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ABSTRACT

This paper discusses the elaboration and application of "scientific culture" categories to the analysis of students' discourse while solving problems in inquiry contexts. Scientific culture means the particular domain culture of science, the culture of science practitioners. The categories proposed include both epistemic operations and procedural and technical operations for work with the microscope. Data are drawn from case studies in the context of a project on students' reasoning and argumentation in high school and at university. The methodology involved observation, videotaping, and audiotaping of students while working in groups to solve biology and physics problems. The issues discussed include the appeal to consistency, the use of comparison, and the construction of data from empirical sources across different disciplinary contexts. The degree of subject-matter dependence of these operations is discussed. Results indicate that students do use epistemic and procedural operations in a way related to scientific culture. Contains 20 references. (Author/PVD)

Scientific Culture and School Culture: epistemic and procedural components

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Abstract

This paper discusses the elaboration and application of "scientific culture" categories to the analysis of students' discourse while solving problems in inquiry contexts. By scientific culture we mean the particular domain culture, as defined by Brown, Collins and Duguid (1989), of science, the culture of science practitioners. The categories proposed include both epistemic operations and procedural and technical operations for work with the microscope. The data are drawn from case studies, in the context of a project about students' reasoning and argumentation in High School and University, and the methodology involved observation, video and audiotaping of students while working in groups solving problems about Biology and Physics.

The issues discussed include the appeal to consistency, the use of comparison and the construction of data from empirical sources across different disciplinary contexts. The degree of subject-matter dependence of these operations is discussed. Results show that students do use epistemic and procedural operations in a way related to scientific culture.

1 The culture of science practitioners: rationale for the study and objectives

This paper discusses the construction and application of a set of categories as a tool to analyse classroom discourse. The dimension of the discourse we are focusing in is the scientific culture as opposed to archetypal school culture. We draw the notion of practitioners' culture from Brown, Collins and Duguid (1989), and by scientific culture we mean the culture of science practitioners.

The notion of situated cognition, in other words that conceptual knowledge cannot be abstracted from the situations in which is learned, has been proposed by Brown, Collins and Duguid (1989). For these authors part of the difficulties that students experience to use this knowledge relate to being asked to use the tools of a discipline without having adopted its culture. Brown *et al* distinguish between the authentic culture of the practitioners of a domain –in our case the authentic cultures of different science fields– and the archetypal school culture. In our opinion the archetypal school culture relate more to learning to act as a student, to what Bloome, Puro e Theodorou (1989) call display, activities that for students mean playing the role that is expected from a student, and for teachers playing the role that is expected from a teacher. In this paper, when we oppose scientific culture to archetypal school culture, what we try to highlight are the aspects from conventional school practices which ignore the culture of science practitioners and focus on issues such as terms, definitions or follow-a-recipe activities. The implication is not to assign a negative label to all "school culture", that includes also positive aspects. It is worth noting that the scientific culture practised in school cannot be exactly the same as the scientific culture of science practitioners, because it has to be transposed, using the term from Joshua and Dupin (1993)

One of our purposes is, then, to characterise the culture of science practicioners, to identify practices related to scientific culture. Our approach is that these practices are better identified, not as stereoyped "steps" of scientific methodologies, but as a set of operations related to doing science. Our notion of doing science relates to science as solving unsolved problems, and draws from Ronald Giere (1988) the consideration of the process of choice among competing claims and theories as an essential part in the building and evaluation of scientific knowledge. In this perspective doing science is less a process of inference and more a process of decision making, less a set of experiences and more a path of scientific reasoning. Giere proposal is framed in what he termed perspectival realism. This could be clarified by an analogy that he suggests (Giere 1995) between scientific representations and road maps which gives a different answer to the old question about the truth in representations (models, theories) about the world. As he says the question whether a map is true or false doesn't make sense, and the representational virtues of maps are different; maps do manage to correspond in various ways with the real world and they are useful when travelling in unfamiliar territories.

One interesting feature in this analogy is that, as Giere says: "*Maps require a large background of human convention for their production and use. Whitout such they are no more than lines on paper*". The same, we believe, happens with scientific representation when learning science; they require, from the students, handling an amount of conventions, names, symbols, inscriptions, ways of drawing and talking, ways of reasoning and communicating. This lead us to the question of science discourse in the classroom.

We are interested in the analysis of classroom discourse, in particular looking for instances of participation of students in the discourse of science practitioners, looking for the students "talking science" (Lemke 1990), for situations when, in Lemke's words, some science is talked about. The question is not one of the researchers (or the teachers) finding the science in the classroom conversation; as Lemke says, if the students themselves don't find the science in it they may learn how to play the classroom game (what we categorise as archetypal school culture) but they won't learn how to talk physics or biology. Lemke defines talking science on the part of the students as their participation in the language-in-use in the science community, that is, among others: observing, describing, comparing, classifying, arguing, reporting etc. The discourse found in science classrooms, this author points out, is influenced by the goal structures established by the curriculum and the teacher, it is not independent of the instruction activities. In this study, conventional laboratory sessions are contrasted against laboratory sessions on the same topic designed to engage students in solving a problem, in argumentation.

Of particular relevance to the analysis of discourse in science classrooms is the sociological approach. Latour and Woolgar (1986) have studied the construction of facts, the transformation of data through conversation (discourse), the processes by which scientists give meaning to their observations, and they do it by analyzing current scientific practice in a biology laboratory. They document instances of transformation of statements into facts, of what they describe as efforts to introduce order in a disordered array of observations; they see inscriptions and writing as a material operations aimed to create order more than to the transfer of information. The sociological perspective has been applied to the study of science curriculum and classrooms, and school labs by Cunningham (1996) and Kelly & Crawford (1997). Kelly & Crawford have explored, through the study of classroom discourse, what counts as science for High School students in a laboratory context. In our case we are trying to identify instances of data construction in the students conversations.

Taking into account these views, our proposal about the culture of science practitioners is that it should include at least two type of components or operations:

1) Epistemic operations: explanation procedures, causal relations, analogies, comparisons etc. which could be interpreted as being specific from the science domain, parallel to the ones proposed by Pontecorvo and Girardet (1993) for social sciences, in particular for History.

2) Procedural and technical operations: including not only the actual use of instruments and apparatus, but also the discussions about it. In this paper we discuss as an instance the operations related to the work with microscope

This study is part of a project on students' reasoning, particularly on their capacity to develop and assess argument. We intend to make a contribution to the study of classroom discourse, an emergent line which offers promise about helping to gain insight in the processes and difficulties in learning Science. One crucial operation in the construction of scientific knowledge is relating data to claims, justifying claims with evidence or, in Toulmin's (1958) terms, using warranted arguments. As this argumentation is the main focus of our project and it is subject to a detailed analysis in other papers (Jiménez-Aleixandre, Bugallo & Duschl 1997, Jiménez-Aleixandre, Díaz de Bustamante & Duschl 1998) we will not discuss it here.

The objectives of the study are:

1) One objective related to the instrument: to construct and test a set of categories as a tool to analyse the science culture dimension in the students' discourse while solving science problems.

2) One objective related to science learning: To identify practices related to scientific culture, in particular the epistemic and procedural operations performed by students' across different disciplinary science contexts.

2 Scientific culture: proposal of an instrument

We propose to distinguish at least two set of categories in the scientific culture: the epistemic operations on the one hand and the procedural and technical operations on the other hand. The list of categories for the operations of the two types are discussed separately, but, as will be seen in the results section, there are several examples of the interaction of the procedural operations, or the features of the instrument, with the epistemic operations during the processes of data construction.

In the construction of a list of categories for the epistemic operations we draw from several sources: on the categories of discourse about conceptual change by Thorley (1992) and on the epistemic operations for social sciences by Pontecorvo and Girardet (1993) to which we have added other. Thorley (1992) developed a framework for analysing classroom discourse based on the conceptual change model which included different dimensions. Several of Thorley dimensions are useful to study the conceptual ecology, for instance the representational modes: analogy, exemplar or attribute, and the consistency factors. Pontecorvo and Girardet (1993) propose explanation procedures used in the social sciences, like locating events in time and space; the list that we have developed is a proposal of epistemic operations used in experimental sciences. In table 1 the categories are represented and in the results sections there are shown instances of students' discourse categorised in each operation.

This list was developed partly by drawing constructs from the literature, and partly as a consequence of our data analysis, as we were trying to interpret the students' conversations and performances. Some of the categories have been widely discussed in the literature, as it is the case with induction, deduction, causality, definition or classification, and there is no need to explain them. There are others that we developed during the analysis, thus we added to Thorley dimension on comparison the category "comparison to prototype" (for instance the ideal prototype of plant cell), that we see different from comparison to an exemplar (like cells in a sample from onion skin) even when the students consider this exemplar as prototype.

Another category that we developed is the one related to data construction, that will be discussed in detail in the results section.

Scientific culture A. epistemic operations	implies
Induction	looking for patterns, regularities
Deduction	identifying particular instances of laws, rules, principles
Causality	relation cause-effect, looking for mechanisms, making predictions
Definition	stating the meaning of a concept
Classification	grouping objects, organisms, according to criteria
Comparison: appeals to analogy	analogy used as primary representation
Comparison: appeals to exemplar	object or organism considered exemplar of a category
Comparison: appeals to prototype	ideal abstraction of a category
Appeals to attribute	significant features of a category
authority or source of knowledge	reference to book, teacher, others as source of knowledge
Consistency with other knowledge	reference to consistency with knowledge
Consistency with experience	events or phenomena quoted as consistent
Commitment to consistency	explicit reference to common explanation
Construction of data	giving meaning to observations; interpretation and reinterpretation
Plausibility	evaluation of own or others' knowledge

Table 1 Categories for epistemic operations

We developed the categories for procedural and technical operations for the particular contexts under study, and they are closely related to the data analysis. Only the ones elaborated for the laboratory work with microscope, which have been used as a tool for analysis with eight from the 13 groups in this study, will be discussed here. The categories are represented in table 2, and discussed with instances in the results section.

Scientific culture B. procedural and technical operations: microscope	implies
Use of inscriptions	drawing to represent samples
Performs operations: lights, changes objective, focus	performing physical operations, e.g. focus
Discusses operations	discussing operations, while performing them or not
constraints of instrument	making explicit constraints that the instrument (microscope) imposes on observation, e.g size of field observed.

Table 2 Categories for procedural and technical operations: microscope

3 Methodology

- Educational context and Participants

The data where drawn from 13 groups: nine groups of High School students (9th and 11th Grade, 14-15 and 16-17 years) and four groups of Student Teachers. The two groups of Student Teachers studied while working in the laboratory were following the Primary Teachers' Certificate, while the two groups studied while solving a paper and pencil problem about Buoyancy were Physics and Chemistry Graduates following the Secondary Teachers' Certificate.

From these, five groups of High School and all the University Students were solving problems designed in an inquiry perspective, while four of the High School students were studied while they performed a standard laboratory task, without any intervention from the researchers. The context of the tasks were Biology (Genetics and Cell Biology in laboratory sessions with microscope) and Physics (Buoyancy). Some of the problems involved only one session and some involved carrying experiences during six to eight sessions. Table 3 summarizes the features of the groups

Group, size	grade	context	task, # sessions
GEN N = 4	9th (14-15 years)	Genetics	paper & pencil problem; 6
LABM1 N = 3	11th (16-17 years)	Lab., microscope	conventional, 1
LABM2 N = 4	11th (16-17 years)	Lab., microscope	conventional, 1
LABM3 N = 3	11th (16-17 years)	Lab., microscope	conventional, 1
LABM4 N = 5	11th (16-17 years)	Lab., microscope	conventional, 1
LABM5 N = 4	11th (16-17 years)	Lab., microscope	unknown sample, 1
LABM6 N = 2	11th (16-17 years)	Lab., microscope	unknown sample, 1
LABM7 N = 4	Student teachers	Lab., microscope	unknown sample, 1
LABM8 N = 4	Student teachers	Lab., microscope (all Cell biology)	unknown sample, 1
BUOY1 N = 3	11th (16-17 years)	Buoyancy	refloat submarine, 8
BUOY2 N = 3	11th (16-17 years)	Buoyancy	refloat submarine, 8
BUOY3 N = 4	Physics & Chem.	Buoyancy	paper & pencil 1
BUOY4 N = 4	graduates	Buoyancy	paper & pencil, 1

Table 3 Summary of the thirteen small groups of participants in the study

– About the tasks:

The Genetics task is a paper and pencil problem: in the context of a chicken farm in their town, students were asked to explain why the chicken born in farms are yellow, in contrast with the spotted color of chicken in the wild; it is described in Jimenez, Bugallo & Duschl (1997).

The microscope task for groups LABM5 to LABM8 is an unknown sample, different for each group, that has to be identified with the help of a handout in which four suspects (two plant-like, two animal-like) of stealing lab equipment are described (Jiménez, Díaz & Duschl 1998). This problem-solving task for the work with microscope is in contrast with standard tasks, as the one performed by groups LABM1 to LABM4, consisting in observation and drawing of a known sample (lily epidermis), the same for all groups.

In the Buoyancy task for Secondary School students (BUOY1 and BUOY2), they are asked to build a physical model for taking afloat a sunk submarine in the seaside near their town (Alvarez et al 1997); in this paper only data from the first sessions, while discussing the task and predicting whether objects will float or sink, are used. The task for University students is a pencil and paper problem, and they were asked to discuss about the bubbles in a glass of soft drink while in free falling from an aerostatic balloon (Alvarez 1998).

– Data collection and analysis:

The students were videotaped, audiotaped and observed during the tasks. The data included the recordings, the field notes from the observers and the productions of the students: drawings, reports, models etc.

The audiotapes were transcribed and the sentences broken into unit of analysis. Then in some of the units instances of the epistemic operations were identified. For the procedural operations a similar analysis was performed with the videotapes. The audio and video transcriptions were then contrasted. The tapes were, in a first step, independently analyzed and coded by two authors. The analysis were then compared, and the differences discussed until an agreement was reached. Sometimes this involves modifications of the categories.

In the next two sections instances of use of epistemic and procedural operations are discussed separately.

4 Use of epistemic operations

There are many instances of use of epistemic operations by the students. Below are shown excerpts from the transcriptions and our interpretation of them. The code of each group is the one used in table 3. The names of the students are pseudonyms, respecting the gender, and we have used in each group names beginning with the same letter.

4.1 Use of induction, deduction, causality

LABM5

line	**transcript**	**category**
23.1	Fabri: I believe that it has chlorophyll	induction *(it is a plant)*
.2	this green spot	

LABM6

line	**transcript**	**category**
376		
.2	Gloria: how many types of cells are?	question
377	Gema:	
.1	I don't know	induction (describes observation)
.2	Some have scratches and some don't!	
378	Gloria: there are three types. I see three.	induction (interpretation)
379	Gema: Which ones? Which is the other one that you see?	sharing interpretation

380	Gloria: the one which has flagelli outside	sharing interpretation
382	Gloria: the ones which are black inside...	sharing interpretation
384	Gloria: and the other which don't... have anything, have nothing inside. Do you see them on this side?	sharing interpretation
393 .3	Gema: Write: There are three types (*of cells*). One with kind of flagellum.	induction *(three types of cells)*

GEN

line	transcript	category
118.1	Rita: I see, you will write...	deduction *(applying these principles to chickens' color)*
118.2	Lamarck says that if it changes during life, it passes to the genes,	
118.3	and Darwin says that it cannot change, what happens in life it doesn't change to genes.	
	.....	
229	Isa: But no, because the traits that you pick during your life are not inherited	deduction

GEN

line	transcript	category
97.1	Rita: But, look, I believe that it is because of food.	relation cause-effect
97.2	The food makes them to have the spotted body. I think so	

BUOY2 session 2

line	transcript	category
51	Doris: These would float, these up: the egg, the wood ball, the aluminium ball...	causality: prediction
53	Diana: Wait...	
54	Daniel: And the orange...	
55	Diana: Don't we have to test it?	
56	Doris: The orange! *(with surprise)*	
57	Diana: The orange floats.	prediction
58	Doris: Yes!	
59	Daniel: Are you sure about it?	
60	Diana: There are oranges in the water. Test it	prediction

From these operations, induction is the one which students use with greater frequency. This is particularly apparent in the experimental situations, trying to identify an unknown sample through the microscope, or working with physical models of a submarine. There are not so many uses of deductions, at least explicitly. The use of causality is related to the nature of the task; for instance is apparent in many occasions while solving the Genetics problem, which asked students to provide an explanation of a phenomenon (the difference in color between chicken in the wild and raised in farms)

4.2 Use of definition, classification

LABM5 **line**	**transcript**	**category**
58	Fabri: What does it mean saprophytic?	definition
59	Felix: That they eat carrion, well, something rotten...	definition

LABM5 **line**	**transcript**	**category**
300	Felix: Look there them tissues, I have some drawings	source of knowledge (*notebook)*
311	Flavio: Look this! It is this one, Felix!	attempt to match
312	Felix: Not that one!	
318	Felix: This one is colenchyma	classification

There are different instances of definition, in many occasions related to terms in the handout or documents that the students were consulting. The instances of classification are frequent while performing the microscope task, as students were trying to match the observation of the sample either with the descriptions in the handout or with information from their notebooks (as in the transcript above) or from their books.

4.3 Use of comparison

LABM5

line	transcript	category
229	Felix: Look here, see? Don't you see little dots inside and nuclei them or whatever they are	attempts at description
231	Felix: They look like donuts, man!	appeal to analogy
232	Flavio: they have a hole inside	description
234	Student: Oh dear!	
235	Felix: it will be one of those parenchyma or sclerenchyma	classification
238	Fabri: Yes, you see rings inside the...	description
244	Felix: But we don't know what are the stomata! They were these with chlorophylle	unable to match observation and information

This is a typical example of students looking at something and not "seeing" it. In previous exchanges they have been looking for the definition of stomata, one of the features quoted in the handout as discriminating two different samples. Then, in 231 Felix describes adequately the stomata appealing at the donuts analogy, and this is completed in lines 232 and 238 by other team members. However, they are unable to recognize these structures as stomata, due to lack of background knowledge.

LABM8

line	transcript	category
78	Julio: It's funny. You can see an external membrane as if it were an estate, and inside little estates at the same time. What I'm trying to say: land distribution.	appeal to analogy *(tissue as fields)*
79	Jacinta: You see an external membrane and inside... divisions	
82	Julio: Wow! Some of these farms... have...	appeal to analogy
83	Jacinta: You see different colors	
84	Julio: No, no. They have different shapes inside	

BUOY3

line	transcript	category
38	Tomas: When a liquid is boiling for instance,	
.1	there are other influences.	appeal to exemplar (*boiling as exemplar of bubbles*)
.2	A cynetic energy is communicated to the molecules... then, well this stuff, steam pressure	
.3	But we are talking... about a gas which has nothing to do with the liquid...	
39	Teacher: Hasn' t it?	
40	Tomas: They are just together in the can.	

LABM7

line	transcript	category
9 .1	Emilio: Well, we take plant cells, don' t we?	
.2	We' ve looked already plant cells through the microscope.	appeal to exemplar
10	Elisa: Yes, here they are (*in notebook*)	inscriptions, drawings
11	Emilio: And, do you remeber how they were?	
12	Elisa: Onion skin.	appeal to exemplar (*onion skin exemplar of plant cell)*

LABM7

line	transcript	category
404 .1	Emma: I wrote, we see that it seems a neurone.	classification
.2	It has kind of nucleus and branches.	appeal to attribute
.3	It is a regular cell.	appeal to prototype
	....	
543	Emilio: This inside, it doesn't seem a regular nucleus.	appeal to prototype

The instances quoted above exemplify the distinction that we draw among appeal to exemplar (water boiling as exemplar of bubbles, onion skin as exemplar of plant cells) and appeal to prototype, the ideal representation of a "regular" cell or a "regular" nucleus (wathever that means for the students). Comparisons with appeal to analogy, exemplar or prototype are widely used in all the groups studied, as a mean to make sense of observations or to tackle with new problems. In the last portion of transcript, line 404, there is also an instance of appeal to attribute.

LABM7

line	**transcript**	**category**
128	Emilio: Look, A plant must have: nucleolus, nucleus, cytoplasm, cell wall.	appeal to attribute

GEN

line	**transcript**	**category**
137	Rita: That would be if Lamarck's theory were	
.1	right,	appeal to authority
.2	but because it isn't right.	(*instruction, teacher*)

LABM5

line	**transcript**	**category**
144	Fabri: Has someone brought a book? Nobody	source of knowledge
	....	
207 .1	Fabri: If we had the science book!	source of knowledge
.2	What do you think they are? They are similar...	
.3	You see a limit. What do you think they are?	

The students also appeal to several sources of knowledge, sometimes as authority about the "right" view, sometimes just as a source of information, as in section 4.2, line 300, when using the drawings in their notes from instruction, or in the references to the book quoted above. This appeal to books and notebooks during a laboratory session is very unusual in standard laboratory sessions, probably because during them students do not feel the need to establish connections among previous knowledge and the routine tasks they are asked to perform. A detailed analysis of the interactions in the groups LABM1 to LABM4 (Jimenez & Diaz 1997) shows that, although it could be assumed that students would use textbooks or notebooks to check, for instance, the features of epidermic and stomata cells which they were asked to draw, only in one occasion, in group LABM3, one of the students took out a notebook, and apparently made an attempt to look for drawings; but he just browsed it a few seconds, then closing it, and the episode didn't seem to affect the development of the task.

4.4 References to consistency

GEN

line	**transcript**	**category**
154.2	Bea: I also heard that it was because of eating yellow feed.	causality *(chicken are yellow because of feed)*

155	Isa: Well, no, because you, even if you eat a lot of salad, your face doesn't turn green.	consistency with experience
157	Isa: No, and your hair neither	

GEN

line	**transcript**	**category**
283	Pat: I marry and go to Africa and have a child, and it is white.	consistency with experience
284	Isa: It's true, all right, Pat	plausibility
285	Student This is comparing chicken to people	commitment to consistency (denied)
295	Carlos: You cannot confuse them (*with people*)	commitment to consistency (denied)

BUOY3

line	**transcript**	**category**
142	Tina: Look, it asks, from a scientific	
.1	perspective, what makes the bubbles go up or not (pause)	causality
.2	The reason is density.	
143	Tomas: Yes, but we were almost saying it is pressure.	causality
	....	
153	Tucho: No, but anyway the claim about density still... is a valid one, now the bubble, inside the Coke tends to go up.	consistency with knowledge

Consistency is a relevant operation in scientific culture, because in order to understand the physical and natural world, there is a need to recognise the universality of explanations, that Newton's mechanics apply to all situations of free fall, and not differently in an elevator and in falling from an aerostatic balloon. In the groups studied there are examples of appeal to consistency and there are also instances, like in lines 285 and 295 of Genetics, quoted above, of students that deny that the laws of inheritance apply in the same way to chickens and to people, an example of anthropocentrism that may be one of the obstacles to a commitment to consistency.

4.5 Construction of data

LABM7

line	transcript	category
581	Emilio: The cells have like branches	attempts description
583	Elisa: That... here...	
584	Emma: Wait! connected by kind of threads	first interpretation
585	Emilio: Connected by these... threads or...	
586	Emma: A kind of threads.	
587	Emilio: By axons!	data construction
590	Emma: What are they? Animal cells	

LABM8

line		transcript	category
190		Julio: Do you know what are these black spots?	observation (question)
191		Javier: What?	
192	.1 .2	Julio: The formation of new nuclei in the cells that what it says in "d"	first interpretation (formation of new nuclei)
194	.1 .2	Julio: "Cells falling out easily" Could it be that the nucleus is dividing, that's why is so dark?	(reads from handout) second interpretation (division)
198		Judit: What could they be? New forms of...	goes to 1st interpretation
199		Julio: it seems that the nucleus was dividing to form... new cells.	data construction: cell division

In a process parallel to data construction analyzed in Latour and Woolgar (1986), the students try to make sense from their observations, in the two excerpts quoted above to interpret unknown samples that they observe through the microscope in terms related both to the information in the handout ("Cells falling out easily" in LABM8) and to their background knowledge (neurones have axons, they are a type of animal cells in LABM7). It is worth noting that the formation of new nuclei and the division of a nucleus to produce new ones are not the same idea, and that, during the construction of the Cell Theory it was a distance of about thirty years and a lot of elaboration from Schleidenn and Schwann first statement about the formation of new nuclei in a way that they compared to the formation of crystals, and the later interpretation about the division of nuclei to generate other nuclei proposed by Virchow. The issue is one of nuclei coming from other nuclei. These two instances of data construction are represented in flowcharts in figures 1 and 2.

(figures 1 and 2 about here)

During this processes that we interpret as data construction, there are cases when the interaction with the instrument, the microscope, the slides, is apparent, like in the examples below.

LABM5

line	transcript	category
89	Flavio: Gosh! Look at this!	begins observation
90	Fabri: Cell... Here is it! It is rubbish!	evaluation of observation
91	Felix: That is an oxygen bubble ¢§ß@!	data construction: (*artifact)* reevaluation of observation

LABM6

line	transcript	category
303	Teacher: If we use the blue one (*objective*) What happens?	teacher's prompt: greater magnification
307	Gloria: Ohh! There are different cells, Gema!	reinterpreting observation (*several cell types)*
308	Gema: Ahh! We have to do everything again!	evaluation of performance
310	Gema: Now everything has changed.	

LABM7

line	transcript	category
280	Eloy: But here you can see it well! with this one (*objective)* of little magnification you can see the layers that are there.	interaction with instrument (feature of sample apparent)
281 .1	Emilio: Stratified...	information from handout
.2	I believe that them layers... if you use the one (*objective*) of 40	data construction (layers)
283	Eloy: Yes, you can see the layers	

The instrument, in this case the microscope and microscope slides, has to be considered an actor, and not just a given, what happens even in accounts of History of Science (Bechtel 1996). It produces artifacts, like the air bubbles in LABM5 which can be confused with cells; in fact during laboratory sessions with microscope, it happens frequently that students spent a good part of the session drawing carefully air bubbles. Also, the use of lenses of different magnification power may change the observation of the sample: either because a greater magnification power allows seeing differences that went masked with other objectives, like in LABM6, where the students were interpreting the sample as having just one cell type until the teacher suggest changing to a greater magnification power, or the opposite, enabling a more general perspective with the lesser magnification objective, like in LABM7, which makes possible to perceive the disposition in layers, a feature relevant to match the unknown sample with information in the handout (stratified).

In summary, it can be said that the students in the groups which were solving problems (all except LABM1 to LABM4) used a wide range of epistemic operations, particularly the ones related with comparison, and showed instances of data construction. This stand in contrast to the interactions in the four groups performing standard tasks, LABM1 to LABM4, which produced exchanges just of a technical nature and did not discuss interpretations of observations (Jimenez and Diaz 1997).

5 Use of procedural and technical operations

There are many instances of use of procedural and technical operations in the thirteen groups studied. First are shown instances from diffferent operations, and then some aspects about the performances of the groups working with microscope in standard settings (LABM1 to 4) and the groups working in a problem solving situation (LABM5 to 8) are compared.

5.1 Use of inscriptions: drawings

LABM6

line	**transcript**	**category**
185	Gloria: We have to make a drawing.	
192	Gloria: Do we have to make dots?	
197 .1 .2	Gema: And draw this round thing, like a hoop and inside has little dots. look at the end.	drawing (instructions)
198	Gloria: Yes.	

199	.1	Gema: It has a shape more or less like this.	drawing (instructions)
	.2	It comes here, the dash. One thinner than the other.	
209		Gema: And now draw first the green spot, then the circle. Yes. Now this big spot, like this with many many dots, many dots.	drawing (instructions)

Drawings are used by students both to make sense of their observations and to communicate with others. Drawing the sample was one of the performances required in the task in all cases, but as will be seen in the comparison, not all the students completed the drawings.

5.2 Performing and discussing operations

In the section about data construction there are some examples of changing objectives. Besides there are other operations performed, like in the instances below.

LABM6

line	**transcript**	**category**
34	Gema: How do you switch...? How do you switch the light on, teacher?	using the light
38	Gema: This one moves it quickly. This one slowly. (*coarse and fine focus screws*)	identifying wheels to focus
49	Gloria: Gema, this is not a bit out of focus?	focusing

LABM7

line		**transcript**	**category**
467		Emilio: Look this one that is indicated with the pointer (*of microscope*) Don't you see it has one... Look!	using the pointer
469		Elisa: They have what?	
482	.1	Emilio: That we believe that...	
	.2	Look a minute there!	
	.3	the one indicated... down there... is like	using the pointer
	.4	It has...! Is that the nucleus?	interpretation

The case of the dyad in group LABM6 has been discussed in detail in other paper (Jimenez, Diaz & Duschl 1997), for instance the confusion between two wheels, the one for focusing and the condenser, which caused them not to be able to make adequate observations during around seven minutes.

5.3 Making explicit constraints of the instrument

All instruments impose constraints on observations. In the case of the microscope these constraints are of different kind. Some, for instance, relate to the need of a very thin sample. Students need to understand the way a microscope magnifies, completely different from a magnifying glass, and that the samples are seen through transparence, so if they are thick it would be impossible to see them. But the relation among transparence and the thickness of samples is rarely discussed by teachers. For instance, the students in group LABM3, as could be interpreted from the analysis of the videotape (Jimenez & Diaz 1997), had a very poor sample; they took it not by peeling a fine layer of epidermis, but by cutting a little piece from the whole lily leaf, in other words mistook size, smallness, for thinness. This sample was not transparent and they couldn't see anything. After their attempts failed, they discarded the sample and prepared a second one. However, as they didn't understand the nature of the problem, and the teacher just told them that the slide was not good, without refering to the transparence, they followed the same procedure. The second sample proved as inadequate as the first, and at the very end of the session the teacher took herself a sample and prepared a slide. We interpret these difficulties as related to a lack of understanding of how the microscope works and not simply as a lack of dexterity.

Other constraints refer to the relation between the size of the portion observed, smaller as greater magnifying power is used, or to the different layers in a sample which couldn't be observed at the same time.

LABM5

line	transcript	category
46	Felix: If we could focus it better in the middle!	focusing
47	Fabri: that's why you cannot see the green.	relating focus with observation
48 .1	Felix: No, because it takes less part of it	constraint of instrument: to greater magnification, smaller portion seen
.2	And if I focus it in the middle you won't see the rest. It is in layers this!	

LABM6

line	transcript	category
113	Gema: I cannot see anything!	
114	Gloria: Of course. You don't know what is outside because it is very big. Because its size is magnified a lot.	constraint of instrument: at great magnification

5.4 Comparison between standard and problem-solving groups

It has been mentioned already, at the end of section 4, that in the groups in conventional settings the use of epistemic operations was not apparent. The analysis of the videotapes allows a comparison of the use of technical operations between the four groups working in a standard task and group LABM6, as seen in table 4 (for groups LABM5, 7 and 8 the session was about twice the time, which difficults comparison).

Students activity / teams LABM	**L1** N=3	**L2** N=4	**L3** N=3	**L4** N=5	**L6** N=2
getting the sample	2 students	1 student	1 student	2 students	2 students
mounting the slide	1 student	1 student	2 students	2 students	2 students
placing slide / focusing	1 student	1 student	2 student	1 student	2 students
observing through the microscope	from 4'32" to 1'51"	from 4'28" to 1'10"	from 7'48" to 1'55"	from 59" to 25"	from 6'52" to 2'23"
drawing (R)	# students	# students	# students	# students	# students
the two cell types with labels				4	
the two types without labels	1	1	2	1	
one cell type	2	2			
(no instructions about it for 6)					2

Table 4 Number of students performing activities (R = required in handout groups 1-4)

The activities performed by the two students in group LABM6 show many similarities or, could we say, it doesn't show the inequalities that can be perceived inside the other four groups, where most of the activities were performed just by one or two students. Perhaps part of this homogeneity can be attributed to group LABM6 being a dyad, what facilitates interactions, but in general it can be said that the students in the four groups working in a problem-solving context were on task most of the time, which allows for a higher participation of most team members. Another issue deserving attention is the time spent observing through the microscope, and here again there is greater homogeneity and the student observing less time (Gloria) is doing it for a longer time that their counterparts in other teams. The longest time correspond to group LABM3 but it has to be attributed rather to their difficulties with a sample of very poor quality as discussed before, that to a detailed observation: by comparing the timelines of these groups (Jimenez & Diaz 1997) it can be seen that in LABM3 the time devoted to a combination of observing and drawing is almost zero.

In summary it can be said that there is a veriety of different situations in which students perform procedural and technical operations with the microscope and that, at least in the groups working in problem-solving contexts, they exhibit an awareness of the features of the instrument and about the way it limits or influence the observation.

6 Discussion and educational implications

About the first objective, the construction of a tool to analyse the scientific culture dimension in the students' discourse, the categories seem to cover many from the operations performed by students and may constitute a little step in the task of better understanding what happens in science classrooms. There is a need for further development, and particularly for elaboration of categories about procedural and technical operations in other fields.

About the second objective, the identification of practices related to scientific culture taking place in science classrooms, it can be said that there is an extensive use both of epistemic and procedural operations by students, not only by 11th Graders or Student teachers, but even by 9th Graders. Some instances are the appeal to consistency, the appeal to analogy or the use of particular criteria and attributes ("pipes" or vessels, disposition in layers, different types of cells) in grouping objects in classification.

Another instance that deserves discussion is the construction of data in a way similar to the one described by Latour and Woolgar (1986) for Biology researchers. There are many examples of operations performed on statements, of transformation of observations into "data". A better occasion for seeing students constructing data is a situation when data are empirical, as happens in experimental settings, like in a Physics session, when they have to construct a model of a submarine, then sink it and then find a way to taking it afloat again; or in the Biology laboratory when working with an unknown sample through the microscope. For instance, the fragments reproduced in section 4.5 or this statement in group LABM-6, line 134 "Some *(cells)* are bigger and some are smaller, but all belong to the same type" which is part of a long discussion which involves interpretation of observation, challenge of the interpretation from another student, reinterpretation in a different way. This particular observation could be interpreted as different cell types, or as a single cell type (but with different sizes). In many case there is, rather than individual construction, co-construction by two or more students in the group. As Pea (1993) says there are many aspects of learning constructed through social interactions, through negotiation of meanings, like in this case.

An interesting aspect is the interaction of the instrument, in the cases studied the microscope, with the process of data construction. The students, not only performed a variety of procedural and technical operations, but also discussed them and referred explicitly to constraints imposed by the instrument on the observation of samples.

There is a suggestion that this kind of operations are likely to occur in classrooms where there are learning environments which offer authentic problems, and therefore opportunities to adopt the authentic scientific culture. It is worth noticing that all the groups studied in a problem-solving context, were able to solve the problem, for instance, identify the unknown sample, while in the groups working in conventional settings there was a proportion of students who didn't perform the task required (draw two types of cells, estimate the size) which apparently were easiest. The involvement in the task, the interest that it raised in the students may account for some of these differences about the task itself. About the operations analyzed, the differences among conventional and problem-solving groups are not just quantitative, but qualitative: in the problem-solving groups there was a kind of conversation, of exchanges, of interpretation and reinterpretation that was not found in the conventional groups. We believe that it can be said that in one case they were not talking science, and in the other they were talking science. This would call for instructional and particularly laboratory design of tasks which require these operations on the part of students.

About further developments, it would be interesting to relate these operations to the background knowledge in each discipline and to explore their subject-matter dependence, which is one of the aspects that we are currently studying.

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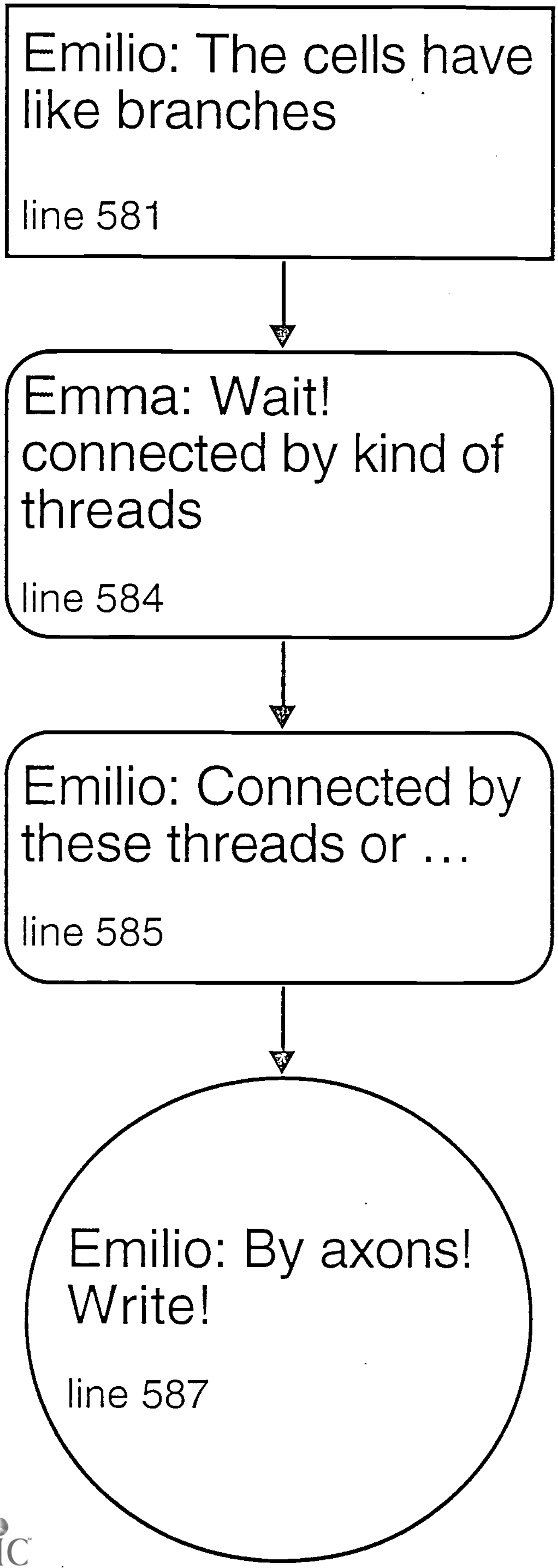
DATA CONSTRUCTION LABM 7



Emilio: The cells have like branches

line 581

Description

Emma: Wait! connected by kind of threads

line 584

1st interpretation

Emilio: Connected by these threads or …

line 585

Emilio: By axons! Write!

line 587

Science terminology

DATA CONSTRUCTION LABM 8

Julio: Do you know what are these black spots?

line 190

Observation

Julio: The formation of new nuclei in the cells that what it says in "d" *[handout]*

line 192

1st interpretation

Julio: "Cells falling out easily" *[reads]* Could it be that the nucleus is dividing, that's why is so dark?

line 194

2nd interpretation

Judit: What could they be? New forms of ...

line 198

Julio: it seems that the nucleus was dividing to form... new cells.

line 199

Data: Cell division

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