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Teaching science with experimental work and computer simulations in a primary teacher education course: what challenges to promote epistemic practices?

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Abstract

The objective of this work is to study how teachers' mediation can promote the development of students' epistemic practices (EPs), in a classroom environment, using computer simulations (CS) articulated with experimental work (EW). In particular, we want to explore characteristics of teacher mediation using CS articulated with EW as a didactical approach and what EPs occur when students work in the pathway from theory (T) to the observable-world (OW), and vice-versa. We report a multi-case study with two teachers of a primary teacher education course. We use multimodal narratives (a description of what happens in the classroom, using several types of data collected) to analyse the students' EPs and the teachers' mediation. This analysis is made using the qualitative analysis software (NVivo 8®).
The results point that the differences in the occurrences and pathways found in students' EPs can be related to the different characteristics of teachers' mediation. The results also point to the existence of students' epistemic practices that were differently promoted depending on the use of CS or EW, which means an interesting complementarity between the two teaching approaches. When teachers' mediation incorporates the use CSs articulated with EW.

Selection and peer-review under responsibility of the University of Tras-os- Montes e Alto Douro (UTAD)

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Keywords:computer simulation; experimental work; teachers' mediation; students' epistemic practices; epistemic pathway.

1. Introduction

The use of computer simulations (CS) as a complementary tool in classroom is referred in science education literature as particularly adequate [1]. There is a growing interest in interactive and collaborative CS because of their potentials in constructivist learning [2,3]. However this usage in classroom requires some attention regarding the teacher mediation in order to potentiate students learning [4].

Experimental work is also widely understood by the scientific community and by teachers as a teaching strategy with great potential in promoting student learning [5]. However, it is often reduced to a set of instructions that the students have to follow mechanically, without establishing conscious connections between the action and the knowledge in development [6].

Therefore, there is the challenge to design and implement a classroom mediation that integrates experimental work as it permits spaces of liberty, creativity and motivation of students based on problem solving related with everyday life [7,8].

In physical science classroom, teacher should provide epistemic support [9] in order for students' engage on epistemic practices (EPs), which is determinant for personal knowledge construction and epistemic competences development about science and technology. Through the occurrence of EPs students have real opportunities for developing the positive attitudes about science, constructing meanings associated with the practice [10] and developing competences [11].

Teachers' mediation, through actions and languages [12] can scaffold and promote the students' EPs [13], helping them connecting theories, practices and explanations of phenomena [9]. The importance of the mediating role of the teacher is well established in the research literature [14]. The teacher mediates the interaction between learner and environment by selecting, changing, amplifying and interpreting objects and processes [15].

As some important science philosophers show [16] the bridge between observable-world and theory demand both pathways: from theory to observable-world and from observable-world to theory. Data can promote a pathway towards a theoretical construction, which can be useful for many systems; with a theoretical model it is possible to better explore the phenomena, to specify its context of use, or create new artefacts. We used the CS as a didactical resource to explore relationships between theory and the observable-world in topics related to hydrodynamics, electrolysis and hydrogen fuel cell in teacher education (pre and in-service primary school teacher training courses). We use also experimental work articulated with use of CS.

In this work we tried to answer the following questions:

1. How does teachers' mediation promote students' Epistemic Pathways, from theory (T) to the observable-world (OW), and vice-versa?
2. Which Epistemic Practices occur more frequently in the each Epistemic Pathway?
3. Which Epistemic Practices occur more frequently when using Computational Simulations, or Experimental Work, or both articulately?

2. Methodology of research

2.1. Cases and intervenient

This research work consisted on a multi-case study [17] involving two physical science teachers from higher education: one from a masters' program (Teacher A) and another from an undergraduate program (Teacher B); both taught physics in the same higher school of education in Portugal. Their main characteristics and background information are presented in table 1. Each teacher made two interventions, each for a different group of students and in distinctive courses. While in the first intervention the main didactical intentionality and approach were centred in the use of CS, in the second intervention the teacher intentionality and approach were addressed in the use of CS in articulation with EW activities.

Table 1. Main characteristics of Teachers

	Teacher A	Teacher B
Gender	Male	Male
Academic degree	PhD student	PhD student
Teaching experience	20 years	4 years
Research experience	14 years	6 years

The table 2 shows the main characteristics of each intervention.

Table 2. Interventions' main characteristics.

		1st Intervention		2nd Intervention	
		Teacher A	Teacher B	Teacher A	Teacher B
Students	Age range	24-55	18 - 35	18-30	18 - 35
	Grade and course	2nd year of a Master Programme in Science Teaching	1st year of an Undergraduate	1st year of a Master in primary education	1st year of an Undergraduate
	Teaching experience	In-service primary school teacher	No experience	No experience	No experience
Classes	Discipline	Experimental work in Science Teaching	Physics	Didactics of Science	Physics
	Topic	Hydrodynamics – Experimental approaches	Hydrodynamics – Archimedes' Law	Hydrodynamics	Electrolysis and Hydrogen Fuel Cell
	Nr. of students	19	16	24	4
	Classroom	Physics Laboratory; space for 4 work groups, 1 computer per group	Physics Laboratory; 5 work groups, 1 computer per group	Physics Laboratory; space for 4 work groups, 1 computer per group	Physics Laboratory; space for 4 work groups, 1 computer per group
	Time	**240 min** 180 min using CS; 60 min of EW.	**240 min** 240 min using CS; EW was not a didactical strategy	**240 min** 120 min using CS; 120 min of EW.	**240 min** 120 min using CS; 120 min of EW.

2.2. Data collection

We used multimodal narratives as a central component of the hermeneutic unit that encompasses all types of data collected inside and outside the classroom [18]. A multimodal narrative is a description of what happens (actions and language) in the classroom, based on audio recording of the lesson, using several documents and the multimodal elements (schemas of spatial organization of the classroom, schemes put on the blackboard by the teacher and/or by students, student reactions, explicit teachers' intentions and decisions, teachers' documents, photocopies of students' notebook, photographs of used equipment, indication of silences and gestures, print screens of CS, amongst others). They are structured in two parts: a first part where it is given an overview of the class and its contextual elements; and a second part that consists in a detailed description of each episode that takes place. The multimodal narratives were done using the same protocol and validated by external researcher. These characteristics allow comparability. The number of episodes is variable. Each one corresponds to the period of time throughout which takes place a particular task.

2.3. Data analysis

In this study, we have analysed two multimodal narrative of each teacher. Teacher's mediation efforts to promote students' EPs were studied taking into account the way computer simulation (CS) and experimental work (EW), as didactical strategies, were introduced and used in class.

The process of multimodal narratives analysis was done in several steps implying different researchers, based on content analysis [19], and using the coding capabilities of NVivo 8®. In all steps the analysis was made by one researcher of our team, who identified and coded the parts of the multimodal narratives which contained evidences about: (a) students' EPs that took place in classroom and; (b) teachers' effort to promote students' EPs using CS and/or EW as a didactical resource to explore relationships between theory and the observable-world. The analysis using the referred two dimensions of analysis was done based on the research referred in the introduction section and in the research about students' epistemic work developed by our research team [11]. The analyses were data-driven, that is without previous categories. This analysis was made as follows:

(a) Select and code the parts of the multimodal narratives related to the pathways from OW to T and from T to OW;
(b) Select and code the parts of the multimodal narratives related to the use of CS and EW;
(c) Identify and code the parts of the multimodal narratives that contain evidences about the occurrence of students' EPs (Fig. 1).

The criterion used to recognize this occurrence was the identification of students' investigative actions, in order to solve a problem or answer to a question [20].

Each category was given a name and a brief description (see table 3). In order to get an effective verification, all multimodal narrative were reanalysed by other researchers (also using NVivo 8®), using the same criteria for evidences. In this verification, a 95% of agreement was obtained in categorizations made by two researchers. When any divergence in the analysis process occurred, the involved researchers discussed and reflected together in order to achieve consensus about the emergent categories.

Fig. 1 shows the result of the coding process. On the left side we see an excerpt from a MN and on the right we can see the bars indicating the occurrence of students' EPs and pathways followed.

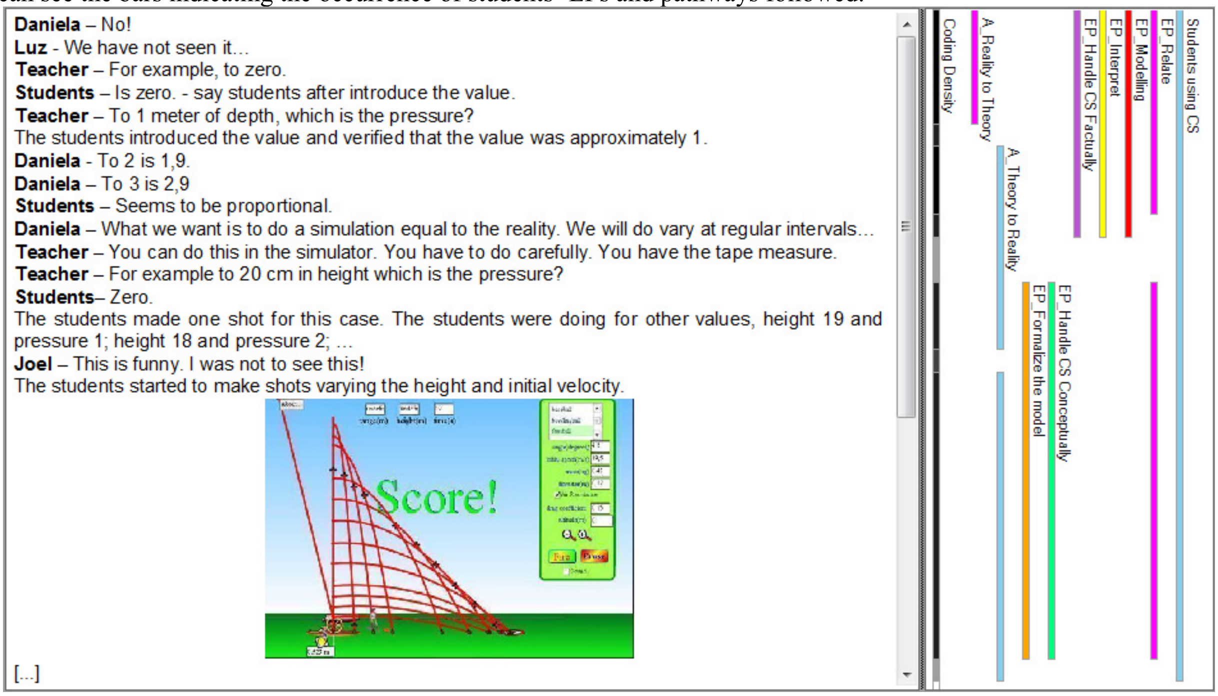

Fig. 1. Coding process example.

3. Results and discussion

3.1. How Teacher Mediation influences Student's Epistemic Pathways

The tasks and the CSs introduced by Teacher A had the main objective of formalising a model that could explain the observable phenomenon of water flowing through a hole made in a bottle. Teacher challenged students to find the best position to make the hole in a plastic bottle, so that the water would go as far as possible, once the bottle was placed on a table. Teacher gave autonomy to explore the CSs and followed students' work. His main task was interacting with students to reinforce their motivation, challenge students to compare the obtained results (using the CS) among them and share their point of view. It was used two CSs available on internet: Projectile Motion – PhET (Fig. 1), that allowed students to predict how varying initial conditions affect the trajectory of a projectile; and Hydrostatic Pressure in Liquids – Fendt, that allowed students to explore the relation between hydrostatic pressure and depth

The tasks and the two CSs introduced by Teacher B had different characteristics: students used an existing model that allowed them to simulate different situations of the observable phenomenon of fluctuation. One CS used was Buoyancy – PhET that allows exploring how buoyancy works with blocks and the other was an Excel spreadsheet simulation [21] (Fig. 2). By inputting data in this simulation, students could determine the minimum of potential energy of a system composed by a body in a fluid. In this case, teacher distributed a guide of activities that defined, in a general way, the dynamics of the class. The teacher followed closely students' work, asking them to explain tasks development in detail in order to motivate and engage them in the activity. The teacher gave detailed information, in particular, about the excel simulation due to its characteristics.

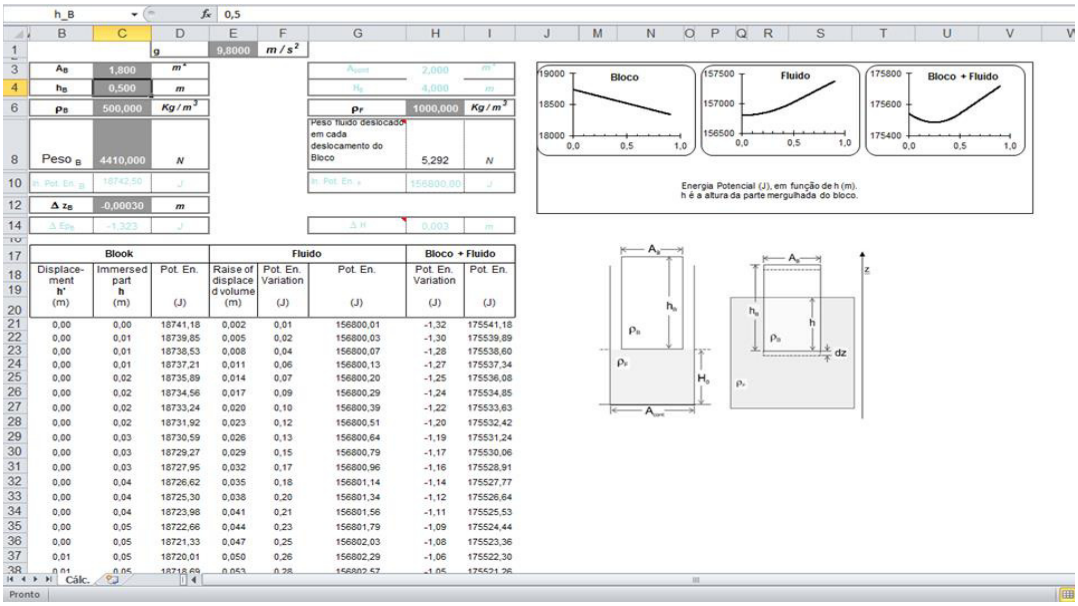

Fig. 2. Layout of the excel simulation.

In the second intervention both teachers used CS in articulation with EW activities.

Teacher A reissued the first approach in its main features: goals, challenge and available resources. It was a work developed in a new course and in a new discipline. Although the general profile of mediation had continued, the second intervention sought to a different time management, giving a better balance along the class, creating more space for organizing and systematizing information. Although the tasks were the same, there were more details requested. Students had the opportunity to explore and discuss situations during the use of CS and, faced with the experimental challenge, to decide which experiments to do, how to do it, with what materials, deciding what to observe and how. Teacher gave autonomy and followed students' work.

In his second intervention, Teacher B dealt with the topic of electrolysis and hydrogen fuel cell. To do this he used two simulations: one on electrolysis (http://www.sepuplhs.org/high/hydrogen/electrolysis_sim.html) (Fig. 3a) and another about the fuel cell (http://www.sepuplhs.org/high/hydrogen/fuelcell_sim.html) (Fig. 3b). The main tasks proposed by the teacher were: to explore the potentialities of the simulation and the processes that it demonstrated, discuss the importance of each process (electrolysis and fuel cell) and make small schemes on the flows of matter and energy in each of the processes.

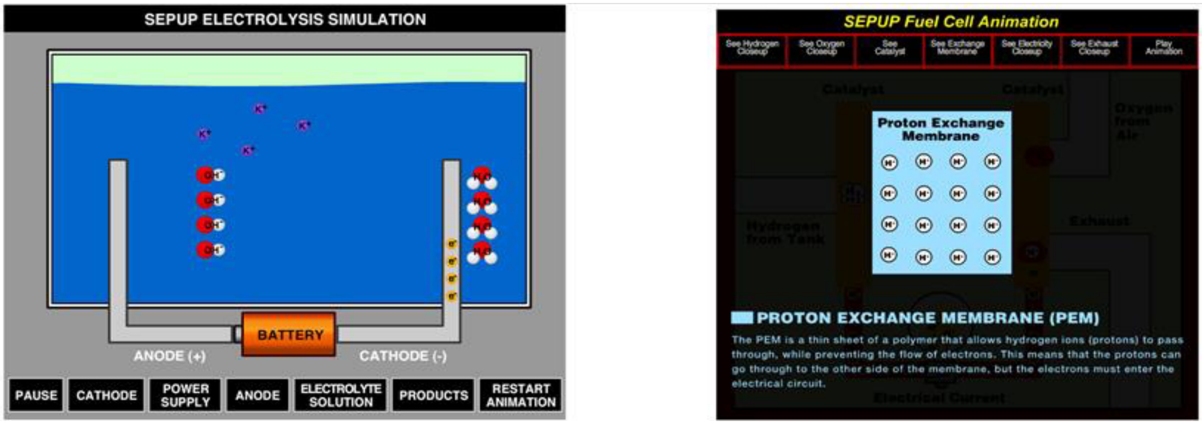

Fig. 3. (a) Simulation about Electrolysis (http://www.sepuplhs.org/high/hydrogen/electrolysis_sim.html); (b) simulation about Fuel Cell (http://www.sepuplhs.org/high/hydrogen/fuelcell_sim.html).

In addition, it is also explored a kit of an actual fuel cell (Fig. 4), that included a photovoltaic panel which supplied the energy necessary for electrolysis of water, from where the hydrogen was obtained and used in the fuel cell. The main tasks were: to assemble and operate the kit, make a schematic diagram of the system, make a debate on the functioning of the kit and about the schematic diagrams of the various groups. Also, to make the following experiments with the system: unplug a part of the system; simulate a malfunction; cover the sun; put distilled water in the water container; unplug the gas supply tubes, calculate the efficiency of the central part of the system (calculating the electrical power supplied by the photovoltaic panel and the one received by the motor, using voltmeters and ammeters). There were therefore two important approaches in this intervention: one that included the use of computer simulations and other which involved experimental work.

These EW and CS posed a demanding request upon students understanding, being about subjects that were not completely straightforward.

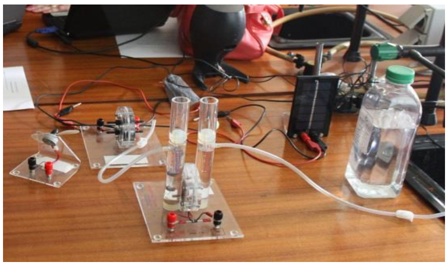

Fig. 4. Photo of the Fuel cell kit.

These different mediation options led to different occurrences of students' EPs in each pathway. This result is in accordance with literature [9,12,13] and stresses that teachers' intentionality has large impact in students' epistemic pathway. The total number of students' EPs occurrences per 60 minutes can be seen in table 3 for each teacher, in each intervention, for both pathways, from observable world to theory (OW-T) and from theory to observable world (T-OW).

Table 3. Total number of students' EPs occurrences in both T and OW pathways.

	1st Intervention		2nd Intervention	
Pathway	**Teacher A**	**Teacher B**	**Teacher A**	**Teacher B**
OW-T	31	8	26	2
T-OW	4	10	8	27

Regarding the two pathways (OW-T and T-OW), there were some patterns that can be found (table 3). In the case of Teacher A, most of students' EPs occur in the pathway OW-T, even though in 2nd intervention this difference is attenuated. With Teacher B most of the students' EPs occur in the pathway T-OW. In the 2nd intervention this aspect was reinforced. This fact enhances the different need of students to mobilize theoretical aspects when developing certain students' EPs. This trend of students' epistemic pathway is in accordance with teaching intentionality in both interventions: obtain a model to explain observable phenomena – Teacher A, and use an existing model to understand how it works in different situations – Teacher B. This also can be related to the different type of mediation carried out by teachers. Teacher A, in both interventions, wanted the students to formalise a model that they could use in others situations. On the other hand, Teacher B used a model as a starting point, and the first need of students was to understand how the model worked. In this situation, *questioning* is an expectable attitude of students.

Even though the time spent in each intervention was the same (240 min), the occurrences of students' EPs in the pathway OW-T decreased in the 2nd intervention, while in the other pathway (T-OW) they increased. This might have been influenced by the relevance given to EW in the 2nd intervention.

3.2. Students' Epistemic Practices identified in each pathway (T-OW, or OW-T) and in each approach (using CS, or performing EW)

From the multimodal narratives analysis we identified the students' EPs that are presented in table 4.

Table 4. Categories of students' EPs

Students' EPs	Brief definition
Prediction	Make predictions of experimental or theoretical results based on the reasoning with knowledge.
Identify empirical conditions	Identify empirical conditions of a physical situation in which the phenomenon(a) occurs.
Questioning	Formulate questions and problems based on knowledge to obtain new understanding of phenomenon, concepts, models or to clarify terms or observations related to empirical conditions of a phenomenon.
Communicate	Present ideas about their epistemic work to the class
Relate	Establish relations between data variables and/or concepts in different situations.
Handle equipment factually	Handle equipment or CS following instructions given by teacher, or tentatively without any guiding knowledge.
Modelling	Develop a conceptualization pathway in order to construct a model of a system.
Formalise the model	Establish a model of a system.
Handle equipment conceptually	Handle equipment or CS guided by knowledge.

In table 5 we present the total number of students' EPs occurrences per 60 minutes for each teacher, in each intervention, when using CS or EW. Considering the moments when CS or EW are used, we found that in the second intervention the number of EPs is similar to 1st intervention in the case of Teacher A, and increased in the case of Teacher B. However, looking at the moments when CS is used by itself, in contrast to what happened in moments of performing EW, we find that from the 1st for the 2nd intervention there was a decrease in the number of EPs in both cases. This should be taken into account when deciding whether to use CS in articulation with EW.

Table 5. Total number of students' EPs occurrences.

	1st Intervention		2nd Intervention	
	Teacher A	**Teacher B**	**Teacher A**	**Teacher B**
CS	17	18	11	8
EW	18	0	23	21
Total EPs	**35**	**18**	**34**	**29**

Fig. 5 and Fig. 6 express the number of occurrences normalized per 60 minutes when, in a given time, students are using the CS or performing EW, in each intervention of both teachers.

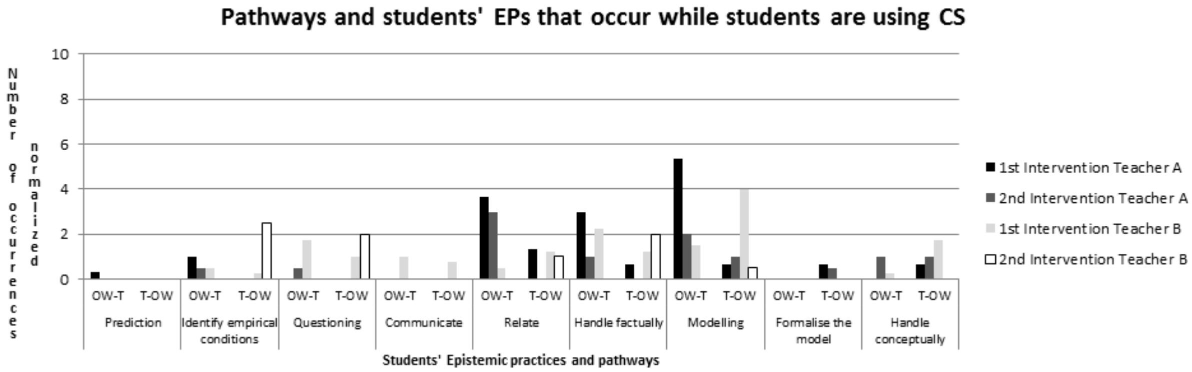

Fig. 5. Students' EPs that occur from observable-world to Theory (OW-T) and from Theory to observable-world (T-OW) pathways, during the use of CS.

There is a good diversity of students' EPs in both activities (CS or EW). The use of CS or EW provide a clear complementarity for certain students' EPs (e.g. *prediction* and *communicate* when performing EW, or *modelling* or *handle conceptually* when using CS). These results indicate that the combination of use of CS and EW in the classroom increases the possibility of students developing epistemic practices.

As mentioned, EW was not a didactical focus in the first intervention. In particular, there was no EW conducted by Teacher B, which justifies the absence of students' EPs related to experimental work in his first intervention (Fig. 6).

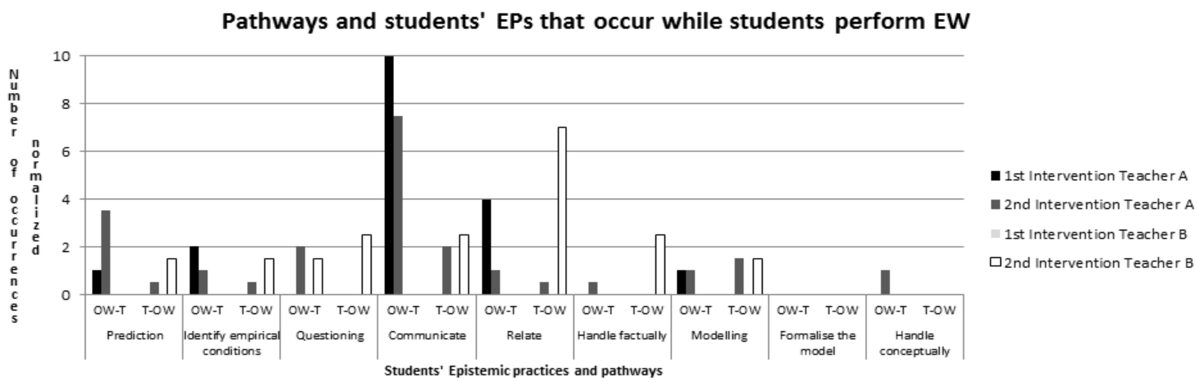

Fig. 6. Students' EPs that occur in from observable-world to Theory (OW-T) and from Theory to observable-world (T-OW) pathways, during the use of EW.

Regarding the type of students' EPs that occurred, we can compare: (a) use of CS and EW and (b) pathways (OW-T and T-OW). Some tendencies were observed:

There are some students' EPs that appear more frequently in one of the type of activity (EW or CS). For example, *prediction* occurs much more often in EW, in contrast to what we expected following to the literature [22]. While using the CS, students are prone to immediately experiment what they are seeing, rather than predict. On the other hand, the EP *Identify empirical conditions* occur more often during the use of the CS. This may happen because the interactivity of the CS allows students to immediately identify the empirical conditions. Also, *relating*, *modelling* and *formalise the model*, which are EPs related the construction of knowledge, occur more often during the use of the CS. The use of CS gave students more inputs, perspectives and insights that are fundamental to the construction of knowledge. In addition, CS works as empirical referent that students can work intellectually. This is not guaranteed to happen when students explore experimental materials. It may be that students do not have tacit knowledge about the materials and so they are limited regarding to intellectual work they can do. This seems to have happened when students explored the fuel cell kit (2nd intervention – Teacher B). The complexity of materials and equipment for which the students had no tacit knowledge made intellectual work a great challenge. The occurrence of the students' EPs *handle factually* and *handle conceptually* is also observed more often with the use of CS than when conducting the EW (figures 5 and 6). An explanation might be the fact that there is a strong interactivity with the CS. Since the interaction with the computer is easy and the feedback obtained with the CS is immediate this leads to less *communication*. Also, this interactivity has no consequences (material damages, costs, danger...) when compared with EW. The use of CS allowed more diversity and number of students' EPs than with EW.

A more detailed analysis of figures 5 and 6 allow us to identify cases of students' EPs whose pattern of variation from the first to the second intervention is not well defined. Taking the example of the EP *Modeling* when using CS (Fig. 5): in the case of Teacher A decreases sharply in the pathway OW-T but increases slightly in the pathway T-OW; whereas in the case of Teacher B decreases in both ways.

Another example is the students' EP *handle conceptually*, when using CS: in the pathway OW-T it increases in the case of Teacher A and decreases in the case of Teacher B; on the other hand in the pathway T-OW it slightly increases in the case of Teacher A and decreases sharply for Teacher B. Also, in Fig. 6 we find identical cases (e.g., the students' EP *communicate*, for teacher A decreases in OW-T and increases in T-OW, and for teacher B it does not change in the pathway OW-T and increases in T-OW).

This lack of a well-defined pattern shows that articulated use of CS and EW (2nd intervention) allows significant gains but may also cause some losses. This should be taken into account by teachers in their lesson plans and it is a challenge for future research towards a greater understanding and enlightenment.

The immediate feedback [23, 24] provided by the strong interactivity of CS encourages students' EPs such as *handle factually* and *handle conceptually* and moderates the occurrence the EP *communication*.

The outcomes also point to the fact that students need some time in order to engage with the resource/teaching approach and be able to produce more quality work (here measured in terms of students' EPs developed). In fact when this time increased, the number of students' EPs was greatly amplified.

4. Conclusions

Results show that when teachers take observable phenomena to challenge students in finding explicative models, students tend to follow through the pathway OW-T. On the other hand, when class starts exploring an interpretative model and, from it, challenge students to simulate or to find examples of observable phenomena, students follow through the pathway T-OW. That is, different mediation options lead to students privilege different epistemic pathways.

Although some students' EPs occurred easily in a certain pathway (OW-T: *identify empirical conditions*, *communication* and *relate*; T-OW: *questioning*), the diversity of students' EPs found in both pathways allows us to conclude that there isn't a type of epistemic practice that determines a pathway. This enrichment of students' challenges contributes to more significant learning favouring different learning styles, which is in agreement with literature [25].

This study, with the focus on two different didactical approaches (CS or EW) showed that some students' EPs emerge more frequently in a specific approach in both pathways. Even though both approaches reveal a good diversity of students' EPs, some appear more frequently in one or the other. The use of CS stimulates students' EPs such as *identify empirical conditions*; *relate*; *modelling* and *formalise the model*, whereas the EW fosters students' EPs such as *prediction* and *communication*. These results suggest that when teachers' mediation comprises the use of CSs and EW increases the potential in promoting student's EPs in number and quality, which reveals an interesting complementarity between the two teaching approaches. This complementarity is, in general, in accordance with the literature, but the specific students' EPs that can be developed with each one approaches is not in accordance with some literature results. Besides, it is not completely clear how this complementarity is related to the characteristics of teacher mediation.

In this study it was identified that the increase of the pathway T-OW in the second intervention coincided with the increase in EW. More studies comparing these approaches, in different situations and mediated by different teachers are needed in order to observe this tendency and be able to draw more conclusions.

Note: The CSs used can be viewed at http://phet.colorado.edu/en/simulation/projectile-motion; http://www.walter-fendt.de/ph14e/hydrostpr.htm; http://phet.colorado.edu/en/simulation/buoyancy; http://www.sepuplhs.org/high/hydrogen/fuelcell_sim.html; http://www.sepuplhs.org/high/hydrogen/electrolysis_sim.html.

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