Res Sci Educ (2011) 41:787–809
DOI 10.1007/s11165-010-9190-5

'Learning Experience' Provided by Science Teaching Practice in a Classroom and the Development of Students' Competences

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Published online: 28 September 2010
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Abstract According to the literature, there is a very important corpus of knowledge that allows for the investigation of some dimensions of 'learning experience' provided to students, in relation to epistemic, pedagogical and meta-cognitive practices. However, in the literature, there is little investigation into the invariance (or not) of the characteristics of students' learning experience while being taught a scientific subject by the same teacher. This paper suggests that the relationship between the learning experience provided and the competences developed is not properly highlighted. This paper analyses the learning experience provided to students in epistemic, pedagogical and meta-cognitive terms. The students were taught the proprieties and applications of light by one teacher, in three classes, over 7 weeks. We analysed the data in each referred learning experience, using a pre-defined category system. The students' competences were evaluated by a competence test. The epistemic demand of each item and the students' performances were also analysed. Our findings point to the non invariance of learning experiences provided to students and the influence of some dimensions of learning experiences provided in the development of certain competences. These findings and their implications are contextualized and discussed.

Keywords Science teaching practice · Learning experience provided · Epistemic practices · Students' competences · Classroom science · Light

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Introduction

In recent years, many science education researchers have focused on classroom science education. For example, there is one research line that investigates an intentional teaching effort, which allows for a high level of learning outcomes in certain domains (e.g. Adúriz-Bravo et al. 2003; Andersson and Bach 2005; Buty et al. 2004; Lopes 2004; Méheut and Psillos 2004; Savinainen et al. 2005).

The present research is about science teaching practice, which can provide students with a certain 'learning experience' (in epistemic, pedagogical and meta-cognitive terms) and can influence the development of students' competences. Any science teaching practice provides students with a certain learning experience. However, the development of students' competences may be influenced by their learning experiences in the classroom. The goal of this study is to highlight these relationships. These relationships have a complex nature particularly because they can be analysed through many perspectives. However, science education research has a corpus of studies (as shown below) on: (i) learning experiences provided to students by science teaching practices; (ii) students' competences development.

Learning Experiences Provided to Students

The learning experiences provided in science classes are related to classroom practices and are conditioned by science teaching practices. These can be influenced by the teachers' subject content knowledge (Childs and McNicholl 2007) or by the teachers' conceptions of teaching and learning (Boulton-Lewis et al. 2001). In order to change their practice, a teacher needs collective and individual support in the classroom (Jones and Eick 2007). However, the characterization of teaching practices in science education has an important corpus of knowledge.

We will focus on research about teaching practices that provide certain learning experiences in epistemic, pedagogical and meta-cognitive terms. Jimenez-Aleixandre et al. (2005) characterized teaching practices in terms of their pedagogical dimensions, based on Toulmin's intellectual ecology. The pedagogical dimensions of teaching practice concern the role given to students in tasks and discussion, the classroom climate created to help students work and manipulate physical situations and the status teachers give to the students' ideas. The same authors found meta-cognitive dimensions in teaching practices, which consist of making explicit the status of students' ideas, what they learned or the relationships among the concepts. There is considerable research about characterizing teaching practices, in terms of epistemic practices (e.g. Kelly and Crawford 1997; Kelly and Chen 1999; Kelly et al. 2000; Reveles et al. 2004). Epistemic practice concerns the students' work guided by the teacher in order to construct knowledge, having, as reference, scientific practices. The epistemic practices emerged from students' attempts to solve a problem or task, mobilizing prior knowledge and using procedures like description, representation, prediction and so on. This characterization used epistemological foundations that arise from the analysis of scientific production in an enlarged context. Another example of this type of research is a study carried out by Crawford (2000), which examined the beliefs and practices of a teacher who successfully developed and sustained inquiry-based teaching in a classroom to embrace the essence of inquiry, by proposing a model of inquiry. Several studies have confirmed that teaching practices centred on students are more effective for student learning (e.g. Akkus et al. 2007; Kahle et al. 2000).

However, more important than the a priori characteristics of teaching practices, are the actual characteristics of teaching practices in the classroom (Akkus et al. 2007) and the teachers' determination to change their teaching practices (Peers et al. 2003). It is not sufficient to desire a teaching practice with certain characteristics. The difference between characteristics of desired teaching practices and actual teaching practices may be remarkable.

For example, Windschitl (2003) found that the participants who eventually used guided and open inquiry during teaching were not those who had authentic views of inquiry, or reflected most deeply on their own inquiry projects; instead, they were the individuals who had significant undergraduate or professional experience with authentic science research.

Teaching practices can also be characterized by students' perceptions. For example, Darby (2005) focused her analysis on how students perceived the role of the teacher's pedagogy in constructing a learning environment they considered encouraging, regarding science learning. On the other hand, Scantlebury et al. (2001) designed, validated and used an evaluation instrument to measure changes in teaching practices.

Students' Competences Development

Competence as a concept is particularly complex; it has been used in a professional context (medical education, e.g. Fox and West 1983; engineering education, e.g. Cabrera et al. 2001; teacher education, e.g. Korthagen 2004). One reason for this complexity is the need to derive a social consensus about the choice of which competences will be assessed and how (Wright et al. 1998). In general terms, we adopted the definition developed by Kirschner et al. (1997, p. 151): "We define competence as the whole of knowledge and skills which people have at their disposal and which they can use efficiently and effectively to reach certain goals in a wide variety of contexts or situations". People are more competent than others are if they are able to mobilize similar knowledge and skills in a larger variety of contexts and situations. Competences development is an iterative process, enlarging knowledge, skills and the contexts and situations in which a person is capable of using them efficiently and effectively. The higher the degree of iteration in the synthesis of the student's competences, the more competent they become (Valverde-Albacete et al. 2003). Therefore, it is possible to evaluate some competences, assessing atomic competences in several contexts and using different concepts (Gregoire 1996). In this context, Lopes and Costa (2007) developed and tested an evaluation methodology for modelling competences and the results indicate that the test identified and delimitated specific modelling competences.

Learning Experience Provided to Students and Students' Competences Development

There are a few studies relating classroom-based science-related learning experiences to the development of students' competences. Three of these studies link teaching practices with students' achievements. Odom et al. (2007) showed that student-centred teaching practices have a positive association with student achievement and a negative association with teacher-centred teaching practices in middle-school science. Taraban et al. (2007) compared teaching that favoured activities in classrooms, which involved students (more collaborative and laboratory-based), to teaching that favoured activities in classrooms, which did not involve students (traditional worksheets). They showed that students gained significantly more content knowledge and knowledge of process skills using the laboratories compared to traditional instruction. Johnson et al. (2007) demonstrated that effective teaching affects positively student learning. The findings obtained by Dean Jr. and Kuhn (2007) supported the importance of learning experiences provided in science classes in the development of students' competences. In particular, we intend to concentrate on: (i) some teaching practices previously studied as epistemic practices (e.g. Jimenez-Aleixandre and Reigosa 2006; Reveles et al. 2004; Samarapungavan et al. 2006) and pedagogic and meta-cognitive practices (e.g. Jimenez-Aleixandre and Reigosa 2006), and (ii) the competences of using knowledge of optics in concrete situations. Obviously, what a teacher does in the classroom depends on their actions and interaction patterns with students. The teacher's actions consist of providing support for learners in complex tasks that enable students to deal with more complex content and skill demands than they could otherwise handle (Reiser 2004).

We are aware that the relationship between the learning experience provided and competences development is complex, therefore not necessarily causal. However, Scantlebury et al. (2001) showed that standards-based teaching practices were the strongest independent predictor of both achievement and attitude, even though we know that achievement may not be sufficient to ensure a student becomes competent.

Research Questions

According to the literature, there is a very important corpus of knowledge allowing us to investigate some dimensions of learning experience provided to students, in terms of epistemic, pedagogical and meta-cognitive practices. However, there is a lack of investigation on the invariance (or not) of the characteristics of the learning experience provided to students, by the same teacher, during the teaching of different science topics. In addition, as discussed, the relationship between the learning experience provided and the competences developed is not properly highlighted.

Consequently, we intend to focus on science teaching practices in the classroom to identify if the learning experiences that are provided retain their characteristics during the teaching of different topics, and to identify the influence of the learning experiences on competences' development. In particular, the research questions are:

> Research Question 1—What learning experiences does the teacher provide to the students in epistemic, pedagogical and meta-cognitive terms? Are the main characteristics of learning experiences invariant during the teaching practices that focus on the different topics taught?
>
> Research Question 2—What are the relationships between the dimensions of the learning experiences provided in the classroom and the development of the competence of using optical knowledge in concrete situations?

Study Description

Participants

The study was carried out in a school in a rural region of Southern Europe with students between the ages of 13 and 16 (grade eight). The topic was 'properties and applications of light'. Three classes took part in the study: class A with 21 students, class B with 20 students and class C with 22 students. Table 1 shows some of the characteristics of each class. The teacher and the school are the same. The 36 year-old teacher is a graduate in

Table 1 Characteristics of participants in study

	Number of students	Age	Students repeating the year	School support (a)	Parents' educational background (b)
Class A	21 (11 boys; 10 girls)	13 or 14 some 16	2	Social support: 17 Special curriculum support: 1	Grade 4: 13 Grade 6: 6 Grade 9: 2
Class B	22 (7 boys; 15 girls)	13 or 14 (some 16)	4	Social support: 19 Special curriculum support: 4	Grade 4: 16 Grade 6: 6
Class C	22 (14 boys; 8 girls)	13, 14, 15 or 16	10	Social support: 19 Special curriculum support: 2	Grade 4: 18 Grade 6: 4

(a) School aids to student who needs financial aids for transport, food and school materials (social support) or school supplementary service to students who have learning disabilities (special curriculum support)

(b) The number of years the students' parents have been involved in the school

physics and chemistry teaching, has an MSc. (a Master's Degree) in physics and chemistry education and has 10 years teaching experience.

In classes A, B and C, the majority of the students demonstrated little interest in physics. In class C, the lack of interest extends to the school itself.

Data Collection: Teaching Practices

The following data about teaching practices was collected:

a) The curriculum designed by the teacher (contains: problems posed, situations analysed, tasks proposed to students; main concepts and theoretical models to use, resources and some traits of teacher mediation).
b) Documents produced or used by the teacher.
c) Students' notebooks.
d) Photographic recording of the 'what I know' (written on the blackboard), with task presentation, and 'what I did' and 'what I learnt' (written on the blackboard) after the accomplishment of each task or the teacher's intervention.
e) Teacher's notes of each lesson.

With this material, the teacher narrated what would happen in the classroom, in a detailed and descriptive way. This narrative corresponded with the temporal order of occurrence. It described: tasks proposed and tasks accomplished, teachers' interventions, questions posed, students' answers, reproduction of some dialogue, graphical schemes used, photos of students working in groups and the reproduction of what was written in 'what I know' (in task presentation) and 'what I did' and 'what I learnt' (after the accomplishment of each task or teacher intervention).

Main Characteristics of Intended Teaching in the Classroom

The teacher's objective was to design, implement and evaluate a feasible research-based curriculum unit (optics, grade eight) aiming to improve learning and teaching quality and student satisfaction.

The design and implementation of this curriculum is based on the Formative Situation framework (Lopes 2004; Lopes et al. 2009), which emphasizes the role of tasks, teacher mediation and articulation. In this framework, the tasks proposed to the students are based on their knowledge and skills; they are also connected with a relevant STS (Science, Technology and Society) context and should be adequate in developing certain competences. On the other hand, teacher mediation (Lopes et al. 2008) articulates the students' knowledge and interests with the activity developed by students and the conceptual field[1] object of teaching.

The curriculum's design takes into account the official curricular orientations (from the Ministry of Education 2001). The implementation lasted for a period of 7 weeks, in 14 lessons of 90 min each. It was composed of a network of 12 teaching modules. Each teaching module involved: (i) the physical situation to explore and use; (ii) the underlying conceptual field in terms of concepts, theoretical models, language and situations that give meaning to the concepts; (iii) student task proposals; (iv) material resources and equipment available; (v) some information about students' knowledge and skills; (vi) teacher mediation traits; (vii) forms to assess the ideas of students; (viii) expected learning outcomes in terms of knowledge, competences and attitudes to develop.

The teacher prepared a detailed mediation for the classes, taking into consideration the following points:

> First, the space organization was carefully considered: the tables were rearranged to allow group work and clusters of tables were adjusted to allow the teacher to work with all students. The resources were made available to all groups.
>
> Second, the teacher organized interactions within the groups by attributing specific roles to some students. There were three main roles: the group leader, the group reporter and the student who was to encourage the team to work; students, who assumed these roles in each group, rotated. This organization created a favourable classroom climate.
>
> Third, the classroom dialogue was organized in the following three steps: (i) after the students had read and tried to understand what had been asked of them, they were invited to explain what they knew by writing 'What I know' on the board; (ii) after accomplishing the tasks, students were invited to make clear 'what I did' , describing what they observed and/or did to develop the answer to the first task; (iii) after a discussion of students' ideas and after the teacher's summary (based on students' work and ideas), the students were invited to make explicit 'what I learnt'.

Simultaneously, the teacher decided, in general terms, on the type of support and information to give the students. The support given to students was a balance between tutoring, monitoring, negotiating and challenging. The tutoring was provided at short intervals, when necessary. The monitoring was provided during the execution of tasks. The negotiating was provided after the execution of the tasks. The challenging component was only used during the project work.

Data Collection: Students' Competences

We collected the data on students' competences, namely the answers on the pre- and post-tests (the description of the competence test and its analysis is described below).

[1] According to Vergnaud (1987, 1991), a conceptual field is a set of interrelated concepts (emphasis on the relational nature of scientific concepts), with a certain dimension and structure, which allows subjects to operate, approach, think and act in a wide range of situations and/or problems.

Competence Test

Student performance before and after instruction was evaluated using a pre-, and post-test, previously validated by two science education experts. The test was composed of 19 items. Thirteen of those items intended to evaluate the competence of using optical knowledge in concrete situations.

The same test was given as a pre-test to all classes 2 weeks before instruction, and as a post-test 2 weeks after instruction.

The answers to each item were evaluated with the following methodology: first, we reproduced all answers and grouped them in performance levels; second, we categorized each group of answers in terms of levels of performance (Lopes et al. 1999). A table was made with the number of answers in each category/level by item. Then, for each item of each group, the weighted average was calculated using the following formula:

$$WA = \frac{\sum (An^{*} Vn)}{T}$$

where: WA is weighted average; An is number of students with answers assessed in level n; Vn is valuation attributed in level n; T is total number of students.

The normalized gain from pre-test to post-test for each item was calculated using Hake's formula (Hake 1998):

$$G = \frac{WA_{pos} - WA_{pre}}{V_{\max} - WA_{pre}}$$

where: G is normalized gain; WA_{pos} is post-test weighted average; WA_{pre} is pre-test weighted average; V_{max} is maximum valuation attributed to each item.

We have presented the categorization according to levels of performance (CP) for two items with different performance by the students: Table 2 for item 1.1 and Table 3 for item 10.2. Levels 0 and 1 are pre-conceptual, level 2 is in empiric zone and the levels between 3 and 5 are the conceptual zone. This categorization was inspired by Mortimer (2000). To categorize the answers in the pre-conceptual zone, we used the work of Viennot (1996).

Table 2 Categorization of the answers to item 1.1 in terms of levels of performance

CP	Level of performance	Examples of students answers
0	Absence of answer, or wrong answer with a justification without sense	No football because our sight is influenced by the dark
1	Correct or wrong answer with a justification according to an alternative conception	The light reflects on the eyes and from the eyes it reflects on the ball, that is how I see the ball on the bed
2	Correct answer with a justification close to objects or events	The light does not reach the ball that is under the bed
3	Correct answer with a justification using one conceptual idea	The bed does not allow light (it is not transparent) to illuminate the ball
4	Correct answer with a justification using more then one conceptual idea	The light only hits the ball that is on the bed Underneath it is shade and there is no light to strike and reflect on the ball
5	Correct answer with justification that articulates the principal conceptual ideas relevant to the answer	The light rays beam on the ball and reflect into our eyes. The rays don't beam on the ball that is under the bed and they don't reflect into our eyes

Table 3 Categorization of the answers to item 10.2 in terms of level of performance

CP	Level of performance	Examples of students' answers
0	Absence of answer, or wrong answer with a justification without sense	With these mirrors we didn't get to see the reality of things
1	Correct or wrong answer with a justification according to an alternative conception	Concave mirror because we were able to see the cars on the other side
2	Correct answer with a justification close to objects or events	Convex mirror, because it allowed us to increase our vision area
3	Correct answer with a justification using one conceptual idea	Convex mirror: it makes the objects smaller. It allows us to see at a greater distance and the car, in that mirror, is smaller
4	Correct answer with a justification using more then one conceptual idea	Convex mirror: it gives smaller images than the object, virtual and direct
5	Correct answer with justification that articulates the principal conceptual ideas relevant to answer	There are no examples

Item 1.1

"1 –Suppose you are in your bedroom with the windows completely closed, having no light coming in from the outside. You have a blue football on your bed and under your bed; you have another football, which is similar.
1.1 - You sit down on your bed and you switch on your bedroom ceiling light, located directly above the centre of your bed. You can see:

- The football on the bed	- The two footballs
- The football under the bed	- No football

Explain your choice"

Item 10.2
"If you have already visited 'mirror houses' you must have noticed that your image appears different, from mirror to mirror. Look at the concave side of a tablespoon and then at the convex side; if you move it away from and towards your face, you will see that your image changes. 10.2. Which of these mirrors is most commonly found at road crossings with poor visibility? Explain your choice"

Results and Discussion

The discussion in this section is organised around the two research questions, which are discussed in turn.

Research Question 1: What Learning Experiences Are Provided?

We analysed the learning experience provided to students by teaching in epistemic, pedagogical and meta-cognitive ways. In general, the learning experience was different from the teaching design. In our study, the teaching was prepared and based on a formative situation framework. However, the learning experience provided depends not only on its design but also on the teacher's background (in scientific, educational and personal terms), on the student's background and interest and on the social interactions between students and teacher. In general, we have framed the analysis of the learning experience provided by the teaching, in terms of three dimensions:

- Pedagogical (PED) dimension. This dimension is based on the work of Jimenez-Aleixandre et al. (2005), which took into account intellectual ecology.
- Meta-cognitive (MET) dimension. This dimension is also based on the work of Jimenez-Aleixandre et al. (2005).
- Epistemic practices (EP) dimension. This dimension is based on the work of Kelly and collaborators (Kelly and Crawford 1997; Kelly and Chen 1999; Kelly et al. 2000; Reveles et al. 2004).

The definition of the categories in each dimension is shown in Table 4. In each dimension, some categories are derived from our framework and the others are derived from the respective referenced work.

The *corpus* that we analysed was composed by 'data collection—teaching' referred above. From these data, we identified four parts; each one is related to a group of items

Table 4 Dimensions and categories to analyse learning experiences provided by teaching

Dimensions of analysis	Categories
Pedagogical (**PED**) (Jimenez-Aleixandre et al. 2005)	1. Students' ideas taken into account. The students' ideas are considered in the conception of tasks and in the teacher–student interaction
	2. Students' active role. Students accomplish the tasks proposed
	3. Explanation. The issue is the object of explanation by the teacher
	4. Classroom climate. The classroom climate allows student participation in the dialogue
	5. Activity discussion. The results of an activity are presented and discussed to enrich concepts
	6. Manipulation of physical situation. Students can manipulate the physical situation presented and propose representations
Metacognitive (**MET**) (Jimenez-Aleixandre et al. 2005)	1. Students' ideas evaluated. Students' ideas are explicitly solicited and assessed
	2. Status of students' previous ideas. The status of what students previously know is made explicit
	3. Status of students' learning. The status of what students learn in class is made explicit
	4. Conceptual field discussed. The conceptual field is explicitly discussed
Epistemic practices (**EP**) (Kelly and collaborators)	1. Description. The teacher asks and aids students in describing phenomena
	2. Phenomena in context. The teacher asks and aids students to recognize phenomena in context
	3. Phenomena-representation. The teacher asks and aids students to connect physical phenomena with their representations
	4. Representation of a physics construct. The teacher asks and aids students to connect representation with a physics construct
	5. Translation. The teacher asks and aids students to translate from observational to conceptual language
	6. Prediction. The teacher asks and aids students to predict what happens based on conceptual knowledge

from a competence test. Table 5 shows the links among the referred four parts, respective subject topic and the pertinent items of the competence test.

Each of the subject topics in Table 5 requested different specific pedagogical, meta-cognitive and epistemic practices. We were interested in describing the structure of learning experiences provided in each part analysed and identifying the categories in each unit of analysis for each type of practice, as shown below for part B (Table 6). This analysis was done in two different time periods: the second, conducted 1 month after the first analysis, is the review of the first. The agreement between both analyses is about 90%.

Now we will show how the categories were identified in each analysis unit for each dimension using three excerpts of data collected from part B of the corpus. We used the teacher's narrative from each lesson, previously confirmed by other collected data on teaching.

For the analysis unit, 'exploratory home task' (Table 6), the respective data are presented in narrative excerpt 1, and from them, we identified the respective categories, as presented in Table 6:

Narrative excerpt 1 (analysis unit: exploratory home task)

"So, at the end of this lesson, I asked the students to carry out, as homework, the tasks where they could refer the microwaves' radiation and IR.

To approach the subject of microwave radiation, I asked the students the following:

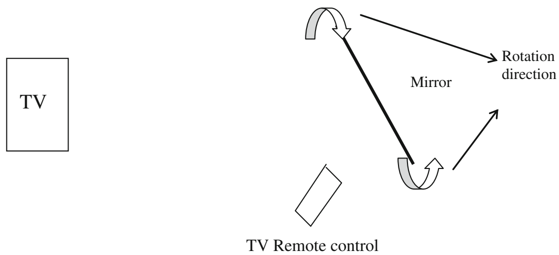
- to describe the microwave's door and to explain what happens when a glass of water is EP1
heated inside; EP2
- to explain what will happen when the glass of water is heated.

Regarding the IR radiation, I asked them if they were able to change the television channel, when:

- they used the TV remote control directly in front of the TV;
- they put a piece of glass, a sheet of paper, a book and a mirror between the TV remote control and the TV;
- they make the radiation of the TV remote control reflect on a mirror (or in a polished surface), while they varied the angle to try to change the channel.

I noticed that this last task was not well understood by the students. I explained, giving the following example: 'suppose that the blackboard is the television, my piece of chalk is the TV remote control, and my Physics book is the mirror'. I asked a student to hold the book and I demonstrated what they needed to do, 'by varying the angle', until they manage to change the TV channel. I asked them if they had understood the procedure. All the students agreed. I sketched the situation on the blackboard to make sure students had no doubts:

PED2



At the end, I had the feeling that this task was fully understood. I also reminded the students that, at the beginning of the next lesson, all the groups would have to describe, explain and sketch all the homework activities."

From excerpt 1, it is clear that there are no occurrences in the meta-cognitive (MET) dimension (see also Table 6). However, in the pedagogical (PED) and epistemic practice (EP) dimensions, there are occurrences: the students were invited to accomplish the tasks proposed (category 2—status of students' previous ideas – of the PED dimension) and the

Table 5 Parts analysed and the pertinent items of competence test

Parts analysed	Subject topic	Items of competence test
A—Session: 1	Objects' vision	1.1; 1.2
B—Session: 7 (final)+8	Electromagnetic radiation	5.1; 5.2; 5.3; 5.4
C—Sessions: 10+11	Lens and images	7.a2; 7.a3; 7.a4; 7.b2; 7.b3; 7.b4
D—Session: 14 (second half)	Convex mirrors	10.2

teacher asked students to describe the phenomena (category 1—description – of the EP dimension). The teacher also asked students to recognize the phenomena in context (category 2—phenomena in context – of the EP dimension).

The second example shows how the analysis was done regarding the analysis unit 'Interaction teacher-students (1)'. The respective data are (and from them we identify the respective categories as presented in Table 6) in 'narrative excerpt 2'.

Narrative excerpt 2 (analysis unit: interaction teacher–students (1))

Teacher (addressing both student B and student C): "earlier, you mentioned that the microwaves
have a lamp inside. When you heated the glass of water, did you observe if the light bulb was PED1
lighted? PED4
- Were you able to see what was inside the microwave when it was working? After an PED5
affirmative answer to these two questions by the two students, I questioned the other students about the behaviour of the door in relation to the visible radiation. All the groups said 'they could see perfectly what was inside, because the door was transparent to the visible light'. New questions were set:

1-Does the radiation cook or heat the food inside microwave?
2- In microwaves, is the heat transferred or not?
3- Does anything happen to you if you are in front of the microwave door?
4- Is the microwave door transparent to the microwave's radiation?
5- Can you see the radiation?

Regarding this set of questions, the answers were discussed in class and the students did not find them too complex. They said the microwave's radiation was responsible for heating the food and, 'as the radiation heated the food there was a transfer of energy'. It seemed to be the logical answer.

Regarding question 3, I noticed that, at the beginning, it was not well understood. I started to
repeat what they had said 'a while ago it was said that the microwave's radiation heated the MET1
food that was inside. Do you think that if you are in front of the microwave while it is working, you will get warm? The students, who did not do the task, thought it obvious that this would not happen. However, I asked the same question of the students who had carried out the task, and they also confirmed it. After this interaction, they easily answered the fourth and fifth questions."

From excerpt 2, it is clear that there are no occurrences in the epistemic practice (EP) dimension (see also Table 6), because the students did not need to think or act by themselves. However, there are occurrences in the pedagogical (PED) and meta-cognitive (MET) dimensions. The teacher used the results of task 1 and discussed them with the students to enrich the concepts of microwave radiation and energy transfer (category 5—activity discussion – of the PED dimension). The students' ideas were taken into account during the teacher–student interaction because the questions took into account the previous answers (category 1—students' ideas taken into account – of the PED dimension). The teacher referred to the answers of all the student groups, which is an indication that the classroom environment allowed the students to participate fully in the dialogue (category 4—classroom climate – of

Table 6 Results of analysis of learning experience provided for part B (we filled the code of categories identified in each analysis unit for each dimension—see Table 4)

Analysis units of part B	Categories identified in each dimension analysed		
Sessions 7 (final) and 8	PED	MET	EP
Exploratory home task: to describe the microwave oven door and explain what happens when a glass of water is warmed up, and to verify if the TV changes channel (whether there is information transmission from the TV remote control to the TV) in three situations	2		1, 2
Initial question: why don't we see certain radiations like the infrared or the microwaves?			
Task 1: to describe the microwave oven door and answer the following questions: is the microwave door opaque to visible radiation? And to domestic microwaves?	2		1, 2
Students' answer (students write 'what I know')		2	
Interaction teacher–students (1) about students' ideas that arise in the home and the classroom tasks	1, 4, 5	1	
Teacher explanation: information and energy transfer with electromagnetic radiation (microwaves and infrared); the same object can be opaque or transparent to different radiations and other electromagnetic radiation (students write 'what I learnt')	3		
Task 2: to describe, explain and schematize what they observed when using the TV remote control in three situations (directly in front of TV, interposing different objects and using a mirror changing the incidence angle)	2		1, 2, 3
Students' answer (students write 'what I do')		3	
Interaction teacher–students (2) students' ideas about home and classroom task	1, 4, 5	1	
Teacher explanation: information and energy transfer with electromagnetic radiation (microwaves and infrared); the same object can be opaque or transparent to different radiations; reflection of electromagnetic radiation; our eyes are not sensitive to certain radiation types	3		
Task 3: to read and to analyse a text on electromagnetic spectrum and several types of solar radiation. To compare frequencies, wavelengths and energies of visible light, radiations, infrared (IR), ultraviolet (UV), microwaves and X-ray	2		
Task 4: exercises about relationships among several variables of the topic	2		
Interaction teacher–students (3) about students' ideas	1, 4	1	
Teacher explanation: energy transfer with electromagnetic radiation depends on its frequency; the same object can be opaque or transparent to different radiations; our eyes are not sensitive to certain radiation types, they are only sensitive to radiation within a range of frequencies	3		
Task 5: exercises using relationships among several variables of the topic	2		

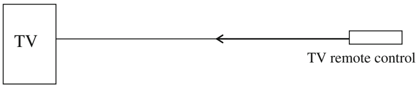
the PED dimension). Finally, it was made clear that the students' ideas were solicited and evaluated explicitly during the dialogue (category 1—Students' ideas evaluated – of the MET dimension).

The third example shows how the analysis was done regarding the analysis unit, task 2. The respective data are in narrative excerpt 3, and from them, we identify the respective categories, as presented in Table 6.

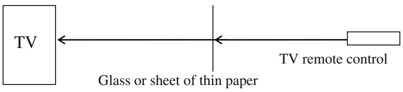
Narrative excerpt 3 (analysis unit: task 2)

“Regarding the second task proposed: to describe, to explain and to schematize what they EP1
observed when using the TV remote control in the described situations, I verified that all students EP2
conducted the experience at home because they all have television sets with remote control. They EP3
all concluded the same thing: the television changed channel when the TV remote control was PED2
used directly in front of the TV and when they put a glass between the TV and the remote control. Other students tried the same thing but with a thin sheet of paper. Regarding the mirror, they all managed to see that when the mirror was put in certain positions, the channel changed.

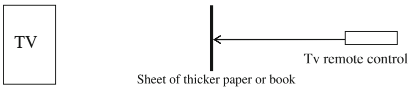
The schemes drawn on the blackboard by the groups of students in the different situations were:



a)
When they used the TV remote control directly



b)
When they put a glass and a sheet of thin paper (alternately) between the TV set and TV remote control



c)
When they put one sheet of thicker paper and a book (alternately) between the TV set and TV remote control

d)
When they used the mirror at different angles

From excerpt 3, it is clear that there are no occurrences in a meta-cognitive (MET) dimension (see also Table 6). However, there are occurrences in the pedagogical (PED) and epistemic practice (EP) dimensions. The students accomplished the tasks proposed (category 2—student active role – of the PED dimension). The students described phenomena (category 1—description – of the EP dimension), and also recognized phenomena in the context of the TV remote control (category 2—phenomena in context – of the EP dimension). Some characteristics of IR radiation (in the context of the TV remote control) were represented with diagrams (category 3—phenomena-representation – of the EP dimension).

The total number of occurrences for each category in each part were analysed and the results are shown in Table 7.

The learning experience provided does not have the same pattern in the different analysis units. There is a decrease in the total score in epistemic and meta-cognitive practices from part A to part D. It is an interesting result because it may be an indicator of the increase in the teacher’s difficulty to use epistemic and meta-cognitive practices for more difficult science topics, since the epistemic demand of the topics increased from part A to part D. On the contrary, the total score in pedagogical practices increased from part A to part D. These relationships are significant as shown in Table 8. These results make sense if the increase in

Table 7 Learning experience provided: number of occurrences for each category per analysis unit

Dimensions of analysis	Categories	Part A	Part B	Part C	Part D
Pedagogical (PED)	1. Student ideas taken into account	2	3	8	4
	2. Student active role	3	6	8	2
	3. Explanation	2	3	6	2
	4. Classroom climate	1	3	6	3
	5. Activity discussion	1	2	4	1
	6. Manipulation of physical situation	0	0	5	2
		Total 9	Total 17	Total 37 (18.5)	Total 14 (28)
Meta-cognitive (MET)	1. Student ideas evaluated	2	3	4	1
	2. Status of students' previous ideas	2	1	2	1
	3. Status of students' learning	1	1	1	0
	4. Conceptual field discussed	1	0	0	0
		Total 6	Total 5	Total 7 (3.5)	Total 2 (4)
Epistemic practices (EP)	1. Description	1	3	3	0
	2. Phenomena in context	2	3	3	0
	3. Phenomena-representation	2	1	0	1
	4. Representation of a physics construct	1	0	0	0
	5. Translation	1	0	4	1
	6. Prediction	1	0	2	0
		Total 8	Total 7	Total 12 (6)	Total 2 (4)

The number between parentheses is the normalized total, that is, the total divided by the number of sessions (see Table 5)

pedagogical practices was the teacher's response to an inadequate transition from one epistemic or meta-cognitive practice to another. These inadequate transitions demand more teacher support for the students, therefore increasing the occurrence of pedagogical practices. There is a positive correlation between meta-cognitive practice and epistemic practice (Table 8); this may mean that they are related in this study. These two results need further analysis.

To identify the transition from one epistemic or meta-cognitive practice to another, we identified the groups of meta-cognitive and epistemic practices in each analysis unit and the sequence of groups of meta-cognitive and epistemic practices for each part analysed. The

Table 8 Pearson correlations matrix: variables of the learning experience provided (PED, MET, EP)

	PED	MET	EP
PED	1.00	**−0.69**	**−0.95**
MET		1.00	**0.78**
EP			1.00

Bold correlations are significant at $p<0.05$

results of these analyses are in Table 9. As the categories of meta-cognitive and epistemic practices are ordered by their epistemic demands, we can verify that:

i) In parts A and B, the transition from one group of meta-cognitive and epistemic practices to another recovers some meta-cognitive or epistemic practices used before.
ii) In parts C and D, the epistemic practices are isolated and their sequence does not conform to an increasing epistemic demand.

The results of the transition from one epistemic or meta-cognitive practice to another, shows a decrease in quality. Further, it shows an increase in the use of pedagogical practices by the teacher, who is aiming to solve the inadequate transition.

Research Question 2: What Are the Relations Between Learning Experience and Competences' Development?

Students' Competences

The normalized gains in classes A, B and C, in items of evaluating the competence of using optical knowledge in concrete situations, are presented in Fig. 1 (see some examples below). All classes show a gain, which means some kind of effectiveness of teaching to develop this particular competence. It seems that the development of students' competences is influenced by the learning experience provided to students, even though these relationships are not causal.

If we take into account the characteristics of the study's participants (namely their lack of interest in physics), the influence of the learning experience provided to students in their competence development seems strong (see Table 1).

If we consider the results on the competence of using optical knowledge in concrete situations (see Fig. 1) and the design of the study, it is possible to verify that, in general terms, the learning experience provided explains the normalized gains obtained in the development of the students' competences.

The results obtained by class C are even more remarkable because these students' academic records are less favourable (in Table 1, notice the students' ages and the number of students that are repeating the year).

To answer our second research question, we need to analyse in further detail, the students' results per class and per item.

We analysed the learning results of the students in each class. For each class and item, we calculated the weighted average of the level of competence performance (CP) as we have previously explained. We obtained the results, presented in Table 10, for the level of competence performance in each post-test item.

Table 9 Transitions from one meta-cognitive (MET) or epistemic practice (EP) to another, inside each analysis unit; and from one analysis unit to another, for each part analysed

	MET	EP
Part A	[2]→[1]→[2]→[1]→[3,4]	[1,2]→[1,2,3]→[3,4,5]
Part B	[2]→[1]→[3]→[1]	[1,2]→[1,2]→[1,2,3]
Part C	[2]→[1]→[1]→[1]→[2]→[1]→[3]	[1]→[1,5]→[1]→[6]→[2]→[5]→[5]→[6,2]→[5]→[2]
Part D	[2]→[1]	[3]→[5]

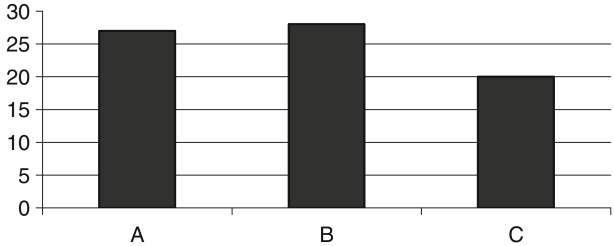


Fig. 1 Normalized gains, in percentage, per class in items that evaluate the competence of using optical knowledge in concrete situations

To appreciate the actual performance of students, we presented some representative answers to item 1.1 from the pre-test and the post-test:

Examples of answers from the pre-test (item 1.1 presented previously in the study description section)	Examples of answers from the pos-test (item 1.1)
CP1	CP3
The two footballs. Because the light lights the entire bedroom. Under the bed there is not much light, but if you look under it, you will be able to see.	The football that is on the bed. The bed does not allow the light to penetrate it because it is not transparent enough to illuminate the ball underneath.
CP2	CP4
The football that is on the bed. Because the light is on the ceiling.	The football that is on the bed. To see this ball it is necessary to have light. The light hits the ball that is on the bed and does not hit the other ball because there is an opaque object (the bed) that creates a shadow.

Item Requirements in Terms of Epistemic Practices

We also analysed the item requirements in terms of epistemic practice demands using criteria based on Kelly and Chen (1999). In general, we verified if the item demanded:

- Prediction
- Relating physical phenomena with representation
- Recognizing phenomena in context
- Relating representation with a physics construct
- Translating from observational features to conceptual language or
- Choice among claims.

Table 10 Average level of competence performance (CP) and normalized gain (G) obtained in two or more of the classes A, B and C for item

	Item of the test												
	1.1	1.2	7-a2	5.3[a]	5.2[a]	7.b2[a]	5.1[a]	7.a3[a]	7.a4[a]	10.2[a]	5.4[a]	7.b3[a]	7.b4[a]
CP (0 to 5)	≥3.5	≥3.5	≥3.1	≥2.6	≥2.3	≥1.8	≥1.7	≥1.6	≥1.0	≥0.9	≥0.6	≥0.6	≥0.4
G (%)	≥46	≥44	≥34	≥38	≥38	≥10	≥27	≥10	≥16	≥0	≥9	≥4	≥5

[a] means that CP and G concern two classes

Table 11 Epistemic practice demands (ED)—levels valuated for each criterion

Criteria	Levels
Prediction	0—not required
	0.5—requires a prediction that can be made based on experience
	1—requires a prediction that must be made based on conceptual knowledge
Relating physical phenomena with representation	0—not required
	0.5—requires an empirical representation of the situation according to the item description
	1—requires a representation of the situation according to the item description, choosing the most important factor or trait to use a physics construct
Recognition of phenomena in context	0—not required
	0.5—requires a recognition of phenomena in context
	1—requires a recognition of phenomena in an unfamiliar (or familiar but complex) context
Relating representation with physics construct	0—not required
	0.5—requires the use of the concepts or relationships in connection with the situation
	1—requires the operation of relationships using a representation of the situation
Translation from observational to conceptual language	0—not required
	0.5—requires a description using scientific terminology
	1—requires a description in conceptual terms that mobilizes several concepts
Choice among claims	0—not required
	0.5—requires a choice among claims that can be done based on experience
	1—requires a choice among claims based on evidence and a physics construct

Each criterion may be valuated by 0, 0.5 or 1. The level of each criterion is explicit in Table 11.

Table 12 shows how these criteria were used for the items 1.1 and 10.2, presented previously.

Table 13 shows the results obtained for analysis of each item in terms of epistemic practices demands (ED) and for conceptual performance (CP) of students in classes A, B and C in each item.

Relations Between the Dimensions of the Learning Experience Provided in Classroom and the Development of the Competences

Using the data relating to the learning experience provided (variables PED, MET and EP), the item characteristics (variable ED) and student performance (variables CP, Gain), we constructed a Pearson correlations matrix using the Statistica© software (see Table 14).

The correlations shown in Table 14 (and previous data), allow for the following results:

i) The student performance, in particular the competence of using optical knowledge in concrete situations, evaluated by the variable CP significantly decreased, with the increase of epistemic practice demands (see **h** in Table 14). This result is interesting because we verified that the epistemic practices provided decreased in qualitative

Table 12 Explanation of how the epistemic practice demands (ED) level was obtained for items 1.1 and 10.2

Item 1.1 requirements (IR) criteria	Level	Description of requirements	Item 10.2 requirements (IR) criteria	Level	Description of requirements
Prediction	0	Not required	Prediction	0	Not required
Relating physical phenomena with representation	0.5	The item demands an empirical representation of the situation in accordance with the item description	Relating physical phenomena with representation	1	Requires recognizing the distance of the car to the mirror as the most important factor in using physics to construct mirror images
Recognition of phenomena in context	0	Not required	Recognition of phenomena in context	1	Requires recognition of phenomena in a complex context (even if familiar)
Relating representation to a physics construct	0	Not required	Relating representation with physics construct	1	Requires operating the information about what images are formed in each mirror at any distance from the car to the mirror
Translation from observational to conceptual language	1	In conceptual terms, a scientific description of the conditions under which a person can see an object is demanded (articulating the concepts of light source, propagation of light, selective absorption of light, human eye as a light receiver)	Translation from observational to conceptual language	0.5	Requires the use of scientific terminology for a familiar situation
Choice among claims	0.5	The item demands choice among claims that can be done based on experience	Choice among claims	0.5	The item demands using experience to choose, based on experience, the correct mirrors
Epistemic practice demand level	2		Epistemic practice demand level	4	

Table 13 Level of performance (CP) obtained in two or more of the classes A, B, C and epistemic practices demands (ED) for an item

	Item of the test												
	1.1	1.2	7-a2	5.3[a]	5.2[a]	7.b2[a]	5.1[a]	7.a3[a]	7.a4[a]	10.2[a]	5.4[a]	7.b3[a]	7.b4[a]
CP (0 to 5)	≥3.5	≥3.5	≥3.1	≥2.6	≥2.3	≥1.8	≥1.7	≥1.6	≥1.0	≥0.9	≥0.6	≥0.6	≥0.4
ED (0 to 5)	2	2	2	3	3	2	3.5	3.5	3.5	4	4	3.5	3.5

[a] means that CP concerns two classes

(Table 9) and quantitative terms (Table 7) in topics with a greater level of epistemic demand.

ii) The normalized gains in items that evaluated the competence of using optical knowledge in concrete situations increased with the performance level in the same items (see **a** in Table 14). This result confirms, once again, that students achieve improved learning when they build knowledge based on something they know already.

iii) The competences of students using optical knowledge in concrete situations increased significantly when there was an increase in the level of epistemic practice, in quantitative and qualitative terms (see **b** and **e**). This result suggests that the epistemic practice dimension of the learning experience is very important for students' learning. Therefore, it is suggested that providing students with opportunities for epistemic practices should be incorporated into future teaching strategies.

iv) The students' competences in using optical knowledge in concrete situations increases significantly with an increase in the meta-cognitive practices provided (see **c** and **f**). This result suggests that the meta-cognitive dimension of the learning experience provided is also very important for students' learning. Therefore, it is again suggested that providing students with opportunities for meta-cognitive practices should be incorporated into future teaching strategies.

v) The students' competence in using optical knowledge in concrete situations is negatively correlated with the pedagogical practice provided (see **d** and **g**). This does not mean that an increase of pedagogical practice decreases the performance of students. As suggested before, the correlations obtained with pedagogical practices make sense because an increase of the pedagogical practices is an unexpected need to approach the decrease of the epistemic practices in qualitative (inadequate transitions) and quantitative terms.

Table 14 Pearson correlations matrix: variables related to learning experience provided (PED, MET, EP), variables related to item characteristics (ED) and variables related to student performance (CP, Gain)

	ED	PED	MET	EP	CP	GAIN
ED	1.00	**0.62**	−0.30	−0.48	**−0.84 (h)**	−0.47
PED		1.00	**−0.69**	**−0.95**	**−0.66 (g)**	**−0.92 (d)**
MET			1.00	**0.78**	**0.60 (f)**	**0.92 (c)**
EP				1.00	**0.61 (e)**	**0.96 (b)**
CP					1.00	**0.67 (a)**
GAIN						1.00

Bold correlations are significant at $p<0.05$

Conclusions, Relevance and Implications

What learning experiences in epistemic, pedagogical and meta-cognitive terms can teachers provide to their students in classrooms? Are they invariant?

Our results indicate that the learning experience provided to students is non-invariant in the sense that it depends on how the topics are approached. It seems quite difficult for the teacher to pay the same attention to different teaching topics, in terms of the learning experience provided. This difficulty, according to our results, may increase with the epistemic practice demands of the issues, showing that the teacher's subject knowledge influences greatly the learning experience of the students; this corresponds with the findings of Childs and McNicholl (2007). In particular, the meta-cognitive and epistemic practices decrease (in qualitative and quantitative terms) in line with the difficulty of the topics being taught. In addition, the pedagogical dimension of Jimenez-Aleixandre et al. (2005) is a clear dimension of the learning experience provided. In our case, this is revealed by teacher-centred teaching practices. This is explained by the teacher intervention due to progressive quality degradation of the meta-cognitive and epistemic practices provided to students. It seems that the teacher recognizes this phenomenon and feels the need to intervene systematically. The most important consequence of this intervention is the breaking up of the students' work.

It was generally assumed that teaching practice is a central characteristic of a teacher. Our results show that the learning experience provided to students may change with the approach to each teaching topic. That is, the same teacher may change their teaching practices during a short interval of time, according to certain circumstances, in accordance with, for example, the requirements of the tasks and/or the difficulty of the topic. It is therefore suggested that it is important to study, in more depth, the teaching practices of different teachers for different subject matters. It is suggested that pedagogical competences are insufficient to maintain the same teaching quality in different circumstances. Therefore, future research should be conducted to identify what aspects of teachers' professional development must be considered.

In our study, the teacher developed an increasing pedagogical activity as a compensation stratagem. What other compensation stratagems can be developed if the teacher's intention fails?

What dimensions of the learning experience provided in the classroom can support the development of competences to be used as knowledge in everyday situations?

The competence of using knowledge in daily situations is very complex to evaluate and develop. Items with the same intention may have several types of epistemic demands. Certain aspects demand a greater care in teaching. However, the findings obtained by Dean Jr. and Kuhn (2007) show that learning experiences provided in science classes are important for the development of students' competences. Our results show that some dimensions of the learning experience provided by teaching may be particularly important for the development of a certain level of performance. This seems to be the case for meta-cognitive and epistemic practices. The results suggest that the dimensions of the learning experience that are provided to students may develop their competences, enabling them to use their scientific knowledge in real situations; unlike the increase of the teacher's pedagogic activity (representing teacher-centred teaching practices, according to Odom et al. (2007)), which is negatively associated with student achievement.

We must consider that an increase in pedagogic activity by the teacher may not necessarily mean lower quality teaching if it does not break up student activity.

Certain competences (in our study, student's use of knowledge in everyday situations) may be better developed if certain dimensions of the learning experience are provided (epistemic and meta-cognitive practices in our study). This relationship is neither linear nor causal. Our results cannot determine a simple relationship between a dimension of the learning experience provided and a certain type of competence. Our results do suggest that it may be dangerous to focus attention on only one dimension of teaching practice in order to develop a certain type of student competence. One implication of our research is that there is a need to study other relationships among teaching-practice dimensions and the development of students' competences.

Acknowledgements We acknowledge the support of Portuguese FCT, project PTDC/CED/66699/2006.

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