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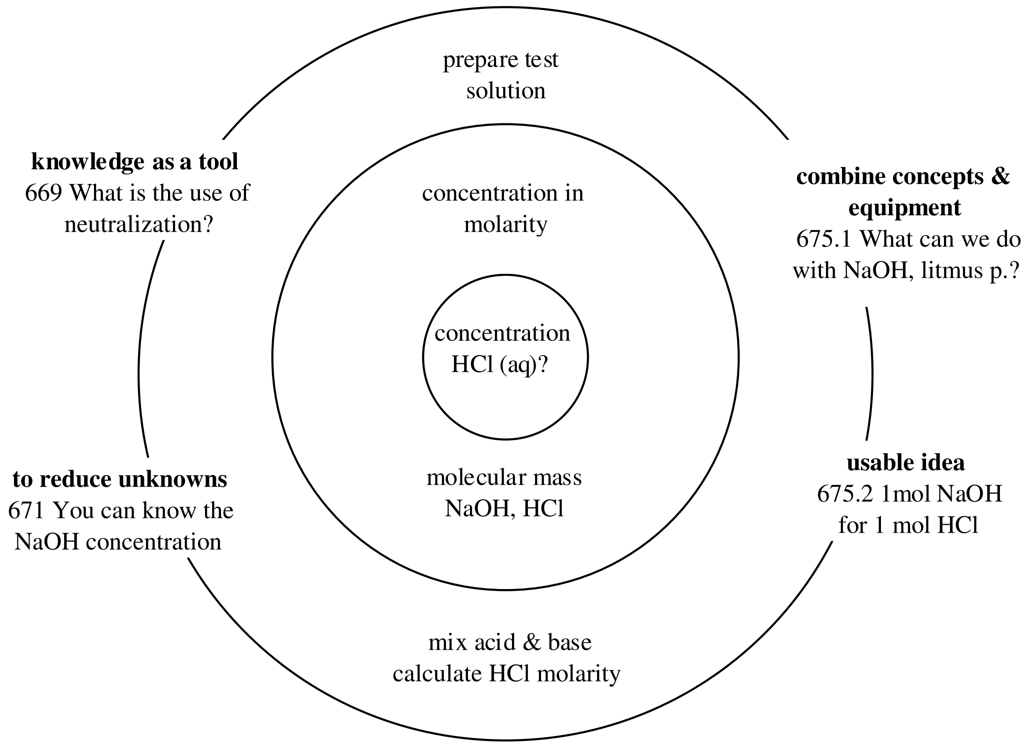

Figure 1 An instance of teacher's scaffolding in the ZPD of two students

Scaffolded Problem–Solving in the Physics and Chemistry Laboratory: Difficulties hindering students' assumption of responsibility

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Abstract

This case study examines the performances of 18 tenth-grade students (age 15 – 16 years) in the process of performing problem–solving tasks in the physics and chemistry laboratory. The study focuses on different types of problems arising in the process of transferring responsibility to students in a context of teacher assistance to autonomous problem solving. The students' conversations were audio and videotaped and their productions collected. Problems were found in relation to i) excessive task difficulty, ii) stereotyped school culture reflecting procedural display rather than genuine problem solving, and iii) problems related to within-group interactions and roles. The findings are discussed in reference to the educational goal of students progressively assuming responsibility in their own learning.

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Keywords: autonomous competence, responsibility, scaffolding, laboratory

Transfer of Responsibility, Scaffolding and Mediation in the School Laboratory

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The situated cognition perspective (Brown, Collins & Duguid, 1989) considers knowledge situated within the context, activity and culture in which it is used, and learning as a process of enculturation achieved through progressive involvement in authentic activities; in other words, as a cognitive apprenticeship (Collins, Brown & Newman, 1989). Learning as legitimate peripheral participation in communities of practice (Lave and Wenger, 1991) is conceived as the process by which a novice gradually adopts a more participative and central role in socially meaningful activities. O'Loughlin (1992) proposes a view of learning as a social appropriation of cultural elements rather than a progression towards more abstract and content-independent ways of thinking, which does not equip learners for personal and social transformation.

Taking as their starting point the social nature of learning Lave and Wenger (1991) relate it to the process by which a novice transforms his or her role from the periphery of the socially significant activity towards a more central role, assuming increasing participation and growing responsibility. Brown et al. (1989) suggest to frame learning within social activity, making deliberate use of the social and physical context: students are required to become involved in authentic activities, inherent to each domain; in science education pertaining to the culture of the scientific community. These authors distinguish scientific culture from school culture: the latter has a stereotyped component, which can be understood as procedural display (Bloome, Puro & Theodorou, 1989), or the exhibition in the classroom of behaviours that the community may consider adequate, but that do not imply any learning. It could be also expressed in terms of the distinction drawn by Habermas (1984) between communicative and dramaturgical action: the participants in a social interaction regulated by communicative action are aiming for the development of a personal relation oriented towards mutual understanding and the argumentative generation of a consensus, whereas the participants in a dramaturgical interaction are both actors and audience for each other. Jiménez-Aleixandre, Bugallo and Duschl (2000) have analyzed a case of procedural display in the science classroom. An example of procedural display in the laboratory might be a student who does not understand what to do and who imitates the behaviour of other students rather than consulting the teacher.

Vygotsky's (1978) perspective of learning within the framework of social interaction and transfer of responsibility involves a series of processes working in interaction with the social surroundings. He proposed the identification of two levels in a person's development: effective, activities that the person can perform without assistance, and potential, the performance of tasks under the supervision of, or in collaboration with, someone more able. The difference between the two levels is the zone of proximal development (ZPD). Vygotsky considers that people's ways of acting are based on their capacities to use both physical and symbolic social tools (mediators), and conceives the differences between the performances of

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Deleted: For Vygotsky, education focused on the ZPD promotes development, whereas education focused on what students are already able to do will tend to lag behind development. He different people or groups in terms of their different capacities to access and to use those instruments. These ideas have been developed by Werstch (1991) as the basis for an analysis of mental actions in cultural, historical and institutional scenarios from a social perspective. Hodson and Hodson (1998a) use them as a basis for their move from constructivism to social constructivism, in which attention is paid not only to the personal process of knowledge construction, but also to social components of the learning process.

Education focused on the ZPD involves the progressive transfer of responsibility from teacher to students as they progress in their completion of the task (Cazden, 1988), and it is in this context that the term *scaffolding* is used (Wood, Bruner & Ross, 1976). The function of the scaffolding (Mercer & Fisher, 1992) is on the one hand to help learners to carry out tasks that they would not be able to achieve alone, and on the other hand to enable the development of a higher level of autonomous competence. The teacher (or adult, or more able peer) begins modelling the process and gradually transferring responsibility to the learner (Fleer, 1992), making it possible for him or her to achieve an objective otherwise beyond his or her capacity (Hodson & Hodson, 1998b). This is consistent with Lave and Wenger's (1991) perspective of legitimate peripheral participation, in which the learner moves from initial lack of autonomy towards increasing responsibility and participation in decision-making.

As Puntambekar and Kolodner (2005) point out the notion of scaffolding was initially developed supposing that a single person would help an individual learner, which is not usual in common classrooms. These authors show that, in real classroom settings, support to the students needs to be provided through many tools and agents, each of which has its own unique affordances, so the students have a wide variety of opportunities to be benefited. In the analysis of scaffolding in a classroom context it is useful to consider the remarks of Wells (1999), who considers not only the specific ZPD of each individual, but also the communal ZPD of the group. In his explanation of the development of psychological processes, Vygotsky (1978) focused basically on interactions within the adult-child dyad; nevertheless, authors like Werstch (1991) suggest that concepts conventionally considered to pertain to individuals - like *mind*, *thought* and *zone of proximal development* - can be extended to situations in which a group of individuals is operating together, allowing us to conceptualize the social distribution of mind.

The transfer of responsibility from the teacher to the group is central in the

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conceptualization of scaffolding, and it is also relevant to analyze the cooperative work. Leont'ev (1978) points out the role of collective work in the development of consciousness: a person's relationship with the physical world can be understood only if analyzed within its social context. For Leont'ev the immediate result of an activity is related to the final result in terms of the relations among the individual and other members of the collective, and true practices of a culture are to be considered in collective terms. So it is important that the cooperative dimensions of students' work receive attention.

In the school laboratory, education conceived as scaffolding oriented towards the ZPD could in our opinion be favoured through open problem solving activities in a small-group context, which helps promote the necessary teacher-student interaction (Reigosa & Jiménez-Aleixandre, 2001a). Here we examine the difficulties arising when a scaffolding educational approach is practiced in such context. Students were presented with problems that were open in terms of their solution or of the route by which it could be reached (Reigosa & Jiménez-Aleixandre, 2001b). For Wells and Chang-Wells (1997), an effective way of promoting learners' capacities to think and solve problems is with a challenge that arouses their interest and invites them to create their own solutions.

In this paper, an autobiographical case study is presented, based on the analysis of the performances of students working in small groups in the laboratory, assisted by their teacher (first author). The research questions are:

– What difficulties arise when we try to provide scaffolding to small groups of students performing problem-solving tasks having as a goal that they would assume increasing responsibility?

– Can continued practice with tasks designed as problems and requiring autonomy from students improve their performances in relation to stereotyped school culture?

Methodology

Participants and Tasks

Data were collected during two consecutive school years in two state-run high schools, both in urban settings. 18 tenth-grade students, two groups of five students and two groups of four (age 15 – 16 years), taught by the first author, performed a series of five practical tasks. In the first year of the study, the students performed only tasks 4 and 5 during four sessions, while in

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the second year they performed all five along thirteen sessions. Since the students are different, in some cases comparisons between cases are made (Shepardson, 1996; Kelly & Crawford, 1997). Table 1 lists the tasks performed by each group, and the Appendix reproduces excerpts from the handouts.

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[Insert table 1 about here]

All tasks were designed by the authors, except # 3, which is an adaptation from the SEPIA project (Duschl & Gitomer, 1991). Although the teacher expected the students to complete them under his guidance, there were some cases when they did not reached complete solutions, as discussed below.

Data Collection and Analysis

The methodology is qualitative; taking into account the relationships among language and context (Lemke, 1998) that cannot be dissociated. The main sources of data are audio and video recordings of the students' verbal and physical actions, and student products, including a report for each task. The study was conceived as action research (McKernan, 1996) designed with the goals of improving the teaching practice of the first author and of sharing its outcomes with the teaching community (Stake, 1995). The naturalistic research paradigm of Lincoln and Guba (1985) was followed, notably the use of inductive analysis to interpret specific social situations, aiming for theory to emerge in interaction with the data by means of immersion in them. All situations considered relevant to the problem under study were identified in the transcriptions and grouped into categories; explanations were then proposed to interpret them. Next, categories and explanations were revised, in some cases leading to refinement or modification. Intersubjectivity of interpretation was sought through continued negotiation of meaning among the authors.

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The situations analyzed correspond to processes of solving the problems in the laboratory by groups of students assisted by the teacher. Assistance involved interaction of the teacher with the group, rather than with individual students, and the analysis focuses on what the group, as a whole, is capable of doing. Assistance was provided with the aim of enabling the group to perform tasks that it would be not able to approach by itself; oriented towards the achievement a greater level of autonomous competence by the students, and analyzed in these terms. In particular cases, the interactions among the students allow to explore differences

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between the ways in which individuals learn, and they are considered when relevant to the problem under study.

The first research question, what difficulties arise in view of the goal of transferring responsibility, means the need to assess whether scaffolding actually took place, evaluating the level of autonomous competence. In line with Mercer and Fisher (1992), who indicate that scaffolding not only implies task completion but also attainment of a higher level of autonomous competence, we have considered that scaffolding takes place in those interactions in which the group was not able to advance in the problem resolution, or they were going along a wrong path, and the teacher helps them to appropriate tools or to clarify ideas that empower them to continue solving the task. But when, even with these interactions the students were not able to progress, it is considered that the scaffolding did not take place (or failed).

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In the transcriptions, glosses are indicated in `Courier` and physical acts of the participants in *italics*. They have been translated to English, though translation is often difficult; for instance, in group 2, task 4 lines 213 - 214 a lay meaning of the Spanish word *acelerado* (*nervous*, *excited*, *uptight*) is influencing the dialogue; the original transcriptions in Spanish are available from the authors.

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The situations that were considered to manifest particular difficulties in scaffolding and in the transfer of responsibility have been grouped into three categories (Table 2), derived inductively and negotiated among authors.

[Insert table 2 about here]

Results: Problems related to the Difficulty of the Task

Sometimes the task is too difficult, so that, in spite of help received, the students will not achieve autonomy. This category can be illustrated with two types of situation: inability to use a resource or a practice, so that the problem in question lacks meaning, and use of words with inappropriate meaning.

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Inability to use a Resource or a Practice

Sometimes the problem presented does not have meaning for the students, as illustrated by the following fragment, corresponding to task 5, in which they were asked to help an explorer

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identify the best among several alternative methods for measuring mass:

Group 2, Task 5, Session 1

Maria	We don't know what we have to do!
Teacher	... he wants to measure the mass of... the stones that he finds. He can do it with the scales, can't he?
Juana	OK, that's it then.
Teacher	But he doesn't want to take the scales because... because it'll take up a lot of space.
Juana	So what does he want to take then? A spring? (*looking incredulous*)
Teacher	So he wants to know if he should take a spring or a rubber band...
Juana	What? What? What?
	(...)
Teacher	Can you measure masses with springs?
Juana	No.
Teacher	Why not?
Juana	Because... Because you measure mass in... in... scales. I don't know, do I?
Juana	Because it's not normal.

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Our interpretation is that, for these students, the idea of measuring masses with something that are not scales lacks meaning. From the point at which the teacher clarifies the goal of the exercise, time passes but the students do not assume greater responsibility. Later the teacher introduces Hooke's Law as a conceptual tool for relating mass and the stretching of springs, and he clarifies that not all springs act in accordance with this law, so there is a need to confirm it for each case. The students then seek to verify accordance with Hooke's Law, though without connecting it with the written instructions. Our interpretation is that this group transformed the task into another one, because of lack of familiarity with the relevant social resources and practices. Social resources (Roth & Bowen, 1995) are the tools, facts, phenomena or theories that are brought into play in the practices or common tasks of the members of a culture. We consider that the activity of these participants was limited because they did not have a good command of the practice consisting of indirectly determining a physical magnitude (here mass) through the measurement of another (here stretching). This interpretation also appears to fit the start of an interaction in group 1:

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Group 1, Task 5, Session 1

Teacher	Why are you measuring the mass of the ball?
Juan	To check it afterwards with the spring, I guess. Or with the rubber band.
Juan	(*Measuring the stretching of the spring after hanging an object weighing 126.7 g*) See? Now it says seventeen point three (*cm*), which is what it's meant to say.

... [2]

Session 3

Juan	How much did we say it'd be with 120 (g)? Seventeen point two (cm)... With a hundred and thirty (g), seventeen point... four (cm). Seventeen point three (cm)... but it went over, it went over a little bit. I mean, that's right.

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Teacher	So... how we can decide how much it should stretch with one hundred and twenty-six point seven (g), from these data?
Juan	A rule of three

In session 1, Juan says that they are going to confirm the mass with the spring but, in session 3, it seems that he is trying to assess whether there is a proportional stretching with each mass, not trying to check whether the numerical values when using the scales and the spring are the same. He suspends weights of known mass (120 and 130 g), and then an object weighing 126.7 g, obtaining a stretch that he considers reasonable. But he does not consider the possibility of quantitatively relating the mass and the stretching until he is assisted by the teacher, at which point he introduces the idea of proportionality as an interpolation resource, mathematically equivalent to the use of Hooke's Law.

Not all the groups experience the same difficulties, nor do all have problems with the practice of determining mass from stretching. Group 4 is not only able to explain why the accordance with Hooke's Law allows the use of a spring to measure masses, but also to discuss the relevance of the numeric values of the elastic constant for the task's goals:

Group 4, Task 5, Session 2

Teacher	Why... does the fact that there is a constant k (`the elastic constant of the spring`), a constant value for k, imply that... the spring is ok?
Tomás	Because that means the stretching is proportional to the weight.
Teo	And because it'll explain there's an equation to say: if it stretches such-and-such an amount, well that's going to tell you exactly what weight you've got.
	(...)
Teo	That the bigger k is, er, the less it stretches for more weight... If k is big, see, there'll be not much stretch for a lot of weight. If k is small, there'll be a lot of stretching with not much weight...
Tito	That shows that it (*the stretching*) doesn't vary much with large weights, so that means it's very precise...
Teo	No, not very precise... The more precise, it's more precise the more it stretches, because the, the distances, the difference between distances is greater, so you can measure with more precision... if this one varies a millimetre, it's very difficult to measure it, but what with this one varies a millimetre, perhaps with this one varies two centimetres. It's much easier to measure and the error is smaller.

This category, lack of capacity to use a given practice, has been illustrated with three interactions. In the first (group 2), the subjects were not able to achieve autonomy despite assistance, so that scaffolding is considered to have been incomplete; by contrast, scaffolding was successful for group 1. Group 4 did not need assistance to use the elastic constant as an interpretative resource for solving the problem. Group 3, for which transcriptions are not

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reproduced, showed similar progress to group 2. In summary, there are tasks that cannot be satisfactorily completed even with the aid of the teacher and can be viewed as lying beyond the group competence. These are difficult for the students in question, though not necessarily for other groups. It is worth noting that with a different teacher or in otherwise different circumstances, the assistance supplied to groups 2 and 3 might have been more effective. As Hodson and Hodson (1998b) point out, the ZPD is not solely an attribute of the learners, but rather is constructed interactively in each particular situation.

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Inappropriate use of terms and concepts

In some situations it seems that difficulties in task completion arise from the ways in which students use words with very different meanings from those assigned in the scientific community. In Vygotskian terms (Vygotsky, 1986), some groups used scientific concepts whereas others used daily concepts. Helping students to build appropriate meanings for concepts is essential for empowering then to develop a greater level of responsibility. An example is found in group 2, task 4, when students were asked to identify the type of movement followed by a ball down a sloping rail. The transcriptions show that the students did not view the concepts of speed, acceleration and force as quantitative magnitudes with a specific meaning related to their definitions, but that they adopted a qualitative view of movement as something either slow or fast:

Group 2, Task 4, Session 1

Dolores	(*standing up without moving from her place, lets the ball roll from as high up as her arm stretches, but without registering the distance. She gives the ball an appreciable push*).
Maria	Why are you doing that?
Dolores	To see what speed it goes at.
	(...)
Dolores	Can you accelerate the ball?
Maria	It depends on the force you use to set it going...
Juana	And it depends on where in the track. (the slope in the rail)
Juana	Is it accelerated?
Dolores	Oh! It can't be accelerated, because it's going slowly. The ball's going calmly.
Sonia	Depends on how you set it rolling.
Maria	The rail goes straight and it goes to a constant speed...
Dolores	It goes down first at a slow speed, then...

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In their qualitative understanding of movement these students use the terms *speed*, *acceleration* and *force* in a confused and indistinct way to refer to something that may be

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either large or small, but that is not analyzed quantitatively; for example, when Juana asks: "Is it accelerated?" (also interpretable as "Is it excited?"), and Dolores replies that the ball is going "calmly" (Spanish "tranquilo"). This conceptual confusion hinders the measurement of the different variables, as illustrated by the following fragment, in which they measure the time that the ball takes to run down half of the rail after measuring the time it takes to run down the whole of it:

Group 2, Task 4, Session 1

Juana	(*sets the ball rolling, giving it appreciable initial impetus*)
Teacher	And is it the same if you give the ball a push?
Juana	Oh. No!
Dolores	You've got to set it going hard.
Juana	No! It's got to be the force that we set it going with from here. (*She points to the end of the ramp*)
Maria	But we can't do that.
Teacher	What's the only way to do it so that it has the same force?
Mercedes	Leave it alone.
Teacher	That's it. From both positions.

When the teacher realizes that the students are giving the ball a push as they set it rolling, he intervenes with the aim of drawing to their attention the modification of the initial conditions of the movement. Dolores' reply is not the one that he is looking for, but Juana grasps the teacher's meaning, that the starting conditions should always be equal, implying that the ball should always be set going with the same initial impetus (we interpret her use of 'force' with this meaning). They seem to realize at this point that it will be impossible to control it unless they modify their procedure. And prompted by the teacher, Mercedes proposes to leave it alone.

The difficulties experienced by this group in the quantitative control of variables, which seem associated with an inability to overcome an initial conceptual framework conceiving movement qualitatively, continue. In the second session dedicated to this task, Dolores lets the ball roll to time how long it takes to reach the end of the rail; but the ball has a small hole in it (to allow it to be used, for instance, as a pendulum), surrounded by a slight depression so that it does not roll smoothly when this area contacts the surface. Since she does not realize this, and not placing the ball in such a way that the hole does not touch the rail, the ball's movement is appreciably slowed down.

Group 2, Task 4, Session 2

Dolores	(*drops the ball*) I didn't give it a push, eh!

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(*The hole in the ball begins to hit the rail and to slow it down*)
Maria But now it's going slower, look.
Sonia Yeah.
Maria Fifteen (*seconds*)
Juana Fifteen. So fifteen in four meters.

Although Maria realizes that the ball is not rolling as expected, they do not pay attention to this, and record a value of 15 seconds for 4 meters. Later they let the ball roll from halfway up the rail, and by chance the hole does not contact the rail surface and rolls freely. They thus obtain the anomalous result that the ball takes twice as long to descend the whole rail as to descend the first half of it (15 s for 4 m versus 7 s for 2 m). When they show these results to the teacher, he points to the incoherence:

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Group 2, Task 4, Session 2

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Teacher Fifteen seconds seems to me rather a lot for four meters.
Juana Alright then.
Teacher Let's see, why don't you do it again.
Juana Pf...
Teacher Because, look, the farther it rolls the faster it goes so it's... it's not normal that it takes seven seconds to get here (*points to the halfway point of the rail*)... but yet eight seconds from here to here (*points from the middle to the bottom of the rail*), when here (*the middle of the rail*) it's already going quite fast.
Maria Didn't you notice that it went slower here?
(*Dolores lets the ball go, and it rolls without problems*)
Maria Now it's nine! I don't understand it at all.

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The teacher points to the result of 15 s for 4 m, and requests a repetition of the experiment, explaining why the data seem anomalous. Although Maria is aware of the fact that the ball was previously rolling more slowly than it should, she seems unable to explain why. After repeating the experiment, they are surprised to obtain 9 seconds instead of 15. The teacher requests another repetition, and this time the hole in the ball contacts the rail surface again:

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Group 2, Task 4, Session 2

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Dolores (*drops the ball, the hole hits the rail surface and slows its movement*)
Teacher Look here. Look, Can't you see that the ball has got a hole in it?
Maria Yes.
Teacher So you have to place it like this, so that the hole never hits it (*he drops the ball*). That is when it goes fast.
Juana Come on then.

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When the teacher sees the ball slowing, he realizes the cause of the anomalous data, telling the students how to place the ball to avoid this problem. As it happens frequently in the

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school laboratory, the hole problem, so readily noticed by the teacher, had not been perceived by the group, pointing that we cannot take for granted that the students will overcome what to experts seem trivial obstacles related to procedures. The process of assistance is a hard-working one for the teacher, requiring close observation of the group's activity and continuous interaction with the students. In addition, their progression is limited, since they develop little autonomy, and are in the end unable to solve the problem. Scaffolding is truncated because it has not been possible to fully transfer the responsibility for task resolution.

It seems that an effective scaffolding requires the task not being too difficult, in other words, being within the students' ZPD; although it may also be the case that the task is too easy, which means that they are able to solve it on their own (in Vygotsky's terms, the task is at their current level of effective development). This type of situation is not well suited for promoting students' higher competence development, since it lags behind of what they already know. An example can be seen in task 1, in which students were asked to find a procedure for separating a mixture of salt and sand:

Group 3, Task 1, Session 1

Santiago	*(reads the handout)* Let's see. What I think we have to do is to put this (the mixture of salt and sand) in... water so that the salt dissolves...
Santiago	and then we filter it and... the water that goes through with the dissolved salt which is so... and the sand will stay in the filter
Susana	Okay.
Santiago	Let's go then.

At the beginning of the session, Santiago correctly suggests adding water to the mixture, so that the salt dissolves, and then to filter the mixture to separate the sand. Scaffolding is not necessary here, since the students are able to resolve the problem themselves.

Results: Problems related to Stereotyped School Culture

Another difficulty interfering with scaffolding and development of autonomy arises as a result of students' sometimes holding stereotyped images about laboratory work. Stereotyped performances deriving from these images relate to the notions of procedural display (Bloome et al., 1989) or dramaturgical action (Habermas, 1984). Many situations of this type are related to students' views of their own role in the laboratory as being simply to follow instructions, seen as the only correct way of performing each task. In such situation roles are

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clearly defined: the teacher gives instructions and the students follow them. For us this view hinders the progressive development of autonomy, since students do not consider it to be part of their *proper* role. This view of student's role as one that follows instructions seems related to a perception of laboratory activities as a closed series of steps, implying among other things that all groups have to do exactly the same. In Reigosa (2002) and Reigosa and Jiménez-Aleixandre (2000) we have developed a range of categories to analyze this manifestations in the school laboratory (Table 3). We consider that these images are a consequence of years of immersion in practical tasks that simply require the execution of a 'cookbook recipe' or prescribed series of steps. Such views hinder effective scaffolding, since students may be reluctant to assume the assumption of responsibility and autonomy in the resolution of problems.

[Insert table 3 about here]

Laboratory Activities Requiring a Closed Unique Sequence of Steps for their Completion

This image can be illustrated by the following interactions in task 5:

Group 2, Task 5

Maria We don't know! What have we got to do?
Maria (*To the teacher*) Either you give us a hint or I resign!
(...)
Juana First we have to, to measure what the spring measures? Right? (*She points to the spring*)
Teacher Don't ask me.
Juana (*Shouting and gesticulating*) Oh, sorry! So, let's see!

Maria seems to consider her right as a student to be told what steps to follow. When the teacher refuses to give detailed instructions, the students display their anger.

Viewing the Clarification of Concepts as Inappropriate or Not Useful.

Task 2 involved deciding which of different laboratory equipment will allow for the most precise measurement of a volume:

Group 3, Task 2, Session 2

Simeón We put one hundred and fifty millilitres in. Total weight... (In reference to an Erlenmeyer flask)
Sergio Yeah, but we're talking about volume, not weight.
Susana No, we're talking about weight.
Sergio About volume and mass.
Simeón About weight.
Sergio About weight and mass.

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Simeón	Weight is equal to mass.
Susana	(inaudible) we're talking about weight, not volume.
Sergio	Volume's equal to the amount of the container that...
Sergio	Well anyway, for the time being let's put it down like this.

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It seems that these students are not clear about which physical magnitude they should be using, besides exhibiting some confusion among them. At the end Sergio suggests avoiding the difficulty without resolving it, and continuing with data collection. This indicates that Sergio is more concerned with continuing to accumulate data – or with not stopping work – than with clarifying concepts that are essential to knowledge construction. The students' lack of interest in clarifying the meaning of these concepts and the relationships among them, which could have been made clear asking the teacher, means that the teacher could not attempt assistance for this issue. Clarification of these concepts would be relevant for the progressive development of autonomy in this context.

Assuming each Piece of Equipment or Resource to Have Only a Single and Predefined Use

The idea that each resource or piece of equipment has only a single use is illustrated by the following example from task 3, in which students had to determine the concentration of a solution of hydrochloric acid. In session 1 the students have not yet decided that they should prepare a test solution, and that they have to decide themselves about the NaOH concentration:

Group 3, Task 3, Session 1

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Santiago	Look... Well. We have to find... Let me see this nice little formula he has there, I don't know, molarity and its... Here! (*reading in notebook*)
Sergio	Moles of solute...
Susana	Right, by...
Sergio	... litres of solution
Santiago	Good. We have to prepare a solution, find out the moles ...
Santiago	... then divide it among the litres, right?
Susana	First to grab sodium hydroxide
Santiago	Mixing it with the...
Susana	No, no, putting it with the acid
Santiago	With the acid eeeh Wherever is it, with zero five liter or whatever
Santiago	Then... finding the... with the formula if hach ce el and en a o hach
Susana	But: What are you going to find with this, if you don't know the proportions?
Santiago	To find the moles

We interpret this to mean that the students have an implicit idea deriving from stereotyped school culture, the belief that formulae (a type of conceptual resource) play an unique role in the resolution of problems: entering the magnitudes in the formula the solution is directly obtained. They talk as if the volume and the concentration of sodium hydroxide were known, not something to be decided by them; and imply to attempt at a short-cut, mixing directly the NaOH with the acid, perhaps prompted by the equation written in the handout, as Santiago implies. Then Susana begins to object these steps and proposes instead to begin by calculating the molecular mass. These views were also shown with equipment, as when students in task 5 asked what was the use of being given scales (needed for weighing small objects and so being able to relate mass and stretching of springs) if they couldn't actually use them to directly measure the masses.

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Imitating Other Students' Behaviour

It is worth noting that not all manifestations of stereotyped school culture are unfavourable for the transfer of responsibility; some are neutral in this respect. An example can be seen in task 1, when the students from group 3 had already solved a problem requiring them to find a procedure to separate a mixture of sand and salt. They had successfully applied their procedure to a portion of the sample provided. However, when they saw other groups using the whole sample, they decided to do the same:

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Group 3, Task 1, Session 1

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Sergio	Okay. So we mix the *(inaudible).* I'm going to get some more water.
Santiago	Go on then. Let's use all (*the mixture*).
Sergio	All of it?
Santiago	Hey, if everyone's putting it all in, I'm going to as well.

For the students it is important to act in a way that is acceptable for the classroom community, so on occasions they perform actions that only make sense as stereotypes. Although they have already solved the problem – which required them to identify a method, not to separate the sample – they appear to doubt whether the task requires a particular procedure, identified by the other groups. By using the whole sample, they preclude the possible criticism that they have worked less than the others. However, we consider this behaviour as neutral with respect to scaffolding: it does not prevent them from resolving the problem, or from acquiring autonomy.

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Comparison of Results: Performances Related to Stereotyped School Culture and Experience

For the second research question, the differences in performances among students who have practiced with tasks designed as problems for a whole term and students who have worked with them only twice, the performances for Task 5, measurement of mass with a spring, were compared (Table 4). The results show that students who had previously completed a total of four other tasks along 13 sessions (Groups 3 and 4) showed fewer stereotyped school culture performances than those who had only completed one previous task (Groups 1 and 2). This suggests that students who have had more opportunities of working with practical tasks designed as problems are less likely to held these views and to show stereotyped performances, including those interfering with assuming increasing responsibility.

[Insert table 4 about here]

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Results: Problems Related to Social Interactions and Group Roles

Sometimes, difficulties for developing greater autonomy are related to social interactions and roles within the small groups. For instance, major differences in the ZPDs of the different students may mean that only some students in the group benefit from a given intervention of the teacher. These problems can be worsened in cases when the group's social structure limits the development of autonomy by some of its members. For example, in Task 5, one of the students from group 1, Juan, assumes leadership, without sharing either his knowledge or his decision-making with the others. When on the second day Juan does not come, the others try to imitate as best as they can the sequence of activities that he was following:

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Group 1, Task 5, Session 2

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Teacher	What are you doing?
Luis	Weighing with... seeing how much it stretches (the spring)
Teacher	Why are you doing that?
	(Long pause)
Luis	Juan told me yesterday. (Pause)
Luis	I can't remember.

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It is worth noting that we have not found in the transcription of the first session any explanation corresponding to Juan telling Luis about it. It seems likely that social interactions and roles limited the benefits of this task for Luis and the other members of the group, who do not appear to have developed appreciable autonomy during this task. Juan's individual ZPD appears to be more advanced than those of his companions. This difference, and what Richmond & Striley (1996) term the alienating effects of Juan's leadership style, means that

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the other participants do not share the knowledge constructed.

When there are major differences in student performances, it is sometimes observed that students with a higher level prefer not to share their knowledge with those of lower level. For example, in Task 5, on session 2 only one member from group 3 was attending (Susana, a student with excellent grades), because the others were playing a basketball match. So the teacher created a new group with three students who were poorly integrated in their respective original groups (Hilaria, Higinia and Herminia, none of whom achieved a pass grade at the end of the year) and Susana. In this new group, Susana refused to share her knowledge:

Group 3, Task 5, Session 2

Hilaria	Susana, what can you calculate with these data?
Susana	Lots of things.
Hilaria	Lots of things, she says!

Susana replies to Hilaria's question with an evasion. Throughout the session, Susana only deigns to help her new companions at the procedural level, without involving them in planning or interpretation, areas in which she chooses to do all the work. We would suggest that there are situations in which advantaged students prefer a group structure in which they do not share their knowledge, perhaps expecting that in this way the group's performance will be better than if they spend time trying to explain relevant aspects to their less able companions. In the view of the more able student, this will optimize the required final products as laboratory reports, which are what, in most cases, are going to be evaluated. This kind of social interactions and roles makes difficult to provide scaffolding for less advantaged students, who will tend to only participate at the practical level, following the instructions of the group leaders and remaining silent in interactions with the teacher, who cannot perform actions oriented towards the ZPDs of the participants who most need it.

There are also instances of successful scaffolding in the ZPD of some students and, at least initially, not of all. In the next excerpt, from Task 3, the layout of the transcription in columns allows for an appreciation of the contributions of each student. The students call the teacher for help, because they cannot progress in a problem perceived as having "two unknowns", the concentration of the acid, and that of the base, because they did not understand that they had to decide the last by themselves (Jiménez-Aleixandre & Reigosa, 2006).

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Group 3, Task 3, Session 1

Susana	**Sergio**	**Teacher**
646 Mmm. No, we don’t understand it...		
	648 It doesn’t say it or	
		649 This acid has a concentration. Whatever, Zero one molar, zero five molar, or whatever
650 But how do we know it?		
		651 That is... the objective of the lab. Ok?
	656 So, if one has thirty six, you have to (*inaudible*) the moles it has, to find the molarity	
		657 Yes, but you couldn’t do it like that, because you don’t know the moles[of HCl] that are here
		660 But what you... do have to get information is that about the acid and the sodium hydroxide neutralizing each other
661 Neutralizing, what does it mean?		
		662 It means that... mixing them, one is no more an acid and the other no more a base. That is, they lose... between them they lose their properties. Neutralizing, cancelling each other
	663 The sodium hydroxide, you say?	
665 Yes, so... the sodium hydroxide and the... hydrochloric acid		
	667 They cancel each other, so we join them	
		669 Yes... but you have to think: what’s the use of that... for our objective that is to know the concentration of this? Ok?
		671 You, the sodium hydroxide, we can prepare it, eeh, put the amount that we want, because is there in the jar. Ok? The sodium hydroxide then, we can know the concentration
	674 Ah. And how much do we put? How much should be in?	
		675.1 Well, what you want. You have to think: What can we do with the sodium hydroxide, and with everything we have, with the litmus paper, etcetera, to know the concentration of this?
		675.2 Taking into account that for each mole of sodium hydroxide it consumes one mole of hydrochloric acid and these two

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moles neutralize each other

The teacher's scaffolding provides four elements of support represented in figure 1: two of them are metacognitive suggestions, one about using the knowledge about neutralization as a tool (669), in the sense of Brown et al. (1989) advising them to think what is the use of it for the task purpose. He also advises them to reflect about how to use the equipment in order to know the concentration (675.1). The other two ideas are a suggestion about how to reduce what the students perceive as two unknowns, telling them that they could choose the amount of NaOH (671), and the equivalence one mol / one mol, making part of the concept of neutralization. This support from the teacher is interpreted as being in the ZPD because he does not provide precise instructions, but suggests them to reflect and attempts at increasing their autonomy. Our interpretation is that it is situated in Sergio's and Susana's ZPD because it seems that the other two students do not benefit from it. The first inner circle in figure 1 represents what these students know from the beginning, the question about finding the concentration of HCl, and the second what they have been able to do on their own, to relate concentration to molarity and to determine the molecular masses. The outer circle is what they will be able to do, as evidenced by the development of the task, with this scaffolding: the students are building conceptual knowledge, and a new meaning for *neutralization* relating the amount of HCl to the amount of NaOH, which enables them to plan actions aimed to solve the task. This transformation of meanings is interpreted as contextualization in Jiménez-Aleixandre and Reigosa (2006)

[Insert figure 1 about here]

Several turns later, after Sergio and Susana decide a testing value (0.5 M) for the NaOH solution and the volume, 10 ml of solution, to be prepared, Santiago seems to realize for the first time the meaning of their actions:

Group 3, Task 3, Session 1

Sergio	So the deal is to calculate a molarity, that is the molarity of one
Santiago	Listen, then: What happens? That beginning from the molarity that we want, what are we doing? Tests, one, two, until we got it, one that we want?
Susana	Yes *(nods)*
Santiago	(...) so we are putting here variations everything until it gives what we want, shit. The concentration that we want.
Susana	Zero five

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Santiago's utterances show that now he understands that they are choosing their own value for the concentration, running a test, indicating that the ZPD of the participants in this group are different. We interpret that he has been supported in his ZPD by Sergio and Susana's discussion and decisions, pointing at the relevance of peer support even unintentional, as in this case.

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Discussion and Conclusions: the Assumption of Responsibility

This report discusses a case study about groups of students performing practical tasks designed as problems. We have focused on the analysis of the assistance provided by the teacher, with the notion of scaffolding and transferring of responsibility as our guiding framework. By means of an inductive and iterative methodology, with negotiation of interpretations among authors, we have identified a range of difficulties arising in the application of scaffolding and in the development of autonomy in these groups.

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In a number of the interactions analyzed, problems arose because task difficulty was inappropriate. Excessive task difficulty can prevent a group of students from assuming increasing responsibility (Cazden, 1988), and inadequate task difficulty fails to facilitate the development of new capacities. Task difficulty must be adjusted to the students' developmental level, beyond what the student is currently capable of achieving unaided, thus promoting the learning of new skills, but without going beyond his or her competence level, since this would impede the development of autonomy. Learning task design thus implies evaluation not only of what students can do by themselves, but also of what they can do with assistance (Brown & Ferrara, 1985). In the case of the school laboratory, this requires from the teacher to evaluate, for each task, a) which symbolic or physical resources are necessary for that task's resolution, b) which of these resources can be assumed that the students have already appropriated, and c) whether it could be reasonably expected that the remaining resources can be appropriated during the performance of the task. This evaluation will be useful for ensuring that a task can provide a context in which the assistance of the teacher can be conceived as scaffolding and promoting the transfer of responsibility. Nevertheless, the evaluation implies that the teacher has to predict whether the students currently have appropriated resources, and whether they will be able to appropriate other: and of course neither prediction can be made with absolute certainty. As is shown in this study, in a single

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task performed by students of the same educational level, transfer of responsibility was more successful for some groups than for others, and some were able to solve the problem without assistance. Faced with this diversity of situations, one possibility is to design tasks of adjustable difficulty; tasks designed in such a way that makes possible to modify their difficulty depending on how the participants' activity develops. It is important to note here that, as indicated by Hodson and Hodson (1998b), the notion of ZPD is not exclusive to the learners, but it is constructed in each situation through *interaction* with the person who guides the learning process. So in the context of school laboratory, the influence of the teacher on the ZPD is another factor that adds to the difficulty of predicting whether or not the students will be able to solve the problem with assistance.

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A second type of difficulty interfering with the efficacy of scaffolding and transfer of responsibility in the laboratory originates from stereotyped school culture, that could be also described as procedural display (Bloome, Puro & Theodorou, 1989) or dramaturgical action (Habermas, 1984), which prevent the students from effectively assuming responsibility. We have developed a frame of categories for this type of situation in the school laboratory, and discussed some examples in which the transfer of responsibility is made difficult by this stereotyped school culture. Laboratory tasks in which students follow a sequence of pre-established and fixed steps are frequent in Spanish schools (Gil, Carrascosa, Furió, & Martínez-Torregrosa, 1991), and in our view years of immersion in such educational systems can cause insecurity among students when they are called upon to enter scenarios in which they must assume responsibility; in such scenarios they will thus tend to adopt stereotyped behaviours that avoid the need to progressively assume this responsibility. We believe that continued experience in open practical activities – consistent with scientific culture, that require students to make procedural and epistemological decisions, and in which the stereotyped performances inherent to school culture lack practical utility – may help students to abandon such school culture. This hypothesis is supported, to a certain extent, by the data showing that students who had greater experience practicing tasks of this type showed them less frequently than students with less experience, although the small size of the sample prevents generalisation.

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Third, other situations that appear to impede effective developing of a higher level of autonomous competence are related to social interactions between the members of the group, and roles assumed within them. In some cases there are significant differences in the ZPDs of the participants, and the more able students show a lack of interest in sharing their knowledge; this often means that less advantaged students gain little benefit from the tasks. Contributing to these problems is the excessive dependence on products (such as laboratory reports) for evaluation and grading. This can lead the more able students to take on the majority of the work, presumably on the view that this will optimize the final product (which provides the basis for grading). These students thus assume increasing responsibility, while other members of the group are marginalized. We consider that forms of evaluation that take into account not only the product but also the process would favour effective scaffolding.

It is worth noting that, in the cases analyzed, in despite of the difficulties for the transfer of responsibility to the students, it can be said that they learned several contents. For instance, in the task of the titration of an acid, they did stoichiometric calculus, and they calculated what was required for the preparation of solutions, they put into practice laboratory procedures (use of the burette or the scales). There are other procedures and techniques that the task allowed them to acquire but they did not, at least to a level enough to complete it. The same can be said about conceptual aspects, as the ones related with acid-base neutralization, which they used during the task and in the writing of a report. There are examples that show the development of skills related to scientific culture, as shown with group 4 in task 5, in which they correctly interpret numerical data using concepts as precision and error.

In conclusion, progressive responsibility transfer to learners is central in learning conceptualization as legitimate peripheral participation, but we would suggest that effective educational implementation of an approach of this type requires not just a perspective adequately grounded in theory, but also a detailed consideration of practical difficulties arising, like the three categories discussed in this paper. Ours is a case study and the results cannot lead to generalisation; we would suggest the need for further research exploring scaffolding, with the aim of identifying and explaining difficulties for the transfer of responsibility, and proposing alternative approaches. This could also shed light on the difficulties experienced when attempting to incorporate to the science classrooms, and particularly to the science laboratories, contexts that require from students to work autonomously as scientist do.

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References

Bloome, D., Puro P., & Theodorou E. (1989). Procedural display and classroom lessons. *Curriculum Inquiry*, 19(3), 265–291.

Brown, A. L., & Ferrara, R. A. (1985). Diagnosing zones of proximal development. In J. V. Wertsch (Ed.) Culture, communication and cognition: Vygotskian perspectives (pp. 139–150). Cambridge: Cambridge University Press.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18, 32–42.

Cazden, C. (1988). *Classroom discourse. The language of teaching and learning*. Portsmouth: Heinemann.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: teaching the crafts of reading, writing and mathematics. In L. B. Resnick (Ed.) Knowing, learning and instruction. Essays en honor of Robert Graser (pp. 453–494). Hillsdale: Lawrence Erlbaum.

Duschl R. A., & Gitomer D. (Coord.) (1991). *The acids & bases unit*. Project SEPIA, University of Pittsburgh.

Fleer, M. (1992). Identifying teacher-child interaction which scaffolds scientific thinking in young children. *Science Education*, 76, 373–397.

Gil, D., Carrascosa, J, Furió, C., & Martínez-Torregrosa J. (1991). *La enseñanza de la ciencia en la educación secundaria* (Science education at secondary level). Barcelona: ICE-Horsori.

Habermas, J. (1984). *The theory of communicative action.* Boston, Beacon Press.

Hodson, D., & Hodson, J. (1998a). From constructivism to social constructivism: a vygotskian perspective on teaching and learning science. *School Science Review,* 79, 33–41.

Hodson, D., & Hodson, J. (1998b). Science education as enculturation: some implications for practice. *School Science Review,* 80, 17–24.

Jiménez-Aleixandre, M. P., Bugallo Rodríguez, A. & Duschl, R. A. (2000). "Doing the

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Task 1 (Separation of substances): 'In a mine from which salt is extracted, it is unfortunately obtained mixed with sand. In order to use the salt, it is necessary to eliminate the sand; otherwise it can't be packaged and sold in supermarkets, for example. We'd like you to test a method in the laboratory for separating the salt from the sand. It's also important that you discuss what they should do in the mine to put your idea into practice, bearing in mind that the mine is in the open air, that a river runs alongside it, and that it is located in a hot sunny country. ¶
Task 2 (Exact measurement of volume): 'A pharmaceutical company wants to sell vials containing a specific amount of a recently invented liquid medicine which is an effective cure for several rare diseases. But like other recently invented drugs, it's very expensive, because the pharmaceutical company wants to recover the money it has invested in the years of research required to develop it and confirm its effectiveness. Since the medicine is so expensive, the company's managers want to know the most accurate way of measuring volumes of liquids in the laboratory; they don't want to put too much liquid in the vials and so lose money, but at the same time they don't want to supply too little. You have ... [3]

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lesson" or "doing science": argument in high school genetics. *Science Education*, 84, 757–792.

Jiménez-Aleixandre, M. P. & Reigosa, C. (2006). Contextualizing practices across epistemic levels in the chemistry laboratory. *Science Education* (published online, February, 8th).

Kelly, G. J., & Crawford, T. (1997). An ethnographic investigation of the discourse processes of school science. *Science Education,* 81, 533–559.

Lave, J., & Wenger, E. (1991). *Situated learning. Legitimate peripheral participation*. Cambridge, Cambridge University Press.

Lemke, J. (1998). Analysing verbal data: Principles, methods and problems. In B. J. Fraser, & K. J. Tobin (Eds.) *International Handbook of Science Education* (pp.1175–1189). Dordrecht: Kluwer.

Leont'ev, A. N. (1978). *Activity, consciousness, and personality*. Englewood Cliffs: Prentice-Hall.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Newbury Park: Sage.

McKernan, J. (1996). *Curriculum action research*. London: Kogan Page.

Mercer, N., & Fisher, E. (1992). How do teachers help children to learn? An analysis of teachers' interventions in computer-based tasks. *Learning and Instruction*, 2, 339–355.

O'Loughlin, M. (1992). Rethinking science education: beyond Piagetian constructivism toward a sociocultural model of teaching and learning. *Journal or Research in Science Teaching,* 29, 791–820.

Puntambekar, S., & Kolodner, J. L. (2005). Toward implementing distributed scaffolding: helping students learn science from design. *Journal or Research in Science Teaching,* 42, 185–217.

Reigosa, C. (2002). Discurso en el laboratorio durante la resolución de problemas de física y química: acciones, justificaciones, cultura científica y mediación (Discourse in the laboratory during physics and chemistry problem solving: actions, justifications, scientific culture and mediation). Unpublished doctoral dissertation. University of Santiago de Compostela.

Reigosa, C. & Jiménez-Aleixandre, M.P. (2000). La cultura científica en la resolución de problemas en el laboratorio. (Scientific culture in problem-solving in the laboratory). *Enseñanza de las Ciencias*. 18, 275–284.

Reigosa, C. & Jiménez-Aleixandre, M. P. (2001a). Deciding how to observe and frame events

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in an open physics problem. *Physics Education, 36, 129–134.*

Reigosa, C. & Jiménez-Aleixandre, M. P. (2001b). Collaborative work in the vygotskian zpd: a case study in the chemistry laboratory. *Paper presented in the 3rd ESERA meeting.* Thessaloniki (Greece). August.

Richmond, G., & Striley, J. (1996). Making meaning in classrooms: social precesses in small group discourses and scientific knowledge building. *Journal of Research in Science Teaching,* 33, 839–858.

Roth, W. -M., & Bowen, G. W. (1995). Knowing and interacting: a study of culture, practices and resources in a grade 8 open-inquiry science classroom guided by a cognitive apprenticeship metaphor. *Cognition and Instruction*, 13, 73–128.

Shepardson, D. P. (1996). Social interactions and the mediation of science learning in two small groups of first-graders. *Journal of Research in Science Teaching*, 33, 159–178.

Stake, R. E. (1995). *The art of case study research*. Thousands Oaks: Sage.

Vygotsky, L. S. (1978). *Mind in society. The development of higher psychological processes*. Cambridge: Harvard University Press.

Vygotsky, L. S. (1986). *Thought and language*. Cambridge: MIT Press.

Wells, G., & Chang-Wells, G. L. (1997). 'What have you learned?': co-construction of the meaning of time. In J. Flood, S. Brice-Heath, & D. Lapp (Eds.) A handbook for literacy educators: research on teaching the communicative and visual arts (pp. 514–527). Macmillan, New York.

Wertsch, J. (1991). *Voices of the mind: a sociocultural approach to mediated action.* Cambridge, Harvard University Press.

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry.* 17, 89–100.

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Appendix: English translation of Task instructions (excerpts)

Task 1 (Separation of substances): In a mine from which salt is extracted, it is unfortunately obtained mixed with sand. In order to use the salt, it is necessary to eliminate the sand; otherwise it can't be packaged and sold in supermarkets, for example. We'd like you to test a method in the laboratory for separating the salt from the sand. It's also important that you discuss what they should do in the mine to put your idea into practice, bearing in mind that the

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mine is in the open air, that a river runs alongside it, and that it is located in a hot sunny country.

Task 2 (Exact measurement of volume): A pharmaceutical company wants to sell vials containing a specific amount of a recently invented liquid medicine, which is an effective cure for several rare diseases. But like other recently invented drugs, it's very expensive, because the pharmaceutical company wants to recover the money it has invested in the years of research required to develop it and confirm its effectiveness. Since the medicine is so expensive, the company's managers want to know the most accurate way of measuring volumes of liquids in the laboratory; they don't want to put too much liquid in the vials and so lose money, but at the same time they don't want to supply too little. You have to decide which laboratory equipment (beaker, Erlenmeyer flask, pipette, etc.) is the most accurate for measuring volumes, and how to use it.

Task 3 (Titration of an acid): Experiments were carried in a laboratory using acid and base solutions, formed by acid and basic substances dissolved in water. After the experiments were completed, the people carrying them were gone and they forgot to label a big bottle with hydrochloric acid dissolved in water. We cannot dispose it directly through the sink, because it could cause pollution, and we want to keep and use it in the future. But before storing it away we need to know its concentration in molarity. Working in groups you have to find a way of knowing the concentration of this solution. Each group will be given a small amount of the acid solution to work with.

Task 4 (Type of movement on a rail): We're going to study the movement of a ball that rolls down a rail, to see what type of movement it is (...). In practice, what we're aiming to do is find out whether the movement is uniform, uniformly accelerated or of some other type.

Task 5 (Measurement of mass using a spring): An explorer wants to be able to measure the mass of small stones (weighing less than 0.5 kg), but does not want to take scales in his luggage because it would take up too much space. He needs to know if instead of scales he could use a spring (or a rubber band, which takes up even less space) together with a tape measure. He asks you to assess whether a spring or a rubber band would work, and if so why. He'd like to know whether any spring or rubber band will work effectively, and if not how he can tell whether a given spring or rubber band will work, and with what accuracy.

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Teacher ... because it'll take up a lot of space.

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Page 23: [3] Deleted	Marilar Aleixandre	3/15/2006 7:57:00 PM

Appendix: Task instructions (excerpts)

Task 1 (Separation of substances): 'In a mine from which salt is extracted, it is unfortunately obtained mixed with sand. In order to use the salt, it is necessary to eliminate the sand; otherwise it can't be packaged and sold in supermarkets, for example. We'd like you to test a method in the laboratory for separating the salt from the sand. It's also important that you discuss what they should do in the mine to put your idea into practice, bearing in mind that the mine is in the open air, that a river runs alongside it, and that it is located in a hot sunny country.

Task 2 (Exact measurement of volume): 'A pharmaceutical company wants to sell vials containing a specific amount of a recently invented liquid medicine which is an effective cure for several rare diseases. But like other recently invented drugs, it's very expensive, because the pharmaceutical company wants to recover the money it has invested in the years of research required to develop it and confirm its effectiveness. Since the medicine is so expensive, the company's managers want to know the most accurate way of measuring volumes of liquids in the laboratory; they don't want to put too much liquid in the vials and so lose money, but at the same time they don't want to supply too little. You have to decide which laboratory equipment (beaker, Erlenmeyer flask, pipette, etc.) is the most accurate for measuring volumes, and how to use it.'

Task 3 (Titration of an acid): 'Experiments were carried in a laboratory using acid and base solutions, formed by acid and basic substances dissolved in water. After the experiments were completed, the people carrying them were gone and they forgot to label a big bottle with hydrochloric acid dissolved in water. We cannot dispose it directly through the sink, because it could cause pollution, and we want to keep and use it in the future. But before storing it away we need to know its concentration in molarity. Working in groups you have to find a way of knowing the concentration of this solution. Each group will be given a small amount of the acid solution to work with.'

Task 4 (Type of movement on a rail): 'In this practical we're going to study the movement of a ball that rolls down a ramp, to see what type of movement it is (...). In practice, what we're aiming to do is find out whether the movement is uniform, uniformly accelerated or of some other type.'

Task 5 (Measurement of mass using a spring): 'An explorer wants to be able to measure the mass of small stones (weighing less than 0.5 kg), but does not want to take scales in his luggage because it would take up too much space. He needs to know if instead of scales he could use a spring (or a rubber band, which takes up even less space) together with a tape measure. He asks you to assess whether a spring or a rubber band would work, and if so why. He'd like to know whether any spring or rubber band will work effectively, and if not how he can tell whether a given spring or rubber band will work, and with what accuracy.

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Authors (2000). *Enseñanza de las Ciencias.*

Author1 (2002). Unpublished doctoral dissertation.

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Authors (2001a). *Physics Education.*

Authors (2001b). *Paper presented in the 3rd ESERA meeting.*

Tables

Table 1. Tasks performed by the students.

Task	**Year 1** Group 1 (n = 5) Group 2 (n = 5)	**Year 2** Group 3 ((n = 4) Group 4 (n = 4)
Separation of substances	-	+
Exact measurement of volume	-	+
Titration of an acid	-	+
Type of movement down a rail	+	+
Measurement of mass with a spring	+	+

Table 2. Categories of difficulties arising in scaffolded ZPD-oriented interventions

DIFFICULTY	**DESCRIPTION**
Excessive task difficulty	The students are not able to complete the task even with scaffolding; the teacher can at best supply instructions, not transfer responsibility. The task lies outside the students' ZPD.
Stereotyped school culture	The students' expectations about their role in the school laboratory are incompatible with the progressive assumption of responsibility.
Problems related to social interactions and group roles	Marked differences in the ZPDs of different group members, or marked inequalities in the group social interactions, so that some members of the group derive little benefit from the task.

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Table 3. Different dimensions of stereotyped school culture

1) Laboratory activities as a closed unique sequence of steps.
2) Viewing searching for a solution, collecting data, or clarifying concepts as inappropriate or not useful.
3) Interpreting the teacher's questions as criticisms.
4) Assuming each piece of equipment & resource to have only a single and predefined use.
5) A tendency for confirmation bias.
6) Reluctance to challenge the teacher's authority.
7) Imitating the behaviour of other students, even when it is not justified.

Table 4. Comparison of manifestations of stereotyped school culture in Task 5.

Group	**Number of instances (in brackets those hindering scaffolding)**
1 (Year 1)	30 (22)
2 (Year 1)	46 (33)
3 (Year 2)	11 (9)
4 (Year 2)	6 (4)