 3, 4 and 5). Specifically, tasks 3, 4 and 5 were addressed to students in each of the three phases (Pre, Post, and Ppost) of the TLS, while tasks 1 and 2 were addressed only in the last two phases because students did not know the 'dots-in-a-box' model before the intervention.

The first two research tasks (tasks 1 and 2) were developed in order to record students' explanations about F/S in a simulated environment with the 'dots-in-a-box' model given. For example, in task 1 students were asked to draw a big wooden sphere and a small iron triangle in their final position in a liquid, considering the densities that are given in the 'dots-in-a-box' visual model (sphere's material: two dots, triangle's material: six dots and liquid's material: four dots). They were also asked to justify their drawings. The sphere should float, and the triangle should sink in this liquid according to the densities given. In task 2, students were requested to predict and justify their choice for the final positions of two objects dropped into a liquid, considering their densities also given in the 'dots-in-a-box' representation (object A's material: two dots, object B's material: three dots and liquid's material: four dots). Both objects in task 2 should float, though at a different level. More specifically and according to the densities given, students should draw object A floating at a higher level than object B. Three more tasks were developed in order to record students' explanations about F/S phenomena from everyday life while the 'dots-in-a-box' model was not given. Specifically, tasks 3 and 4 asked the students to predict and justify their choice concerning the F/S of a life buoy and an anchor respectively. Task 5 asked the students what change they would make to the system of a ball made of plasticine being sunk into a tank with water so that the ball would float on the water. Reference to the comparison of material densities is considered to be the expected learning outcome in all tasks, while a moderate expected learning outcome could be the reference to the material of the object.

Coding

Students' responses were analysed according to a top-down analysis, i.e., taking into consideration the categories in the relevant literature (Havu-Nuutinen, 2005; Perkins & Grotzer, 2005; Smith et al., 1992), in parallel with a bottom-up analysis (Strauss & Corbin, 1994) when this was necessary. In other words, some codes were developed from the literature, and others emerged from the data. Students' answers in all cases were coded in a continuum from irrelevant and non-answers (coded as 0 in all measurements) to scientific (in terms of expected learning outcomes).

Specifically, in the two tasks where material densities were given (tasks 1 and 2), students' responses were classified into two categories, 'causal relational' and 'causal linear' reasoning (Tables 1 and 2; Perkins & Grotzer, 2005). Answers based on causal relational reasoning to explain F/S, e.g., 'object A floats because its density is smaller than the liquid's and object B sinks because its density is higher than the liquid's' in task 1, were classified as 'causal relational' in category 1, which were considered as reflecting the 'scientific view' in explaining F/S phenomena. Additionally, answers that used causal linear reasoning were classified as 'causal linear' in category 0. The main subcategories of category 0 were: a) linear though correct answers, e.g., 'object A will float and object B will sink, because the amount of material does not matter', b) tautological answers (i.e., tautology between the statement and the drawing of the students), e.g., 'object A will float and object B will sink', c) reference to the weight, e.g., 'object A will float because it is light and object B will sink because it is heavy' and d) irrelevant and non-answers, e.g., 'the liquid floats because they have the same density thus it cannot sink' all found in task 1. It is assumed that only two categories were revealed in these two tasks, mainly due to their 'on-off' character, stemming from the fact that material densities 'were given'; and, secondarily, due to the expected learning outcome in such type of tasks which was the use of causal relational reasoning in F/S explanations. Nevertheless, answer allocation in the subcategories is also presented and discussed in the next sections.

On the contrary, in the three tasks in which materials' densities 'were not given' (tasks 3, 4, and 5) students' responses were classified into four categories (Tables 3, 4 and 5). Answers that were based on causal relational reasoning to explain F/S, using densities comparison in these explanations, e.g., 'I can change the ball into wood because it (wood) has less density than water so it will float' in task 5, were classified in category 3. Answers that referred to the material or both to the weight and material of the object, e.g., 'I would change plasticine into plastic' in task 5, were classified in category 2. Answers that either directly or indirectly referred only to the weight of the object, e.g., 'I would cut the ball into two pieces to make it float' in task 5, were classified in category 1. Finally, no answers, irrelevant answers, e.g., 'I would make a ball out of leaves' in task 5, or answers that had a teleological character, e.g., 'it floats in order to save people' in task 3, were classified in category 0.

The analysis of all students' answers has been realized by the first two authors, with 85% agreement which following discussion and the reframing of the criteria was increased to 100%. For instance, for category 2: 'Reference to material or both to weight and material' regarding tasks 3, 4, and 5, it has been decided to include answers referring both to weight and material during this discussion because these answers showed a shift towards the expected learning outcomes. Due to the small number of participants, non-parametric statistical hypothesis test and specifically Wilcoxon signed-rank analysis has been used in order to investigate the possible existence of a statistically significant change in students' responses between Pre, Post, and Ppost time points.

Table 1. Students' answers in task 1 concerning objects' F/S (densities are given)

Categories	Pre		Post		Ppost	
	First Imp	Second Imp	First Imp	Second Imp	First Imp	Second Imp
1: causal relational reasoning (densities comparison) – CR	-	-	8	26	6	23
0: causal linear reasoning – CL	-	-	4	15	6	18
Total	12	41	12	41	12	41

NOTES: a. Ppost stands for Post post and indicates the measurements seven months after the implementation, and b. Imp stands for implementation

Table 2. Students' answers in task 2 concerning objects' F/S (densities are given)

Categories	Pre		Post		Ppost	
	First Imp	Second Imp	First Imp	Second Imp	First Imp	Second Imp
1: causal relational reasoning (densities comparison) – CR	-	-	8	30	6	22
0: causal linear reasoning – CL	-	-	4	12	6	19
Total	12	41	12	41	12	41

Results

Simulated environment ('dots-in-a-box' model given)

Students' answers in tasks 1 and 2, recording their explanations concerning F/S in a simulated environment, with the 'dots-in-a-box' model given, showed that students could successfully use density's model in causal relational reasoning, both in the first and second implementation (see students' answers in tasks 1 and 2, Table 1 and Table 2 respectively).

Specifically, in task 1, in the first implementation, eight out of 12 students just after the intervention and six out of 12 students seven months later used causal relational reasoning in justifying their choice. The rest of students' answers that were categorized as causal linear reasoning (category 0) were firstly allocated in subcategory (c) reference to the weight; and secondly in subcategory (d) irrelevant and non-answers (see section 'Research method, coding' for examples).

In the second implementation, 26 out of 41 students just after the intervention and 23 out of 41 students seven months later used causal relational reasoning in justifying their choice. The rest of the students' answers that were categorized as causal linear reasoning (category 0) were firstly allocated in subcategory (b) tautological answers, secondly in subcategory (a) linear though correct answers, thirdly in subcategory (c) reference to the weight, and fourthly in subcategory (d) irrelevant and non-answers (see section 'Research method, coding' for examples). Neither in the first (z=1.00, p=.317, d=0.31) nor in the second implementation (z=.905, p=.366, d= 0.28) did students' answers present a statistically significant change when testing pairs of variables between Post and Ppost time points, meaning that any improvement in explaining F/S phenomena using causal relational reasoning had been retained seven months later.

Moreover, in task 2, in the first implementation, eight out of 12 students just after the intervention and six out of 12 students seven months later used causal relational reasoning in justifying their choice. Almost all of these students (seven just after the intervention and six students seven months later) could also understand the different float level of the two objects using the 'dots-in-a-box' model. The student who used causal relational reasoning but did not understand different float level had answered that 'Both objects will float at the same level because they have lower density than the liquid.' The rest of students' answers that were categorized as causal linear reasoning (category 0) were firstly allocated in subcategory (c) reference to the weight and secondly in subcategory (d) irrelevant and non-answers (see section 'Research method, coding' for examples).

In the second implementation 30 out of 41 students just after the intervention and 22 out of 41 students seven months later used causal relational reasoning in justifying their choice. However, only 22 students just after the intervention and 12 students seven months later seemed to understand different float level in relation to material density. The students who used causal relational reasoning but did not understand different float level assumed that both objects would float at the same level because their density was lower than liquid density. The rest of students' answers that were categorized as causal linear reasoning (category 0) were firstly allocated in subcategory (b) tautological answers, secondly in subcategory (a) linear though correct answers, thirdly in subcategory (c) reference to the weight, and fourthly in subcategory (d) irrelevant and non-answers (see section 'Research method, coding' for examples). In the second implementation (z=2.309, p=.021, d=0.72), unlike the first (z=1.00, p=.317, d=0.31), students' answers presented a statistically significant change when testing pairs of variables between Post and Ppost time points, meaning that only in the first implementation conceptual improvement had been retained seven months later.

However, these statistically significant results should be seen as a consequence of the students' relatively enhanced success just after the second implementation compared to students' success just after the first implementation and should also be related to the same percentage of the students that made use of causal relational reasoning seven months later in both implementations (Table 2). Furthermore, both in tasks 1 and 2, students' answers that were categorized in category 0, in the second implementation, have been allocated in subcategories which are closer to the expected learning outcome. Specifically, most of these students' answers in the first implementation either referred to the weight of the objects, a well-recorded alternative idea concerning F/S phenomena or were irrelevant and non-answers. On the contrary, in the second implementation, most of the respective answers were tautological or linear, though correct.

In general, students' responses in both tasks 1 and 2 showed that when the 'dots-in-a-box' model was given, in a simulated environment, students could successfully use it in causal relational reasoning to explain F/S phenomena, even when the case was not taught, i.e., predicting and explaining different float level.

Everyday life environment ('dots-in-a-box' model not given)

In the case of the tasks that negotiated F/S phenomena of daily life, where the 'dots-in-a-box' model was not given, success was modest. The students that could provide an explanation of F/S using object's and liquid's density comparison were far fewer both in the first and second implementation, just after intervention and seven months later as well without significant differences between the two implementations (see students' answers in task 3, task 4 and task 5, Tables 3, 4, and 5 respectively). However, it seems that students revealed much more stability concerning this kind of reasoning in the second implementation given the fact that in the first implementation and task 5 (see Table 5) no student used causal relational reasoning just after the intervention. In addition, the percentage of the students that referred to the material in their F/S explanations (category 2) was, in the case of all these three tasks, higher in the second implementation.

In general, in the first implementation, students' answers presented a statistically significant improvement only in task 3 (z=2.333, p=.020, d=0.73) and task 4 (z=2.121, p=.034, d=0.66), just after the intervention, which was marginally retained seven months later only in the case of task 3 (z=1.89, p=.059, d= 0.59). On the contrary, students' answers in task 3 (z=2.665, p=.008, d=0.83), task 4 (z=3.446, p=.001, d= 1.08) and task 5 (z=2.142, p=.032, d= 0.67), concerning second implementation, just after the intervention, presented a statistically significant improvement, which was retained seven months later. For instance, in task 3 the improvement in the average performance of students just after the intervention was statistically significant (z=2.665, p=.008, d= 0.83), while seven months later there was no statistically significant change in their performance compared to that just after intervention (z=1.238, p=.216, d= 0.39).

There is also a qualitative note, which has been revealed by comparing the results in task 3, task 4 and task 5 between the first and second implementation and confirms that in the second implementation teaching was more successful and learning was steering towards scientific understanding. More specifically, it has been revealed that students' answers that were categorized in category 3, in all these three tasks, in the second implementation comprised only densities comparison and no reference to the material, as was the case in the first implementation where no student could focus only on densities comparison. For instance, in the first implementation, a student's answer in category 3 (task 4) was that 'the anchor sinks because it is made of iron and because its density is bigger than water'.

Table 3. Students' answers in task 3 concerning the F/S of a life buoy (densities not given)

Categories	Pre		Post		Ppost	
	First Imp	Second Imp	First Imp	Second Imp	First Imp	Second Imp
3: Densities' comparison – CR	0	0	4	9	1	5
2: Reference to material or both to weight and material – CL	9	34	6	29	8	31
1: Reference to weight – CL	0	1	1	1	1	2
0: Teleological – CL	3	6	1	2	2	3
Total	12	41	12	41	12	41

Table 4. Students' answers in task 4 concerning the F/S of an anchor (densities not given)

Categories	Pre		Post		Ppost	
	First Imp	Second Imp	First Imp	Second Imp	First Imp	Second Imp
3: Densities' comparison – CR	0	0	4	11	1	7
2: Reference to material or both to weight and material – CL	2	11	3	13	5	18
1: Reference to weight – CL	9	23	4	14	5	12
0: Teleological – CL	1	7	1	3	1	4
Total	12	41	12	41	12	41

Table 5. Students' answers in task 5 concerning the F/S of the plasticine ball (densities are not given)

Categories	Pre		Post		Ppost	
	First Imp	Second Imp	First Imp	Second Imp	First Imp	Second Imp
3: Densities' comparison – CR	0	0	0	6	2	4
2: Reference to material or both to weight and material – CL	1	21	3	21	4	19
1: Reference to weight – CL	10	13	8	10	4	12
0: Teleological – CL	1	7	1	4	2	6
Total	12	41	12	41	12	41

Furthermore, only in the second implementation, a few responses referred to the 'dots-in-a-box' model although the task did not mention it, indicating in a qualitative manner the impact of explicit linkage between simulated and real experiments during instruction. For example, a student's answer in category 3 (task 4) was that 'it (the anchor) sinks because it has more dots than water'. In addition, some of the students' answers that were categorized in category 2, in the second implementation were referring to the liquid's material. More specifically, in task 5, at least seven and five students' answers, in the Post and Ppost questionnaire respectively, reflected this situation, e.g., 'I would change the liquid which is in the tank and put another one to enable the ball to float.' Reference to the liquid is considered to be significant because it is well reported that students tend to focus on the characteristics of the object that is floating or sinking and find it difficult to realize the liquid's importance in the phenomenon (Smith et al., 1992).

Discussion and conclusions

The increasing interest in ICT integration in science classroom practice is illustrated in the continuous researchers' effort to propose appropriate theoretical models, such as Technological Pedagogical Content Knowledge (TPACK) model, in order to describe and develop effective educational environments and applications for science education (Jimoyannis, 2010). In this framework, there is a need to investigate innovative methodologies and pedagogical strategies in order to integrate simulations in inquiry-based activities (Michaloudis & Hatzikraniotis, 2017).

Besides, researchers who adopt an analogical encoding approach argue that comparing two instances of a principle which is an intended learning outcome is a powerful means of promoting learning (Gentner et al., 2003; Kurtz et al., 2001). However, there are divergences concerning the necessity or the effectiveness of explicit instruction for comparison (Jaakkola et al., 2011; Mason & Tornatora, 2014).

Having this in mind, the present study aimed to investigate the effects of explicit instruction for linking the reasoning of simulated and real F/S experimental settings on students' learning outcomes. The results showed a statistically significant improvement in the students' performance in explaining F/S phenomena, which remained stable seven months later, mostly where there was explicit instruction in linking simulated with everyday life F/S experimental settings rather than where these experimental settings were only combined and implicitly linked. So, the shift from students' initial ideas to the intended learning outcomes is indicated with bigger arrows in the case of explicit instruction (Figure 3). The practical usefulness of the results is further confirmed by the Cohen's d effect sizes which vary between medium (0.3) to large (1.1) values, indicating an important size of nonoverlap percentage in the two groups.

This statistically significant improvement in students' conceptual understanding was most relevant to an understanding of the importance of the material in F/S phenomena (Intended learning outcome A, Figure 3) and secondarily to an understanding of the usefulness of using causal relational reasoning in their explanations (Intended learning outcome B, Figure 3), in line with the results in Perkins and Grotzer's (2005) research. Therefore, explicit instruction helped students to a greater extent in using the material of the objects in their F/S explanations rather than objects' to liquid's density comparison. This is logical, given the fact that the first is an example of causal linear reasoning, while the latter is an example of more complex causal relational reasoning (Perkins & Grotzer, 2005).

Several qualitative indications also reinforced these results. For instance, references to the weight of the objects, a well-recorded alternative idea concerning F/S phenomena, were more often associated with the implicit linking of the simulated to the real experimental settings, i.e., in the first implementation. On the contrary, references to the material of the objects in students' F/S explanations were more frequent where that explicit instruction for comparison existed, i.e., in the second implementation. In addition, some of those students' answers that referred to the material, in the second implementation, were referring to the liquid's material. Remember that the liquid's material is an important factor in explaining F/S phenomenon as it is well reported that students find it difficult to realize liquid's importance in F/S phenomenon and tend to focus on the characteristics of the object (Smith et al., 1992).

It is also evident from the results that, even with an explicit instruction in linking real with simulated environments, i.e., in the second implementation, students were far more successful in using causal relational reasoning (Intended learning outcome B, Figure 3) when they confronted a F/S phenomenon in a simulated environment than in an everyday life situation. This was the situation even when the case was not taught, i.e., predicting and explaining different float level (in Task 2). An explanation of that could be that the time given for metacognitive discussion, concerning the linking between explanations of the simulated and the real F/S phenomena, was limited due to the focus on other procedural and epistemological knowledge (aspects of the Control of Variables Strategy and the nature of models) as well. Our assumption is in line with the remarks of Kurtz et al. (2001) that introducing students to analogical encoding procedures should be continuous and time-consuming. Furthermore, it should be taken into account that a difficult case like the present one becomes more challenging when it is implemented in a real classroom situation, rather than in a simple experimental context, as with most of the research referred to in the Literature review and Research context sections.

At this point, the limitations of this research should be noted. Firstly, the small number of the participants does neither permit the researchers to implement parametric tests nor generalize their conclusions. In addition, a more even balance between the participants in the two implementations would have been more helpful. Secondly, this research's primary aim was to design and develop a TLS, which would include well-researched teaching-learning activities empirically adapted to student reasoning of F/S phenomena. The research, being part of a broader European project, did not focus only on the specific question; and consequently, the available teaching and learning time was separated into different teaching goals. Possibly, research focusing only on the specific research question could dedicate the necessary time and reflect on its significance.

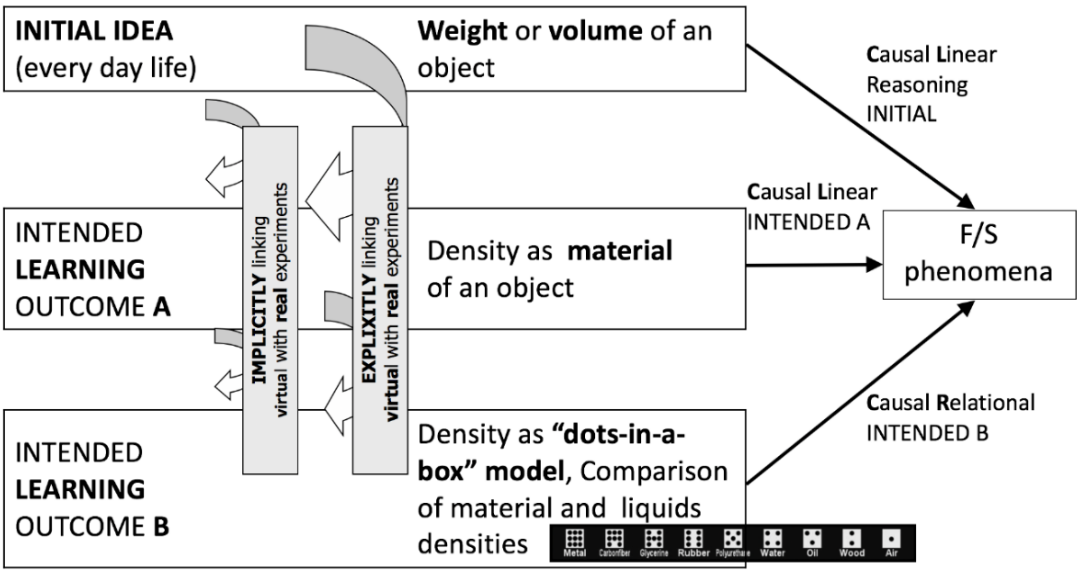

Figure 3. Explicit instruction for linking the reasoning of simulated and real experimental settings is more effective than implicit one

Suggestions for educational practice

The results of the present study were in line with Mason and Tornatora's (2014) research evidence and indicated that it is beneficial not only to combine but also to explicitly link simulated and real activities of F/S phenomena (Figure 3). So, in contrast to Jaakkola et al.'s (2011) research findings, explicit instruction could considerably improve students' conceptual understanding also in the case of simulated and real activities combination and not only in a simulated environment.

These results have substantial implications for educational practice, enriching at the same time our knowledge about pedagogical and instructional issues (i.e., why and how to use simulations to enhance learning) that are often taken for granted in the framework of TPACK model (Jimoyannis, 2010). Specifically, the results suggest that when teaching students about F/S, the students can gain better understanding when they are explicitly guided to link the simulation and the real experimental settings than if they have implicit instruction concerning the same content.

Concluding, this paper, in conjunction with the relevant literature, contributes to the literature concerning the role of linking real with simulated experiments in two ways: pinpointing the beneficial characteristic of explicit instruction in linking these two types of experiment and indicating an outline of how this linkage could be achieved. Moreover, this linkage is theoretically supported by the concept of analogical encoding. Despite that, further research will be necessary to see whether and how a more intense focus on metacognitive discussions which would link the two different experimental settings of F/S phenomena (simulated and real), could enhance the students' improvement.

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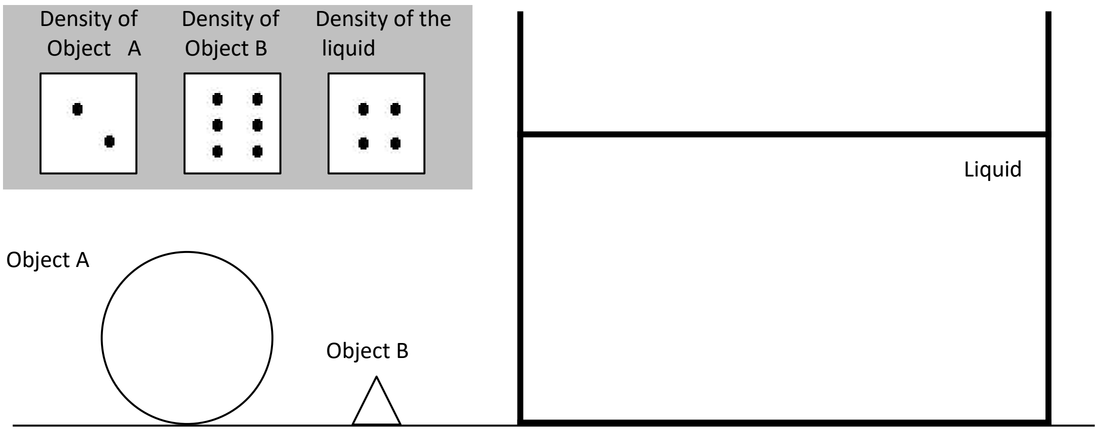
Appendix A. The five questionnaire tasks

Task 1



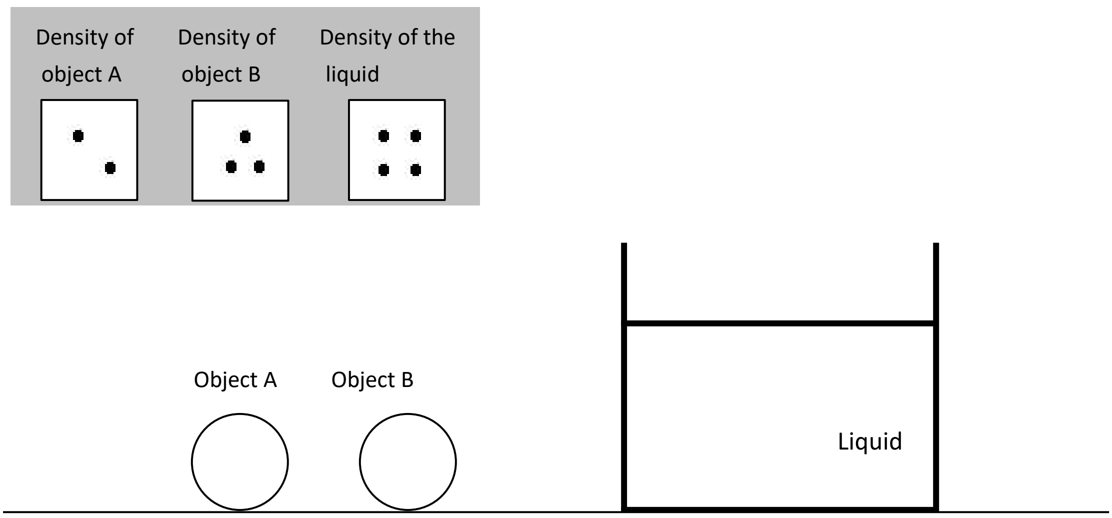
You are given two objects A and B and a vessel which contains a liquid. Both the objects' and liquid's densities are represented with 'the dotted cubes' model, as you can see on the grey panel. If you drop objects A and B in the vessel with the liquid, what will their final position be? Justify your answer:

....

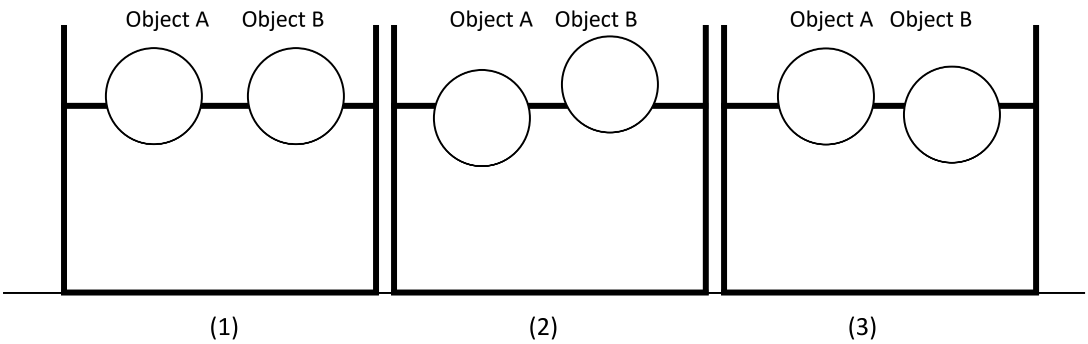
....

Could you draw the objects A and B in their final position within the liquid?

Task 2



Both the objects' and liquid's densities are represented with 'the dotted cubes' model, as you can see on the grey panel. We drop objects A and B into the liquid. Tick number 1, 2 or 3 of the picture which best represents the final positions of the two objects after we have dropped them into the liquid.



Justify your choice:

………
………

Task 3

On a big ship, among others, you can find a life-buoy. Does it float or sink if we drop it into the sea? Justify your answer.

The life-buoy: floats ☐ sinks ☐ I do not know ☐

Because:
………

Task 4

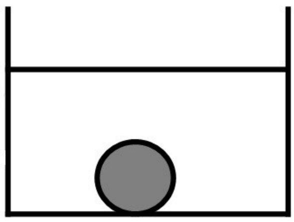
On a big ship, among others, you can find an anchor. Does it float or sink if we drop it into the sea? Justify your answer.

The anchor: floats ☐ sinks ☐ I do not know ☐

Because:
………

Task 5

In the picture, we see a plasticine ball, which is sunk within a tank filled with water. Could you change a feature (factor) so that the ball floats? Describe which feature you would change and in which way.



………
………

To cite this article: Zoupidis, A., Spyrtou, A., Pnevmatikos, D., & Kariotoglou, P. (2018). Explicitly linking simulated with real experiments for conceptual understanding of floating/sinking phenomena. *Themes in eLearning*, 11(1), 35-52.

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