Students–Exhibits Interaction at a Science Center

Agostinho Botelho, Ana M. Morais

Department of Education, School of Science, University of Lisbon, Lisbon, Portugal

Received 9 March 2005; Accepted 26 October 2005

Abstract: In this study we investigate students' learning during their interaction with two exhibits at a science center. Specifically, we analyze both students' procedures when interacting with exhibits and their understanding of the scientific concepts presented therein. Bernstein's theory of pedagogic discourse (1990, 2000) provided the sociological foundation to assess the exhibit–student interaction and allowed analysis of the influence of the characteristics of students, exhibits, and interactions on students' learning. Eight students (ages 12ndash;13 years of age) with distinct sociological characteristics participated in the study. Several findings emerged from the results. First, the characteristics of the students, exhibits, and interactions appeared to influence student learning. Second, to most students, what they did interactively (procedures) seems not to have had any direct consequence on what they learned (concept understanding). Third, the data analysis suggest an important role for designers and teachers in overcoming the limitations of exhibit–student interaction. © 2006 Wiley Periodicals, Inc. J Res Sci Teach 43: 987–1018, 2006

As new science museums are created and existing museums are renovated, the exhibits are becoming increasingly interactive (Reid, 1997; Swift, 1997). To signal this change, many museums are now known as "science centers." We believe that this change to more participative exhibits has implications for teaching and learning science. The attraction and involvement power of these exhibits has led to various studies analyzing their educational potential (e.g., Anderson & Lucas, 1997; Falk, Moussori, & Coulson, 1998; Feher, 1990; Henriksen, 1998; Serrel, 1997).

These studies showed that, during the interaction with exhibits, specific characteristics influenced visitor behavior. Falk et al. (1985) identified three broad groups of characteristics that influence visitor behavior in a museum: visitor characteristics; setting or environmental characteristics; and exhibit characteristics. In this exploratory study, we sought to make these characteristics more specific and to perform a more detailed analysis by using Bernstein's theory of pedagogic discourse as the theoretical framework.

Correspondence to: A. Botelho; E-mail: ajbotelho@netcabo.pt
DOI 10.1002/tea.20135
Published online 8 August 2006 in Wiley InterScience (www.interscience.wiley.com).

Literature Review on Exhibit–Student Interaction

In contrast to earlier learning studies showing that museums only occasionally facilitate learning, recent studies have supported the premise that learning does take place in museums (Falk & Dierking, 2000). Museums offer opportunities to interact with materials, objects, and ideas that may not otherwise be readily available to learners (Jackson & Hann, 1994; Miles, 1987; Russell, 1995; Thier & Linn, 1976).

The level of interaction with exhibits depends on a number of variables. Several studies have focused on visitor characteristics and on the relation between these characteristics and learning data. Gender is among the aspects studied most often. Some investigators (Kubota & Olstad, 1991; Tulley & Lucas, 1990) noted differences between boys and girls in the way they interact with exhibits. Tulley and Lucas (1990) observed that boys had greater exploratory capacity and dexterity than girls during their interaction with the "Lock-and-Key Exhibit," in the Launch Pad area of the Science Museum, London. Kubota and Oldstad (1991) studied the relationship between novelty, exploratory behavior, and learning. They observed that previous activities promoting the reduction of novelty have distinct effects on boys and girls—in the case of boys, these activities promoted an exploratory behavior and cognitive gains in relation to the scientific knowledge transmitted by the exhibit. This evidenced the role of gender in exploratory behavioral trends during exhibits.

Boisvert and Slez (1994) studied the relationship between gender and social group and three types of behavior considered important prerequisites for learning in museums: (1) attraction (an exhibit's ability to grab a visitor's attention); (2) holding power (how long an exhibit holds visitors' attention); and (3) engagement (the level of interaction with the exhibit)—in exhibits related to the human body. The results showed the absence of significant differences in the relationship between each visitor's characteristic (gender) and the three types of behavior. The authors found a comparable interest for the human body among both boys and girls. Busque (1991) also demonstrated a lack of difference between boys' and girls' interest in a study of an interactive exhibit at the Ottawa Museum.

Despite the fact that research has focused on various students' characteristics, no study has been done on the socioeconomic status of the students' families or on students' school achievement. However, many studies on schools' formal contexts (e.g., Morais & Neves, 2001) have shown the importance of sociological variables for scientific learning. The characteristics (attraction, holding power, and engagement) of exhibits have also been studied and related to visitor characteristics (Boisvert & Slez, 1994).

Some researchers have pointed to characteristics of exhibits that can arouse interest, allow involvement, and transmit ideas. Carlisle (1985) observed students visiting the Arts, Science and Technology Center (now Science World) in Vancouver, Canada, and recorded the exhibits the students chose, the length of time spent at each exhibit, and the level of involvement at each exhibit. Other researchers have used these same parameters—choice, length of stay, and level of involvement—to measure the success of the exhibits (Cone & Kendall, 1978). Carlisle used these results, however, to gain insight into the learning behaviors of the students. She found that most students orientate themselves when they first arrive, involve themselves in both solitary and social experiences, but with sharing and cooperative behaviors predominating, and most students made repeated visits to some exhibits. She concluded that the center as a learning environment provided a context that "motivated, encouraged meaningful behavior and social interaction, was pleasurable, and held the potential for learning scientific facts and principles" (Carlisle, 1985, p. 32).

Other factors that could affect exhibit–student interaction are related to previous knowledge, the reading of labels, and the design of the exhibit. Symington and Boundy (1986) found that students may bring a great deal of relevant knowledge to a museum, but do not necessarily use it to direct attention or change their understanding as a result of viewing the displays, and concluded that this is partly because most of the students did not read the labels. Other authors (Falk, 1997; Gilbert & Stocklmayer, 2001) demonstrated the influence of exhibit design on visitor behavior. Falk (1997) analyzed the effect of two exhibits, one with and another without explicit labeling, and observed that, in the first case, visitors not only learned more about the specific information and general ideas but spent more time in exploring the exhibition. Gilbert and Stochlmayer (2001) included the idea of memory retrieval in their analysis of how the interaction with the exhibit could elicit the remembrance of former experiences, which constitute an analogy to the construction of the present experience. These past experiences may include school experiences.

Literature Review on Learning Context

What is learned is inseparable from how it is learned, which means that students respond differently to an experience depending on the environment that they encounter (Botelho & Morais, 2003, 2004; Morais et al., 2000). They react differently to questions from a stranger or a peer; they respond differently to environments that allow free exploration as compared with a tightly structured environment (Botelho, 2004). Other authors have emphasized the idea that knowledge construction may be influenced and aided by contexts, and that these contexts afford rich links with the students' interests (Carr & Barker, 1994; Hein, 1991; Hein & Price, 1994). Fensham and Gunstone (1994) discussed the "reflexive and interactive relationship between knowledge and actions" (p. 5), each one feeding on the other. Lave and Wenger (1991) and other situated cognitive educationalists saw the context as influencing not only what is learned but as being an inherent part of what is learned.

Driver and Asoko (1994) emphasized the importance of context. They argued that learning science involves both personal and social processes, and suggested that if knowledge construction is seen as a purely individual process then it amounts to discovery learning. They view science learning as a process of enculturation, and described a social constructivist view as one in which there is interplay between personal experience, language, and socialization in the process of learning science. Also contributing to a social constructivist was Lemke (1990), who described learning science as learning to "talk science," as well as others with ideas of cognitive apprenticeship and situated cognition (Lave & Wenger, 1991; Rogoff & Lave, 1984).

At the level of the museums, Falk and Dierking (2000) indicated the importance of context and postulated a "contextual model of learning" to describe learning in museums, summarizing much of the research findings in museum studies. The model includes three interlinked contexts: personal; sociocultural; and physical—with the intersection of these contexts describing the learning experience of visiting a museum. The personal context includes: (1) motivation and expectations; (2) individual's prior knowledge, interests, and beliefs; and (3) choice and control. The social context includes: (4) within-group sociocultural mediation; and (5) facilitated mediation by others. The physical context includes: (6) advance organizers and orientation; (7) design; and (8) reinforcing events and experiences outside the museum.

Despite the importance of context in creating adequate learning contexts for students, Escot (1999) argued that giving students' opportunities to learn does not mean that students do learn. We then should ask: What do students need to learn with success? We believe that part of the answer can be found in Bernstein's theory of pedagogic discourse (Bernstein, 1990, 2000). According to Bernstein, the characteristics of pedagogic context are very important. However, he also noted that students must have rules that allow them to recognize these characteristics, and rules that allow them to produce the text expected in this context.

Theoretical Framework

Bernstein's theory of pedagogic discourse (Bernstein, 1990, 2000) provided the sociological concepts necessary to characterize the interaction and to analyze the influence of specific sociological characteristics on students' scientific learning, in the pedagogic context of a science center. We use the expression ''pedagogic context'' as a context wherein relations of transmission, acquisition, and evaluation of any form of knowledge take a place (e.g., family, school, and museums, at diverse levels). Bernstein considered three main categories in any pedagogic context: subjects; spaces; and discourses.

Subjects are the persons (e.g., student, teacher, mother, friend, manager, designer, and curator), discourses are forms of knowledge specific of a context (e.g., academic and nonacademic knowledge, various disciplines), and spaces are a specific subject's space (e.g., teacher's space and students' space).

In the specific pedagogic context of a science center, we can consider various relations between subjects (e.g., teacher–student, student–student, designer–student), spaces (e.g., various exhibit spaces, biology exhibit spaces, and physics exhibit spaces in a science museum), and discourses (e.g., student ideas–exhibit ideas).

Pedagogic contexts are regulated by power and control. Power refers to relations between categories and, consequently, it establishes category positions, whereas control refers to communication between categories.

Bernstein used the sociological concept of classification to characterize power relations and the sociological concept of framing to characterize control relations in pedagogic contexts, whether in the school or other sites. Classification (C) refers to the degree of maintenance between categories (subjects, spaces, and discourses) and expresses the power of a category over the others (power relations). It is weak when boundaries are blurred and strong when boundaries are well marked.[1] Framing (F) refers to the communicative outcomes of the relations between categories in the pedagogic relation and expresses the control of one category over the other (control relations). It is weak when lower categories have any form of control over the relation and strong when higher categories have control over the relation.[2] Framing between subjects refers to the control they have over selection, sequence, pacing, and evaluation criteria[3]—that is, the discursive rules that regulate the instructional pedagogic practice. It also refers to the hierarchical rules, which regulate the norms of social conduct, or the regulative pedagogic practice. Variations in classification and framing at various levels and in the coding orientation itself determine specific modalities of code. These modalities of code regulate specific pedagogic practices, either in school or other agencies (e.g. families, museums). Classification values of pedagogic practices create specific recognition rules whereby students recognize the specificity of a particular context. If classification values change from strong to weak, so do their contexts and recognition rules. Framing values shape the form of pedagogic communication and context management. Different framing values transmit different rules for the creation of texts, whether these texts are instructional or regulative. Figure 1 shows the relation between these concepts.

To study the instructional and regulative texts produced by students in specific contexts of learning, we used a model (Figure 2) constructed by Morais and Neves (2001), which shows the relations between specific coding orientation and socioaffective dispositions in text production. The interrelation shown in the model, between specific coding orientation and socioaffective dispositions, highlights their mutual influence. Although constituting different realities within the subject, the possession of a specific coding orientation may be limited by socioaffective dispositions, which are in turn limited by coding orientation. According to

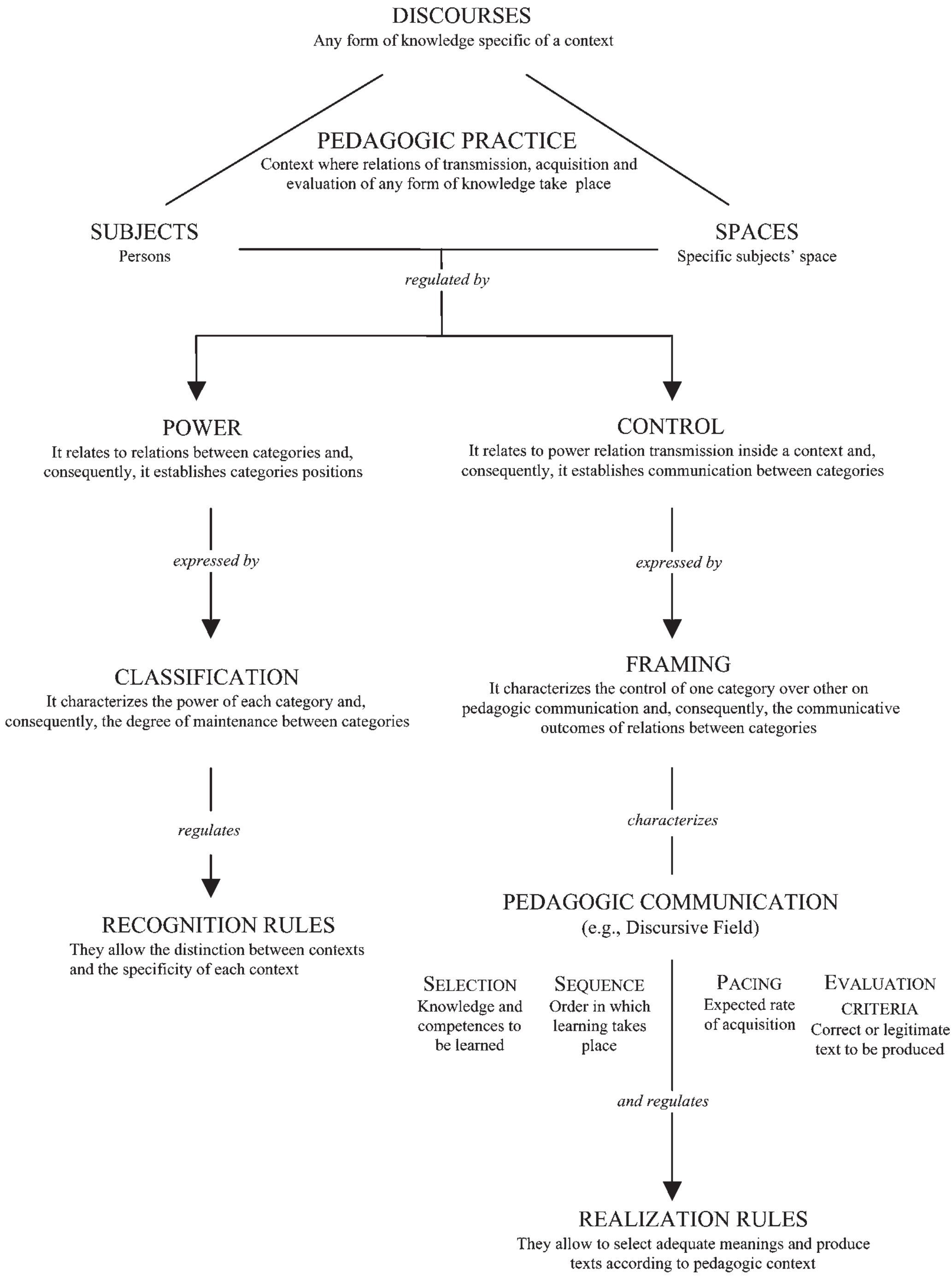


Figure 1. Pedogogic context dynamics (based on Bernstein, 2000).

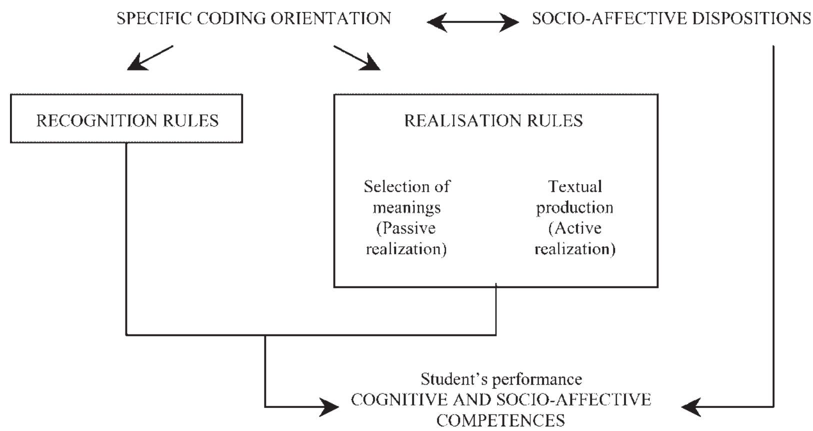


Figure 2. Cognitive and socioaffective competence as given by coding orientation and socioaffective dispositions specific to the context (Morais & Neves, 2001).

Bernstein (1990), text production in a given context depends on the possession of the specific coding orientation to that context. This means that subjects must have both the recognition rules (be able to recognize the context) and the realization rules (be able to produce a text adequate for that context). Realization rules concern both the selection and the production of meanings. Subjects must select adequate meanings and produce texts according to them, showing correct performance in context and demonstrating possession of both recognition and realization rules.

Failure to show performance may indicate lack of recognition or realization rules, or both. Without realization rules, subjects may not be able to select meanings or produce them, or both. If they are able to select meanings but are incapable of producing the text, then they have a passive realization. If the text is produced, they then exhibit active realization. However, for text production to be accomplished, subjects must also possess socioaffective dispositions specific to the context—that is, they must have the appropriate aspirations, motivations, and values. According to Bernstein, recognition rules regulate realization rules. Both rules and the requisite socioaffective dispositions are socially acquired and become part of the subject's internal structures.

For exemplifying these relations among the cognitive competencies required in specific learning contexts, we would say that students receiving a pedagogic practice that requires, for instance, problem-solving competence, succeed by: (a) recognizing the specificity of the microcontext of problem solving within their practice (recognition rules); (b) selecting meanings adequate for that microcontext, that is, knowing how to proceed to solve problems correctly (passive realization); (c) producing the text, that is, presenting a correct solution to the problem (active realization); and (d) possessing socioaffective dispositions favorable to that realization (motivations, aspirations, and values).

Bernstein's theory encompasses both the macro level of the educational system and the micro level of the school and classroom. However, the theoretical concepts he developed, and which constitute a powerful internal language of description, have allowed the development of an external language of description to study a multiplicity of contexts, from the school itself to the family and teacher training. What we have done in the present study was to extend it still further to the context of science centers.

Purpose of the Study

The present study is part of the research that has been carried out by the ESSA Group[4] and used specific aspects of Bernstein's theory of pedagogic discourse to compare students' performance during their interaction with exhibits. Therefore, the applicability of this theory in the analysis of the learning that takes place in science centers is appreciated.

Within the context of exhibit–student interaction, we considered two microcontexts of the interaction: students' procedures in exhibits and students' understanding of scientific concepts involved in exhibits. Concerning the microcontext of procedures, we analyzed the extent to which students could recognize the specific procedures of that context, more specifically if they could identify and characterize the exhibits with which they interacted, and if they could produce them correctly. Concerning the microcontext of concept understanding, we analyzed the knowledge students already had about the concepts involved in the exhibits and the extent to which they were able to acquire these concepts.

The following question guided our research: How are characteristics of students, exhibits, and student–exhibit interactions influencing students' learning in the exhibit–student interaction, when this interaction is evaluated using Bernstein's theory?

We analyzed the results in terms of students' specific coding orientation—that is, in terms of recognition and realization rules that students must possess for learning. If students possess recognition rules they can distinguish the various contexts and, if they possess realization rules, they can select (passive realization) and produce (active realization) the text specific to each microcontext. We also studied the relation between the results and the characteristics of: (1) students (family socioeconomic status, gender, and achievement); (2) exhibits (exhibit design, what happens when students activate the exhibit and evaluation criteria); and (3) interaction on students' learning.

Methodology

In what follows we describe the students that participated in the study, the exhibits with which the students interacted, the visit to a science center, and a sociological description of the exhibit–student relationship. We also describe the data collection and the analysis processes. We used qualitative methods for gathering data and a comprehensive–interpretative model for the analysis of results because we sought to understand the meaning of students' performance levels as a result of interaction with the exhibits.

Students

This study is the result of a 1-year educational research project and intended to be an exploratory investigation while containing some degree of depth in the analysis of results. We selected eight students who represented all possible combinations of three variables with two variants each, gender, achievement, and parents' education and occupation, as indicators of socioeconomic status.[5] These students are not a random sample but rather a carefully selected group of participants representing preselected variables. All came from the same school class of the seventh grade (ages 12–13 years). To determine the family's socioeconomic status, we used a composite index of the academic qualifications and occupations of the mother (MAQ and MO, respectively) and the father (FAQ and FO, respectively), according to formulas.[6]

$$\frac{\mathrm{FO+FAQ+MO+MAQ}}{24} \times 100.$$

Based on the data obtained, we constructed a two-degree scale in which I (17–50%) represents the lowest family's socioeconomic status and II (51–100%) the highest family's socioeconomic status. Both groups of boys and girls contained an equal number of low/medium school achievers and high/very high school achievers. Figure 5 shows the distribution of students by gender, family socioeconomic status, and school achievement. Students were given pseudonyms.

The Exhibits

We developed our study based on exhibits at the Knowledge Science Center—Live Science, Lisbon, Portugal. We selected two exhibits from the exhibitions present at the time the study took place—"The Hot Air Balloon" (Figure 3) and the "The Hydrogen Rocket" (Figure 4)—which were part of the exhibition "Look, Do and Learn," conceived by Techniquest, Cardiff Science Center. Both exhibits involved only two manipulating activities: press two buttons for the hot air balloon exhibit, and turn a handle and press a button for the hydrogen rocket exhibit. The former involved Charles's Law and the latter the constitution of the water molecule, the concept of combustion, and electrolysis of the water.

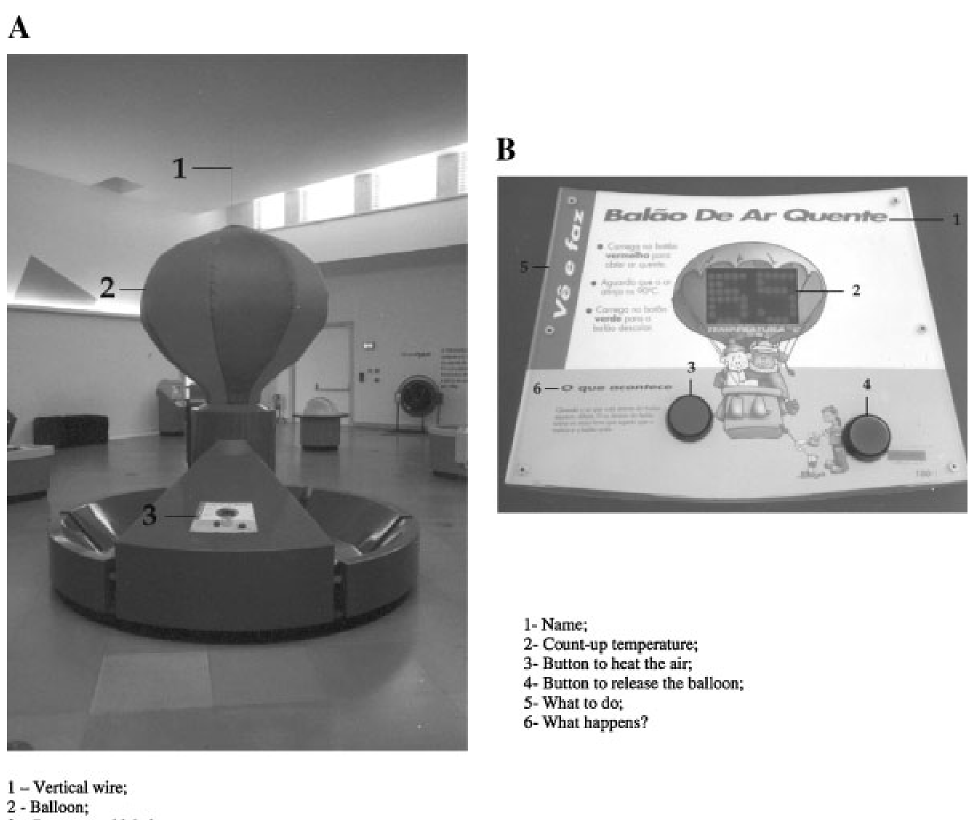
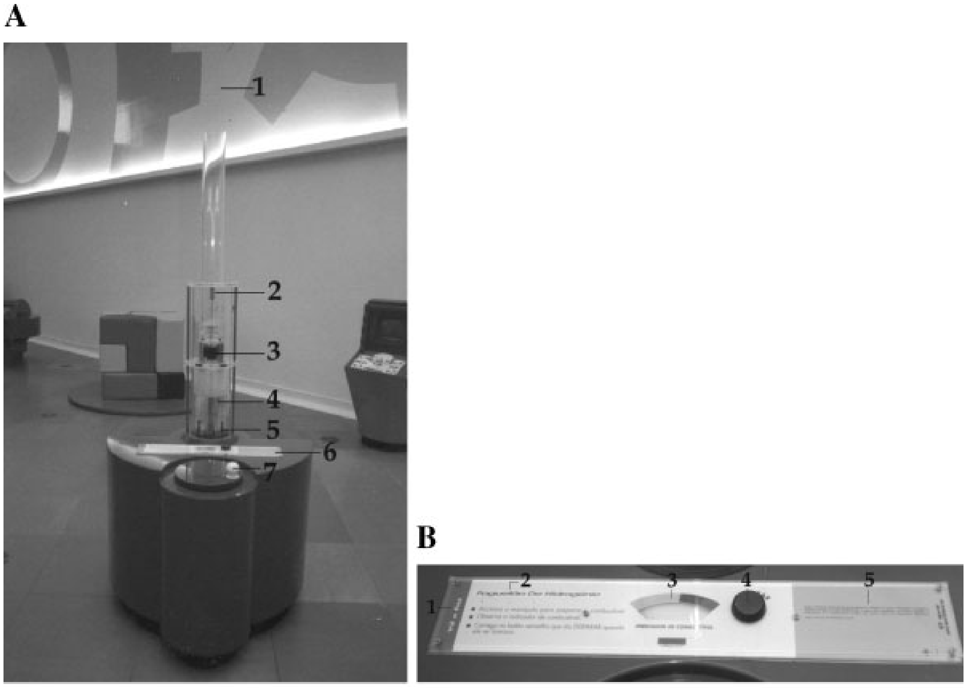


Figure 3. "The Hot Air Balloon" exhibit. (A) General view. (B) Panel 3 from (A), amplified.



1- Vertical wire;
2- Object (rocket);
3- Count-down sequence;
4- Water recipient;
5- Electrodes;
6- Label and buttons;
7- Handle

1- What to do;
2- Name;
3- Level of fuel;
4- Button to start the count-down sequence;
5- What happens?

Figure 4. ‘‘The Hydrogen Rocket’’ exhibit. (A) General view. (B) Panel 6 from (A), amplified.

We based our selection on the information given by the science center’s curators. The two exhibits were the most visible and attractive in the exhibition, so they were the most frequently visited.

We intentionally used two exhibits with the same sociological characteristics—that is, with the same values for classification and framing. This allowed us to concentrate on these characteristics. The analysis was centered only on the relations between the eight students and the two selected exhibits. However, it is important to stress that the exhibition as a whole showed a marked boundary between the various exhibits; each exhibit was isolated in the exhibition without any relation to other exhibits. This applied to both the message entailed in the various exhibits and the spaces they were allocated, although the former was particularly marked. The only criteria used to display the exhibits in the exhibition rooms were the aesthetic and degree of attraction of the exhibits. This means that the exhibits were displayed throughout the room according to the perceptions of the team that organized the exhibition, and who was concerned with the distribution of the exhibits with lesser attraction power in strategic places of the exhibition room and the exhibits with greater attraction power in more discrete places. There was no concern for establishing any connection when any one visitor passed from one exhibit to another—each exhibit was important in itself. This means that, to the organizers of the exhibition, it was unimportant how each visitor started and proceeded with the visit. Looking at the whole exhibition

STUDENTS-EXHIBITS INTERACTION AT THE LEVEL OF PROCEDURES

STUDENTS' CHARACTERISTICS				EXHIBIT TITLE			COMPONENTS										RR	PROCEDURES								PRL	ARL
							DESIGNATION					FUNCTION						IDENTIFIES				PERFORMS					
Ach.	FSEL	Name	Exhibit	N	I	C	1	2	3	4	5	1	2	3	4	5		a)	b)	c)	d)	a)	b)	c)	d)		
H	II	Sofia	Balloon	●			✓	✓	✓	✓	✓	✓		✓	✓	✓	III	-	●	●	●	●	●	-	●	II	II
			Rocket	●			-	✓	✓	✓	-	-	-	✓	-		I	-	●	●	●	●	●	●	●	II	III
L	I	Raquel	Balloon		●		✓	✓	✓	✓	✓	✓		×	-	✓	II	-	●	●	●	●	●	●	●	II	III
			Rocket		●		✓	✓	-	✓	✓	✓	-	-	×		II	-	●	●	●	●	●	●	●	II	III
H	III	Sara	Balloon		●		✓	✓	✓	✓	✓	✓		✓	✓	✓	III	-	●	●	●	-	●	-	●	II	I
			Rocket	●			-	✓	✓	✓	×	-	✓	✓	✓		II	-	●	●	●	-	●	●	●	II	II
L	III	Sónia	Balloon		●		✓	✓	✓	✓	✓	✓		✓	✓	✓	III	-	●	●	●	●	●	●	●	II	III
			Rocket	●			-	✓	✓	✓	-	-	✓	✓	✓		II	-	●	●	●	●	●	●	●	II	III
H	I	Miguel	Balloon		●		✓	✓	✓	✓	✓	✓		✓	✓	✓	III	-	●	●	●	●	●	●	●	II	III
			Rocket			●	✓	✓	✓	✓	✓	✓	✓	✓	✓		III	-	●	●	●	●	●	●	●	II	III
L	I	Carlos	Balloon	●			✓	✓	×	✓	✓	✓		×	×	✓	II	-	●	●	●	●	●	●	●	II	III
			Rocket	●			✓	✓	✓	✓	-	✓	-	✓	×		II	-	●	●	●	-	●	●	●	II	II
H	III	Nuno	Balloon		●		✓	✓	✓	✓	✓	✓		✓	✓	✓	III	-	●	●	●	-	●	●	●	II	II
			Rocket			●	-	✓	✓	✓	-	-	×	✓	×		II	-	●	●	●	●	●	●	●	II	III
L	III	Paulo	Balloon			●	✓	✓	×	✓	✓	✓		×	✓	✓	III	-	●	●	●	●	●	●	●	II	III
			Rocket		●		×	✓	✓	✓	✓	×	-	✓	-		II	-	●	●	●	●	●	●	●	II	III

Figure 5. Results from the three levels considered in the interaction with exhibits at the level of procedures and respective degrees of recognition/realization.

Notes

EXHIBIT TITLE:

Balloon: (N) Does not know; (I) Incomplete answer (e.g.: balloon); (C) Correct answer (e.g. Hot Air Balloon); (●) Selected answer.

Hydrogen Rocket: (N) Does not know; (I) Incomplete answer (e.g.: rocket); (C) Correct answer (e.g. Hydrogen rocket); (●) Selected answer.

COMPONENTS:

Balloon: (1) Balloon's going up vertical wire; (2) Balloon; (3) Count-up temperature; (4) Button to start the heating of the air; (5) Button to release the balloon; (✓) Answers correctly; (-) Does not know; (×) Answers incorrectly.

Hydrogen Rocket: (1) Count-down sequence; (2) Handle; (3) Button to start the count-down sequence; (4) Level of fuel; (5) Object (rocket); (✓) Answers correctly; (-) Does not know; (x) Answers incorrectly.

PROCEDURES:

Balloon: (a) Read instructions; (b) Press red button; (c) Wait until temperature reaches 90°C; (d) Press green button; (●) Identifies/performs; (-) Does not identify/perform.

Hydrogen Rocket: (a) Read instructions; (b) Rotate white handle; (c) Look at the level of fuel; (d) Press red button; (●) Identifies/performs; (-) Does not identify/perform.

Ach — Achievement; FSEL - Family socioeconomic level; RR - Recognition; PRL - Passive realization; ARL - Active realization.; I, II, III - Degrees of the rules

one could not find any link between the various exhibits. The scientific areas, themes, facts, and concepts present in each exhibit had no preconceived interrelations. Classification was therefore very strong between the various exhibits that constituted the exhibition.

The Trip to the Science Center

Seventh grade teachers programmed a visit to the science center to increase interest in science, without having planned any specific tasks for the students. Students could freely explore the entire area. The visit took 90 minutes and involved the five classes from the school. Each class spent 30 minutes on the exhibition.

Sociological Exhibit–Student Relation

Social interaction is usually seen as an interaction between persons. In the context of museums, this interaction occurs mainly between students, students and explainers, and family members. However, each exhibit present in a museum entails a sociological message. Messages transmitted by the exhibit may or may not be received by the students, depending on their specific coding orientation. When students interact with exhibits, they interact with ‘‘invisible subjects whose image is an exhibit.’’ In this study, we analyzed exhibit–student relations as a social interaction between students and these subjects.

Science centers have a pedagogical function, although distinct from that of schools. Like the school context, the context of interactive exhibitions entails a pedagogical practice, determining a particular relation between the subjects present, directly or indirectly, in that context. Distinct modalities of the pedagogical code underlie distinct pedagogical practices, which are more or less favorable to the learning of socially differentiated students. A model based on Morais et al. (1993, 1996, 2001) orientated the characterization of the pedagogical practice, in sociological terms. According to the model, any pedagogic practice can be analyzed in terms of classification (C) and framing (F). We sought to determine whether the same kind of analysis was productive when applied in the context of science centers.

We used a scale of values of classification and framing from very weak to very strong (C^{--}, C^{-}, C^{+}, C^{++} and F^{--}, F^{-}, F^{+}, F^{++}) in which the signs ‘‘++’’ indicate relative degrees of very strong classification/framing and the signs ‘‘−−’’ very weak classification/framing. The other values (‘‘+’’ and ‘‘−’’) indicate intermediate degrees. We focused the characterization of the context on the relation of communication between the students and the subject(s) behind the exhibit (i.e., the constructors of each exhibit) as this was the crucial aspect of the study. It was possible to infer the sociological characteristics of the designer–student relation through the ‘‘features’’ chosen by the designers to ‘‘be present in public’’—the exhibit.

In spite of this communicational relation between the transmitter and the acquirer, this does not necessarily lead to a teaching/learning traditional perspective; rather the messages sent by the transmitter (facts or other kind of data) may act as a basis and orientation to the construction of concepts by students.

Characterization of the microcontext “concept understanding.” With respect to control relations, particularly in the case of selection, the students did not have any participation in the choice of the themes/contents present in the exhibits—the responsibility of the selection was entirely with the team that planned the exhibits. Framing was therefore very strong (F^{++}). Also, students could interfere in the sequence of facts and concepts presented, which was a consequence of the order chosen by designers. However, students had some control over mental appropriation and integration of the various contents. This means that strong framing regulated sequence (F^{+}). Students controlled the time available for the understanding of concepts, meaning that very weak framing (F^{--}) characterized pacing. For both exhibits, it was not explicit for students what was expected from them to learn; that is, framing of the evaluation criteria was very weak (F^{--}).

When we consider the power relations, it was the designers who determined, through the characteristics of the exhibits, the control students had on the relation between exhibit and students. This means that a strong classification (C^{++}) regulated the designer–student power relations.

Characterization of the microcontext “procedures.” When we looked at power relations between designers and students, we found that there were designers who determined the exhibit–student relation. It is the designers who defined the behavior students should have in relation to each of the exhibits, through its general aspect, its characteristics, and the sequence of the manipulating activities. This means that the designer–student power relations were regulated by a strong classification (C^{++}). In other words, the designers determined the legitimate relations between subjects in the context of the exhibit–student interaction. These relations were also determined by the directors of the museum and by the principles that guide this kind of science museum.

With regard to control relations, we analyzed the discursive rules selection, sequence, pacing, and evaluation criteria. The student did not have any choice of the procedures indicated in the exhibits, meaning that the procedures necessary for the correct functioning of the exhibits were controlled entirely by designers, and therefore framing was very strong at this level (F^{++}).

We analyzed the sequence in terms of the tasks the student should do, when working with each one of the exhibits. In the case of the exhibit "The Hot Air Balloon," its designers had established the sequence, which was written down on the information panel. However, the student had some control in that sequence because he/she could first press the red button instead of the green button. It is clear that such a procedure would not lead to the expected result, but the student was free to do so and thus alter the pre-established sequence. Another aspect could also be changed by the student: Instead of waiting for the air inside the balloon to reach 90°C to press the green button (number 4, Figure 3B), as indicated in the instructions, the student could press the button before the temperature reached 90°C and the balloon would go up.

Something similar occurred in the exhibit "The Hydrogen Rocket." The sequence of tasks was also pre-established, but the student could change this sequence and, instead of first turning the white handle (number 7, Figure 4A), he/she could press the red button (number 4, Figure 4B). Similar to what happens with the hot air balloon, this decision by the student would not lead to the expected result. In this exhibit, there was the possibility of changing another aspect of the sequence of tasks. The student, instead of waiting for the red button to light up to be pressed, could do so before it lit up. In this case, if there was already enough combustibility, the rocket would go up when the red button was pressed, with no need to wait for the lighted sign, as indicated in the third stage of the instructions. In this way, the student changed the sequence of tasks, although the control over this discursive rule was discrete, as this was not explicit to him/her. There was strong framing (F^{+}), although not as strong as at the level of the selection of scientific content.

We considered that pacing was regulated by a very weak framing, because students had total control over the time they had to use and interact with the exhibits. The trip had an ending time but students could spend the entire time with one or two exhibits, according to their own interests. Evaluation criteria were explicit in both exhibits as it was clear to the students what was expected of them. It was also quite explicit, in both exhibits, what one should do to obtain a given result—to make the balloon and the rocket go up. Therefore, a very strong framing regulated this discursive rule (F^{++}).

Table 1 shows the characteristics of the two microcontexts concerning power and control relations.

Data Collection and Analysis

We collected the data using three types of instruments: questionnaires; face-to-face interviews; and video recordings. We used these three distinct instruments to collect all data needed, to reduce bias, and to triangulate the results. These instruments and their application are described as follows.

Questionnaires. We used various questionnaires. First, we constructed a questionnaire to gather data about personal and family characteristics: name of the student; age; gender; achievement level in science; parents' qualifications and occupations; and number of times he/she has visited museums and when and where.

Table 1
Sociological characteristics of the microcontexts "Concept understanding" and "Procedures"

		Exhibit–Student Relations				
			Control Relations (F)			
			Discursive Rules			
Exhibit	Microcontexts	Power Relations (C)	Selection	Sequence	Pacing	Evaluation Criteria
Hot Air Balloon	Concept understanding	C^{++}	F^{++}	F^{+}	F^{--}	F^{--}
	Procedures	C^{++}	F^{++}	F^{+}	F^{--}	F^{++}
Hydrogen Rocket	Concept understanding	C^{++}	F^{++}	F^{+}	F^{--}	F^{--}
	Procedures	C^{++}	F^{++}	F^{+}	F^{--}	F^{++}

The students from the five school classes (120 students) in their seventh year of schooling answered the questionnaire during science class 3 months before the visit to the science center. We then selected eight students, all from the same school class, who possessed the characteristics needed for the study.

Second, we constructed a questionnaire to study answers that students would give to the following questions:

1. What is a combustible?
2. Give four examples of materials that are combustibles and four of materials that are not combustibles.
3. What are the elements that constitute water? How can you separate these elements? Explain the process.
4. How does the balloon go up? How does the balloon go down? (the questionnaire presented a balloon photo but the hot air mechanism was hidden).

To construct the categories of answers and to classify each in terms of its sociological meaning, the four classes, which did not contain the eight students of the study, answered the questionnaire, 2 months earlier. We identified four distinct students' conceptions: common sense; wrong; incomplete; and correct. These categories are used when we analyzed the results obtained in the exhibit–student interaction at the level of concept understanding.

We classified each category according to its sociological meaning. Table 2 presents these meanings. Afonso (1995) used this method with success.

Third, we constructed a questionnaire with multiple-choice questions to gather data about knowledge of the scientific concepts related to the exhibits. Students who participated in the visit to the museum answered this questionnaire twice: first, in school, 2 days before the visit to the museum; and second, in a room at the science center, immediately after the visit. This allowed us to compare students' knowledge before and after the visit.

With regard to the hot air balloon, and in order to facilitate the analysis, we considered two stages: the going up of the balloon and the going down of the balloon. Four questions made up the questionnaire, two with respect to the phenomena of the going up of the balloon and two with respect to the going down of the balloon. In both cases, the first question was a multiple-choice question with four options and the second question was a justification of the option chosen:

Table 2
Correspondence between students' answers and the possession of recognition and realization rules

Answers	Recognition rules	Passive Realization Rules	Active Realization Rules
CS option	−		
Wr option	−/+	−	
I option	+	−	−
C option	+	+	
Correct justification	+	+	+

(+) Possession of the rule; (−) Absence of the rule; If students select a common sense (CS) option, this means that they do not possess recognition rules because they cannot identify the context. If they select a wrong option (Wr), they can nor identify the context or know what text must produced or can they recognize the context but do not know what text they neither must produce. This situation could occur if the students select an incomplete option (I), that is, students recognize the context and incorrectly select the text that they have to produce. If students select a correct (C) option, this means that they recognized the context and they selected the correct text (passive realization rules). The possession of active realization rules is given by the correct justification.

Think of a balloon to take people up, like the one in the figure.

1.1 From the options that follow, indicate the one that explains why the balloon goes up:
- The balloon goes up because it is pushed by the wind.
- The balloon goes up because has a working engine.
- The balloon goes up because there is hot air inside.
- The balloon goes up because the air inside is hotter than the air outside.

1.2 Justify the option selected.

2.1 From the options that follow, indicate the one that explains why the balloon goes down:
- The balloon goes down because it lost air from the inside.
- The balloon goes down because the engine stopped working.
- The balloon goes down because is full of cold air.
- The balloon goes down because the air inside cools down.

2.2 Justify the option selected.

The options of the first question allowed for analysis of the nature of the scientific concepts possessed by the students and also understanding of the sociological meaning, in terms of recognition and passive realization (according to Table 2). In fact, to answer the questionnaire correctly, students should recognize the context; that is, they should have recognition rules and should select the adequate text and have passive realization rules. The second question, which asked the students to produce a text, would give information about active realization.

We obtained the level of specific coding orientation (SCO) by adding the SCO for each part (the going up of the balloon and the going down of the balloon). We considered two degrees for each one of the rules. When a student had recognition rules (or realization rules) in only one of the two parts, we assigned degree I and when the student had recognition rules (or realization rules) in the two parts we assigned degree II (i.e., a two-point scale).

With regard to the hydrogen rocket, we questioned the students about the constitution of the water molecule (a multiple-choice question with four options). With regard to the concept of electrolysis, we questioned them about ways of separating water elements (the first question was a multiple-choice question with four options and the second question was a justification of the option taken). In the justification, students were to explain how the selected process would separate the elements. With respect to the definition of combustible, we first asked students to choose among four options. We also asked them for justification as to why these materials were combustibles. The questions were as follows:

1.1 From the options that follow, mark the one that is correct:
- Only the petrol is a combustible.
- Both hydrogen and petrol are combustibles.
- Both water and carbon are combustibles.
- Only the hydrogen is a combustible.

1.2 Explain why it is that the substance is a combustible.

2.1 From the options that follow, mark the one that better indicates the elements that are part of the water:
- Hydrogen.
- Hydrogen and oxygen.
- Carbon and helium.
- Oxygen.

3.1 From the options that follow, mark the one that better indicates the process used to separate the elements that are part of the water:
- Letting water boil.
- Heating the water.
- Transporting electric current into the water.
- Transporting electric current into and out of the water.

3.2 Explain why the elements that constitute the water can be separated through this process.

As noted earlier with regard to the hot air balloon, the options allowed the analysis of the nature of the concepts possessed by the students and an understanding of their sociological meaning (according to Table 2). We gave one point to each situation (the constitution of the water molecule, the water electrolysis, and the concept of combustible) for which the student possession of a given rule. Three would be the maximum number of points.

To study the relation between the results at the level of concept understanding (Botelho & Morais, 2004) and at the level of procedures (Botelho & Morais, 2003), we determined the degree of SCO by using the formula:

$$\mathrm{SCO} = \frac{\mathrm{RR} + \mathrm{RL}}{\mathrm{Total}} \times 100$$

where recognition rules (RR) is given by the total number of points obtained in situations that intend to test the possession of recognition rules, and realization rules (RL) is given by the total of points relative to realization rules. The total of possible points is 38 for the performance at the level of procedures and 15 for the performance at the level of concept understanding. We converted the number of points achieved by each student to a four-degree scale[7]: 1–25, degree I; 26–50, degree II; 51–75, degree III; and 76–100, degree IV.

Fourth, we constructed a questionnaire to gather data about students' behaviors during the interaction with the exhibits. After the visit to the exhibition, we expected that the students could identify and characterize some of the exhibits present in it and we also expected that they could recognize some of the elements of that context. According to this study's perspective, we took this procedure as an indicator of recognition rules: if the students were able to identify and characterize the exhibits, then they possessed recognition rules; if they were unable to do so, then they did not possess these rules. Three questions related to the hot balloon and three related to the hydrogen rocket made up the questionnaire. The questions were the same for both exhibits:

What is the name of the exhibit?
Identify the numbered parts on the exhibit picture.
What is the function of each one of these parts?

When the students had answered the questions, we gave them a photo of the exhibit. To determine the degree of recognition and realization possessed by each of the students we used a numerical scale. In the case of the name of the exhibit, there was a 0–2-point scale: 0—does not answer; 1—incomplete answer (e.g., ''balloon''); 2—correct answer (e.g., ''hot air balloon''). With respect to the exhibit components, we gave one point to each correct designation or function. Thus, there was a 0–5-point scale for the designations and a 0–4-point scale for the functions. These three aspects gave information about the possession of recognition rules and we constructed a 0–3-point scale[8] to indicate the degree of recognition: 0—does not recognize; 1—4—degree I; 5–8—degree II; and 9–11—degree III.

We associated the identification of the procedures with passive realization and used a four-degree scale: 0—does not realize; 1–2—degree I; 3—degree II; 4—degree III, to indicate the degree of passive realization. We followed the same procedure for students' performance. Doing the required procedures means the possession of active realization and a 0–3-point scale indicates the degree of active realization: 0—does not realize; 1–2—degree I; 3—degree II; and 4—degree III.

Fifth, we constructed a questionnaire to gather data about students' socioaffective dispositions related to the exhibits interaction. The questionnaire was the same for both exhibits and was made up of three questions. The questions included opinions about exhibits' appearance/design, time spent with the interaction, and students' feelings during interaction:

1. I think the exhibit was:
   1.1 (a)Very pretty; (b) pretty; (c) normal; (d) ugly; (e) very ugly.
   1.2 (a)Very funny; (b) funny; (c) normal; (d) not funny; (e) not at all funny.
2. From the moment I started working with the exhibit until it went up, I think it took: (a) too much time; (b) much time; (c) enough time; (d) little time; (e) much little time.
3. During the time that you interacted with the exhibit, you: (a) enjoyed yourself; (b) had fun yourself; (c) played; (d) learned new things; (e) felt it was useless; (f) felt it was annoying; (g) understood what was happening; (h) felt it was very complicated (indicate yes or no; you may signal more than one sentence).

Face-to-face interviews. To assess students' knowledge of the scientific concepts present in the exhibits, we used the aforementioned questionnaire and face-to-face interviews. We used these interviews to get a better understanding of the answers given to the entry and the exit questionnaires. Both interviews took place in a school classroom one day after the entry questionnaire and one day after the visit to the science center, respectively.

We also gathered data about students' behavior during the interaction with exhibits by using interviews. Both the entry and the exit interview focused on the following issues: exhibit aim; things (facts/concepts) that the exhibit demonstrated; procedures necessary for the balloon and the rocket for going up; and how these procedures cause the balloon and the rocket to go up.

Video records. One of the behaviors expected from students when visiting the exhibition, was that they made correctly undertook the procedures necessary for proper functioning of the exhibits. However, to do so, students needed to have access to the correct instructions. In the case of the two exhibits studied, the students should have read the instructions or watched other classmates doing these procedures. If the student could identify the procedures, he/she would possess passive realization rules that he/she could identify the expected correct behaviors, independently of those behaviors being performed or not being performed. If the student could not identify the procedures, he/she would not possess these rules. If the students correctly performed the sequence of tasks necessary for functioning of the exhibit, this would mean that they possessed active realization rules. If the students did not perform correctly, they would not have these rules.

We observed students' behavior during the visit to the science museum and we analyzed the level of interaction (degree of active realization) with the two exhibits. To do this, we used a scale with the various possible expected behaviors, where the classifying principle was correct–incorrect behavior. We gathered the data through video recording during 30 minutes. We placed four video cameras at strategic places in the science center. At all stages of the collection and analysis of the data we followed ethical principles and legal constraints. We informed the parents, students, and the school about all objectives and procedures of the research project and we obtained consent. We guaranteed the confidentiality of the data and family rights and privacy.

Results

We separated the results into two sections. The first section presents the results of the exhibit–student interactions at the level of the procedures and at the level of concept understanding. The second section presents the results of the relationship between students' procedures and concept understanding.

Exhibit–Student Interaction at the Level of Procedures

In this section, we present the results for the hot air balloon and for the hydrogen rocket, comparing them before and after the interaction. We then compare the two exhibits. Figure 5 shows the results obtained and respective degrees of recognition and realization.

The Hot Air Balloon exhibit. Most students were unable to indicate the name of the exhibit correctly, saying only that it was a balloon; only Paulo identified the exhibit as the "hot air balloon." Most students easily indicated the five parts constituting the exhibit; only Carlos and Paulo gave an incorrect answer to part number 3. Similarly, most students were able to identify the function of each one of the four parts. From a sociological point of view, this means that the group generally possessed recognition rules at a high level (degree III).

With regard to procedures identification, there was a general absence of identification of the part of the procedures concerning the reading of instructions. Students easily identified the other three procedures. The information about passive realization given at this level of analysis showed that students had an intermediate degree of realization rules (degree II).

Although most students could correctly identify the expected procedures after the interaction with the balloon, with the exception of reading of the instructions, we observed that, during the interaction, they followed the procedures they had identified when reading the instructions. Considering that this level of analysis gives information about the active component of realization, we can see that the active realization generally attained intermediate to high levels. It is important to note that the students with low achievement (Raquel, Sónia, Carlos, and Paulo) attained high levels of active realization.

When we look at the students' socioeconomic status and their achievement, the results indicate those with both low socioeconomic status and low achievement (Raquel and Carlos) possessed recognition rules at a level lower than the other students. We found no differences in passive realization rules, but with respect to active realization rules students with low socioeconomic status and low achievement showed values higher than those with high socioeconomic status and high achievement (Sara and Nuno). With regard to the relationship between student gender and possession of recognition and passive realization rules, we found no differences between girls and boys. The difference was limited to active realization rules, where boys generally showed better results.

The Hydrogen Rocket exhibit. The results concerning the identification of the name of the exhibit show that only two students (Miguel and Nuno) identified it correctly. Two students gave an incomplete answer (Raquel and Paulo), and four answered incorrectly. When naming the parts of the exhibit, only Miguel identified all of them correctly. Other students were either unable to identify one or more names or gave the wrong answer to one of the exhibit's parts. The exhibit's parts, which showed to be more difficult to identify, were the ''count-down sequence'' (number 3, Figure 4A) and the ''object used to simulate the rocket'' (number 2, Figure 4A). It is of interest to note that only three students (Raquel, Miguel, and Paulo) could associate the object with a rocket.

Again, only Miguel made an identification of the function of all parts of the exhibit. Other students showed difficulty in identifying the function of the various parts. This difficulty was particularly evident in the case of components 1, 2, and 4. In general, the whole group had an intermediate degree of recognition (degree II).

With the exception of the reading of instructions, students easily identified the procedures. None of the students achieved the highest degree of passive realization, with degree II being the level achieved by the whole group. During the interaction, all students easily performed the expected procedures, with the exception of Sara and Carlos who did not read the instructions. This means that only Sara and Carlos possessed an intermediate degree of active realization (degree II), whereas other students achieved a high degree (degree III).

We found no differences between students in terms of socioeconomic status, gender, and achievement.

The two exhibits. Figure 6 shows the degree of recognition and realization for the two exhibits.

Analysis of the three graphs shows that, in general, the students possessed an intermediate to high level of recognition rules for both the hot air balloon and the hydrogen rocket. There were no differences between the two exhibits concerning passive realization. Active realization was, in general, slightly higher in the case of the rocket than in the case of the balloon.

The answers to the questionnaire pertaining to students' socioaffective disposition[9] showed varied results, some of which were noteworthy. Socially advantaged students thought the exhibits were annoying; they did not enjoy themselves and considered everything very complicated. On the contrary, socially disadvantaged students considered the exhibits funny, enjoyed themselves, and did not find them overly complicated. With regard to students' understanding of what happened during the interaction with the exhibits, the majority said they understood what happened with the balloon but not with the rocket. Most students indicated that they spent too much time with the balloon but not enough time with the rocket exhibit.

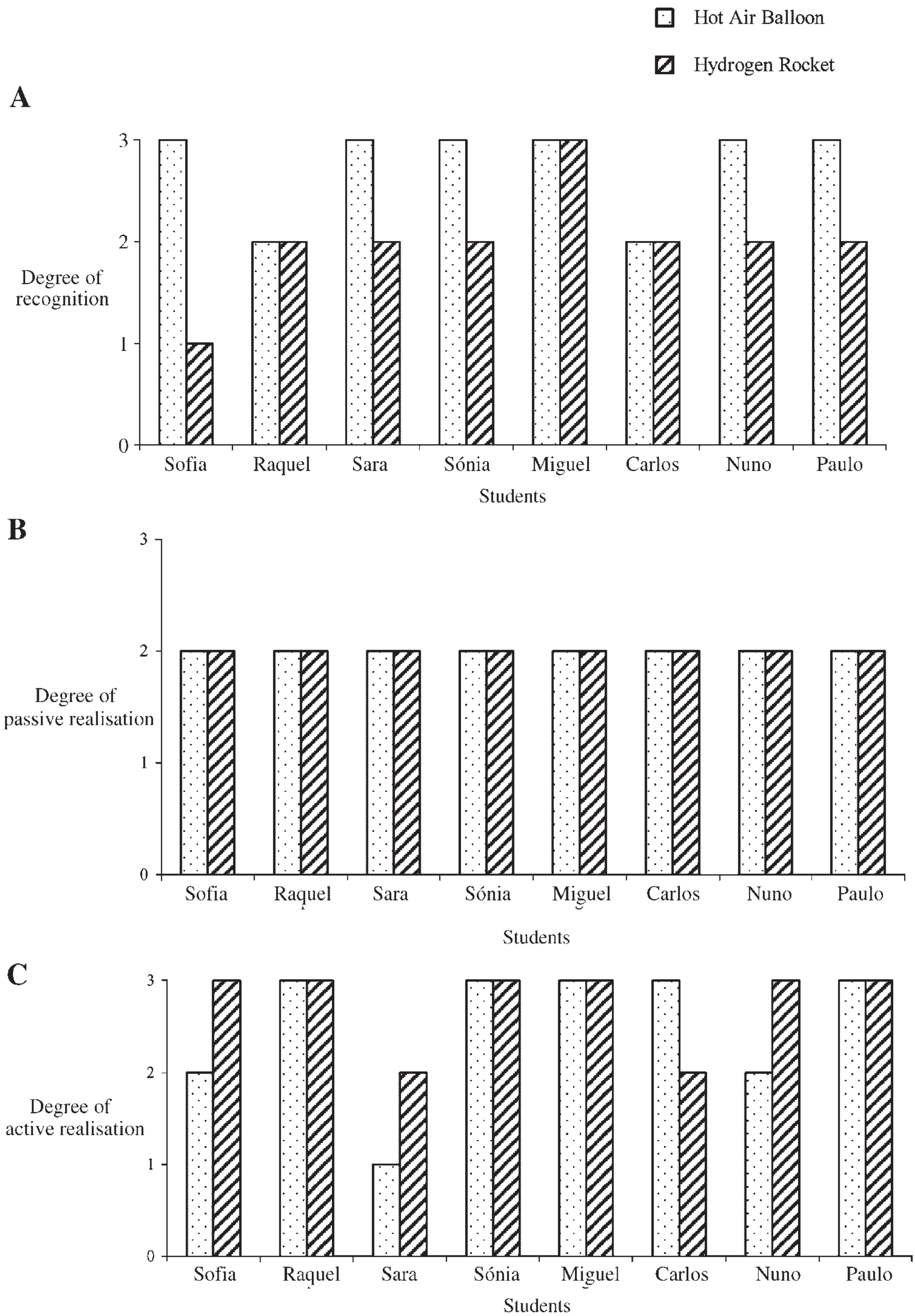


Figure 6. Comparison of degree of recognition, passive realization, active realization for the "The Hot Air Balloon" and "The Hydrogen Rocket" exhibits.

HOT AIR BALLOON – STUDENT'S CONCEPTIONS AND SCO

STUDENTS	BALLOON'S GOING UP						BALLOON'S GOING DOWN						SCO					
	CATEGORIES				JUST.		CATEGORIES				JUST.		RR		PRL		ARL	
	CS	W	I	C	Wr	Cr	CS	W	I	C	Wr	Cr	B	A	B	A	B	A
Sofia				• ×	• →	×				• ×	• →	×	II	II	II	II	–	II
Raquel				• ×	• ×		• ×				• ×		I	I	I	I	–	–
Sara				• ×	• →	×				• ×	• ×		II	II	II	II	–	I
Sónia			• →	×	• ×		• →	→	→	×	• ×		I	II	–	II	–	–
Miguel				• ×	• →	×				• ×	• →	×	II	II	II	II	–	II
Carlos		• ×			• ×		• ×				• ×		–	–	–	–	–	–
Nuno			• →	×	• →	×	• →	→	×		• ×		I	I	–	I	–	I
Paulo			• →	×	• ×					• ×	• ×		II	II	I	II	–	–

Figure 7. Students' conceptions concerning the phenomena of going up and going down of the balloon and their sociological meaning in terms of SCO.

Notes:

Conceptions when explaining the going up of the balloon:

CS - The balloon goes up because it is pushed by the wind.

W - The balloon goes up because has a working engine.

I - The balloon goes up because there is hot air inside.

C - The balloon goes up because the air inside is hotter than the air outside.

Conceptions when explaining the going down of the balloon

CS - The balloon goes down because lost air from the inside.

W - The balloon goes down because the engine stopped working.

I - The balloon goes down because is full of cold air.

C - The balloon goes down because the air inside cools down.

Conceptions: CS - Common sense; W - Wrong; I - Incomplete; C - Correct; Justification: Wr - Wrong; Cr - Correct; (SCO) Specific coding orientation: RR - Recognition rules; PRL - Passive realization rules; ARL - Active realization rules; Symbols: (•) - Before the interaction; (×) - After the interaction; (→) - Direction of evolution.

Exhibit–Student Interaction at the Level of Concept Understanding

At the level of concept understanding, we analyzed the knowledge students possessed about the concepts involved in the exhibits, before the visit, and if they had acquired these concepts after the visit and also their degree of acquisition.

The Hot Air Balloon exhibit. Figure 7 shows the results obtained in terms of the categories of answers chosen by students (common sense, incorrect, incomplete, and correct), respective justification (incorrect or correct), and sociological meaning in terms of specific coding orientation.

Concerning the balloon's going up, analysis of students' conceptions shows that, before the visit to the science museum, students chose options involving conceptions of a school character—that is, incorrect, incomplete, and correct. Girls and high-achievement students (Sofia, Sara, and Miguel) chose predominantly the options that involve correct knowledge. When we look at the justifications given by students, we can see that no student gave a correct justification; that is, they did not know why the air inside that was hotter than the outside air made the balloon go up. These results suggest that, before the visit, students showed more difficulties at the level of realization than at the level of recognition.

After interaction with the exhibits, only three students (Sónia, Nuno, and Paulo) changed their concept option from incomplete to correct, and four students (Sofia, Sara, Miguel, and Nuno) gave a correct justification to their option. These four students all had high achievement and they demonstrated a high degree of recognition and realization. They were the only students who had active realization after the visit.

Concerning the balloon's going down, the results showed that, before the interaction, four students gave common-sense answers (Raquel, Sónia, Carlos, and Nuno), and the other four (Sofia, Sara, Miguel, and Paulo) gave correct answers. When we look at the justifications given by the students, we see that, before the interaction, no student gave a correct justification; that is, they did not know why the cool air inside the balloon made it go down.

After the interaction, four students showed knowledge changes. Two changed their common-sense option, one (Sónia) to the correct conception and another (Nuno) to the incomplete conception. The other two (Sofia and Miguel) changed their incorrect justification to their correct choice to a correct justification.

Globally, the results show that only two students, both of low socioeconomic status and with low achievement (Raquel and Carlos), did not change their conceptions.

The levels of recognition were the same before and after the visit (levels II and I). After the visit, the levels of passive and active realization increased for some students. Sónia and Nuno, who did not possess passive realization, were able to acquire it and Paulo proceeded from degree I to degree II. No student possessed active realization before the visit; after the visit Sofia and Miguel attained degree II and Sara and Nuno degree I.

The Hydrogen Rocket exhibit. The constitution of the water molecule, the water electrolysis process, and the concept of combustible were the ideas involved in working with the hydrogen rocket. To obtain a global view of the results, Figure 8 shows a comparison of the categories of answers given by students and the respective degree of specific coding orientation, before and after visiting the museum.

Students' recognition was low before the visit to the museum (degree I for most students and degree II for only one). This means that common-sense conceptions were the most valued. With the exception of Carlos, all students with high achievement (Sofia, Sara, Miguel, and Nuno) possessed passive realization, although to a reduced degree (degree I and II). This means that these students had the most correct conceptions. There was a total absence of active realization for all students.

The evolution was not great after the visit, considering that most changes occurred from degree I to II and that the highest degree (degree III) was present only once. Sofia, Sónia, Miguel, and Nuno stood out by increasing recognition after the visit. For Sofia, Sónia, and Nuno there was a one-degree increase, from I to II, and for Miguel a two-degree increase, from I to III. With respect to passive realization, Sofia and Miguel stood out by increasing one degree, from I to II. These two students were the only ones with active realization, although only to a limited extent (degree I).

Carlos constituted a particular case in relation to the water molecule constitution. Although only degree I, he had recognition and passive realization. After the visit, however, it seems he lost them. This finding, although unusual, is of interest because it may point to the influence of interaction with the exhibits to develop misconceptions.

When we analyzed the justifications given, we saw that, before the visit to the museum, none of the students justified any of the options relative to the three scientific contents, which means absence of active realization. The interaction with the rocket did not lead students much further. Only two students were able to form a justification, but only for the definition of combustible, thus showing active realization.

STUDENT'S CONCEPTIONS AND SCO

STUDENTS	WATER'S MOLECULE CONSTITUTION				COMBUSTIBLE EXAMPLES						WATER ELECTROLYSIS						SCO					
	CATEGORIES				CATEGORIES				JUST.		CATEGORIES				JUST.		RR		PRL		ARL	
	CS	W	I	C	CS	W	I	C	Wr	Cr	CS	W	I	C	Wr	Cr	B	A	B	A	B	A
Sofia				● ×	● →			×	●	×	● ×				● ×		I	II	I	II	-	I
Raquel		● ×			● ×				● ×		● ×				● ×		-	-	-	-	-	-
Sara				● ×				● ×	● ×		● ×				● ×		II	II	II	II	-	-
Sónia			● ×		● ×				● ×		● →		×		– –		I	II	-	-	-	-
Miguel				● ×	● →			×	● →	×	● →		×		● ×		I	III	I	II	-	I
Carlos	×			← ●	● ×				● ×		● ×				● ×		I	-	I	-	-	-
Nuno				● ×	● ×				● ×		● →		×		● ×		I	II	I	I	-	-
Paulo		● →		×	● →			×	● ×		● ×				● ×		-	II	-	II	-	-

Figure 8. Students' conceptions concerning the constitution of the water molecule, example of a combustible, and the electrolysis process of water, and their sociological meaning in terms of SCO.

Notes:

Conceptions about the water's molecule constitution:
CS - Oxygen
W - Carbon and Helium
I - Hydrogen
C - Hydrogen and Oxygen
Conceptions about combustible examples:
CS - Petrol
W - Water and Carbon Dioxide
H - Hydrogen
C - Hydrogen and Petrol
Conceptions about the process of water's electrolysis
CS - Letting water boil
W - Heating it
I - Transporting electric current into the water
C -Transporting electric current into and out the water
Conceptions: CS - Common sense; W - Wrong; I - Incomplete; C - Correct; Justification: Wr - Wrong; Cr - Correct; (SCO) Specific coding orientation: RR - Recognition rules; PRL - Passive realization rules; ARL - Active realization rules; B - Before the visit to the science center; A - After the visit to the science center; Symbols: (•) - Before the interaction; (×) - After the interaction; (→) - Direction of evolution.

With regard to evolution, before and after the visit, among students with distinct characteristics (socioeconomic status, achievement, and gender), both low and high socioeconomic status students showed some improvement for both recognition and passive realization rules. However, the latter increased more than the former. In the case of active realization rules, only two students (Sofia and Miguel), both low socioeconomic status, increased their understanding. With regard to gender and for all rules, both boys and girls increased understanding, but boys increased more than girls. When we consider the achievement groups, we observe that, for recognition rules and passive realization rules, both low and high achievers increased, but the latter increased more than the former. In the case of active realization rules, only two students (Sofia and Miguel), both with low socioeconomic status and high achievement, showed an increase.

Relation Between Procedures and Concept Understanding

Figure 9 compares the degree of SCO obtained in the two microcontexts of the study. An analysis of the graph shows that, although for some students there seemed to be a direct relationship between procedures and concept understanding, such as with Sofia, Sara, and Miguel, this relation was not present in general. This means that what students do (procedures) does not seem to have a direct influence on what they learn (concept understanding). Students had poorer results at the level of concept understanding than at the level of procedures. Figure 9 also shows that there were no cases in which the results obtained for scientific learning were higher than the results for procedures.

Discussion

Exhibit–Student Interaction at the Level of Procedures

The Hot Air Balloon exhibit. At the level of recognition, the high degree of recognition obtained suggests that students, in general, could easily characterize the exhibit. We considered recognition as the identification of the exhibit title and the designation and function of the exhibit components. We believe that the design of this exhibit allows students to identify the context easily. This is a very important condition for obtaining good results, and confirms the results of others (Falk & Dierking, 2000; Gilbert & Stocklmayer, 2001) about the importance of the exhibit's design to the learning process.

The fact that, at the realization level, socially disadvantaged students (Raquel and Carlos) attained better results than socially advantaged students (Sara and Nuno) may be explained by the fact that, for socially advantaged students, the impact of environmental novelty on learning in out-of-school settings was potentially nonexistent. It may be that the museum is only one more context, among those many contexts they have already had access to, and therefore they have little curiosity with the interaction. In contrast, for socially disadvantaged students, this context may be

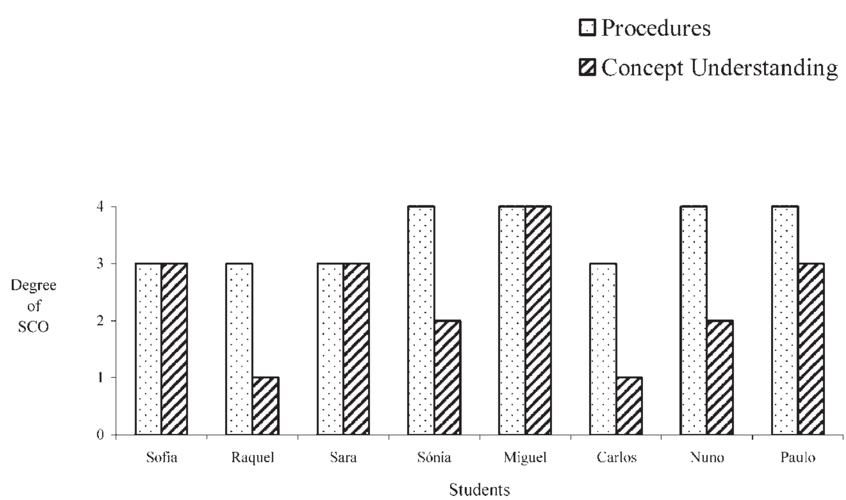


Figure 9. Comparison of performance (SCO) at the level of procedures and concept understanding.

a unique experience in their lives and, consequently, curiosity and commitment may be greater. For them the impact of environment novelty seemed to enhance learning. Many studies have demonstrated that a considerable amount of the learning that occurs in free-choice conditions is a result of novelty-seeking behavior (Anderson & Lucas, 1997; Kubota & Olstad, 1991). The results we obtained in studying students' socioaffective dispositions supports this explanatory hypothesis by showing that socially advantaged students had less favorable dispositions toward the interaction for both the balloon and the rocket exhibits. We can look at these dispositions as the personal influence on learning processes referred to by Driver et al. (1994) and Falk and Dierking (2000). Students' socioaffective dispositions seem to relate to their learning success.

The fact that some students who had a high degree of recognition rules did not possess realization rules may be related to the absence of rules that allow one to produce the text expected in this context, or they did have them and could not produce the text for some unknown reason. We should note that these are the students who had less favorable socioaffective' dispositions, which may help to explain their results. According to Bernstein (1990, 2000) students need to possess realization rules to produce the correct text. This is important because recognition of context is not enough to produce the expected text.

The Hydrogen Rocket exhibit. The fact that all students, with the exception of two students (Sofia and Miguel), had an intermediate degree of recognition may be primarily a consequence of the fact that these students showed great difficulty in identifying both the name of the exhibit and the function of some of its parts. The design of this exhibit was more complex than that of the balloon. It was difficult to relate the exhibit to a hydrogen rocket. First, the object simulating the rocket (number 2, Figure 4A) did not have physical characteristics similar to a true rocket, but rather just a small plastic piece. Second, the students could not relate the hydrogen to the combustible, which moves the object, because the hydrogen is not visible. Students simply saw a transparent liquid—water (number 4, Figure 4A)—and the bubbles, which came out of the water, but were easily seen. It was then very difficult for students to establish a relation between the liquid and the combustible. Some of the functions of the components were not easily identifiable. The glass of the water's recipient was partially foggy and this did not permit adequate visibility. These findings emphasize the importance of design of the exhibit.

We could explain the intermediate degree of passive realization by the fact that, during the interviews, when we asked students about the posted procedures needed to make the exhibit work, they did not consider reading of the instructions as necessary. This suggests that students did not attribute importance to reading the labels as part of the procedure. Although there was an intermediate degree of passive realization, the degree of active realization was generally high. We consider this aspect very important.

The two exhibits. When we look at the interaction with the two exhibits, the easier recognition showed by students in the context of the balloon exhibit seems to be explained by both the specific characteristics of each exhibit and the results obtained at the level of students' socioaffective disposition in relation to the tasks required. The set of mechanisms inherent to functioning of the balloon were visually simpler to the students than the procedures of the rocket. The other characteristics of the rocket we mentioned also seem to justify the results. In the case of the balloon, the mechanisms that permit heating of the air were placed inside the exhibit, making it difficult for students to understand how the air was heated. On the other hand, the phenomena associated with the going up and down of the balloon seem to be simpler than those of the rocket. This may explain the better results in the case of the balloon. The fact that most students, when answering the questionnaire, said that they had understood what happened during the interaction with the balloon but they did not understand it in the case of the rocket may also explain the different results.

With regard to realization, the absence of differences in the passive dimension may be the result of the fact that all students select the necessary procedures for the correct functioning of the exhibits, with the exception of reading the instructions. The high degree of passive and active realization may be the result of one of the sociological characteristics of the two exhibit contexts. The evaluation criteria were characterized by very strong framing; that is, the procedures required to make the exhibits function were clear to the students. As pointed out by Falk (1997), reading the instruction labeling is a fundamental procedure that informs students of what they are to do. This study confirms that labels should specify procedures and the sequence required.

Based on the results obtained in the case of active realization, we detected two behaviors related to correct functioning of the balloon. Some students did not read the labels with the instructions and did not wait until the temperature reached 90°C to press the button to release the balloon. It was necessary to wait about 6–7 minutes to reach that temperature. Moreover, students are supposed to keep their finger on the button during that time. Our perception is confirmed by the fact that, according to the questionnaire findings, most students believed that they had spent too much time with the balloon, although there was sufficient time with the rocket. This situation occurred with Sofia and Sara who, in the case of the balloon, did not wait for the temperature to reach 90°C to press the green button. The fact that some students did not read the instructions may explain the poorer results with the balloon. There was an exception with Carlos, who showed a higher degree of active realization in the case of the balloon than in the case of the rocket.

The fact that, in the case of the balloon, students needed to hold down a button for 6–7 minutes, shows a poor exhibit design. It is clear that few students are willing to wait that long in the context of an exhibit. Designers should be aware that ‘‘details’’ such as these can prevent the success of an exhibit. Teachers should also be aware that they must be critical of the organization and structure of the exhibits they attend with their students.

Exhibit–Student Interaction at the Level of Concept Understanding

The Hot Air Balloon exhibit. A positive evolution from entry to exit occurred with the six students for the three rules, which may be related to the exhibit characteristics, particularly the information given in the label instructions, as well as possessing SCO.

With respect to exhibit characteristics, the first step in the label instructions indicates ‘‘Press the red button to obtain hot air’’ and the second indicates ‘‘Wait until the air reaches 90°C.’’ These instructions informed the students that the air heats. However, only two options for the balloon going up, incomplete and correct, used the ‘‘hot air’’ expression, leading us to believe that this may explain the results obtained. The four lowest achievement students did not understand the reason why the balloon goes up. If the expression ‘‘inside the balloon’’ had been added to the first step of the instructions (i.e., ‘‘Press the red button to obtain hot air inside the balloon’’), then these students may have achieved better results. The difficulty that most students encountered in understanding why the balloon goes down may be related to the fact that nothing in the instructions point to this phenomenon.

The results show the influence of students’ achievement and socioeconomic status on performance. They may have developed realization rules in the context of concept understanding in other situations—namely in the school—to produce the expected text in this context.

The Hydrogen Rocket exhibit. A positive evolution, from entry to exit in the center exhibit, occurred with five students, and this evolution was evident, especially at the level of recognition and passive realization rules. This may be related to the exhibit characteristics, particularly to the information given to students and information presented in the instructions, and also to the presence of SCO.

With regard to exhibit characteristics, the instructions presented indicated "Turn the handle until you have enough rocket fuel (when the lights go green)," and the explanation given was "You are producing electricity which transforms the liquid into gases, hydrogen, and oxygen. When you press the button, the gases mix and have an ignition. Various types of space rockets use the hydrogen as fuel." We do not find any reference to liquid as being water. This should have been clarified by the designers of the exhibit. If students knew the constitution of water, we believe they would have learned it elsewhere, as revealed by the results. As Carlos's results demonstrate, it is important to assure that the exhibit–student interaction does not contribute to confusion of correct conceptions.

With respect to the combustible examples, the fact that only three students learned, after the interaction, that hydrogen is a combustible may mean that they did not read the label. The "What happens?" label section indicates "hydrogen as fuel." The only information present on the label that helps explain why the hydrogen is a combustible is "The gases mixed and have an ignition." This information is so vague that we believe it does not help students to obtain the answer. They are only able to learn the example. The same happened with the water electrolysis. The wording on the label, "You are producing electricity which transforms the liquid into gases, hydrogen and oxygen," does not explain why this happened.

The results reflect the influence of students' achievement. High achievers obtained the best results. As with the balloon, it may be that they have already acquired the realization rules for the context of concept understanding in other situations, such as in school, which helped them to produce the expected text in this context.

The two exhibits. The results based on the answers to the two questionnaires show: (1) a relation between the use of interactive exhibits and the understanding of scientific concepts; (2) some influence of sociological characteristics related to both the family (socioeconomic status) and school (achievement) on that relation; and (3) a relation between the possession of recognition and realization rules and the understanding of scientific concepts. These results emphasize the value of interactive exhibits a potential tool for understanding scientific concepts and in decreasing the gap between socially differentiated students.

Whereas socially disadvantaged students (Raquel and Carlos) revealed high socioaffective dispositions at the level of the procedures, consequently obtaining good results at that level, we found that these students had poor results at the level of concept understanding. This is an interesting area for analysis. It seems that these exhibits have some limitations for disadvantaged students at the level of concept understanding. Therefore, we need to think about what the exhibit should change to promote understanding of scientific concepts and what students need to learn about these concepts in science exhibits. The students had socioaffective dispositions to interact with exhibits at the level of procedures, but they revealed an absence of recognition and realization rules at the level of concept understanding. We must ask why that happens. Sociological characteristics of the exhibits may be a reason. At the level of concept understanding, the evaluation criteria were not explicit, and it was unclear to students what they were expected to learn and understand.

Students' Procedures and Concept Understanding

We observed that what most students did (procedures) had no direct influence on what they learned (concept understanding); that is, values obtained in the microcontext of procedures did not correspond to values obtained in the microcontext of concept understanding. One reason for this discrepancy may be found in the sociological differences of the exhibits at the level of procedures and concept understanding. In the context of concept understanding, the evaluation criteria were regulated by a weak framing (F^{--}), whereas in the context of procedures they were regulated by a strong framing (F^{--}). This means that the evaluation criteria are more explicit to the students at the level of procedures and this may facilitate carrying out of the activity. The evaluation criteria were not explicit at the level of concept understanding, and thus it was not clear to students what they were expected to understand and learn. It is therefore understandable that results at the level of concept understanding were lower than at the level of procedures.

Another aspect to consider is that what students could see or do in the exhibit helps little to understand the scientific concepts involved. We believe it is important to define precisely the aim of the exhibit. This would help science center educators and teachers concentrate on what and how they must act to help students.

Conclusions

This study has investigated the influence of some characteristics of students, exhibits, and exhibit–student interaction on students' learning, when they interact with two exhibits at a science center. With respect to students' characteristics, we were unable to reach definitive conclusions, although their family background and achievement appeared to influence learning with the exhibits. Socially advantaged and disadvantaged students reacted differently to each microcontext. We need additional studies to get a better understanding of this influence and to help exhibit designers to conceive exhibits that allow for reduction of learning differences among students with these characteristics.

Our study has allowed us to identify the influence of specific coding orientation (SCO) on students' performance. Recognition and realization rules were found to be crucial factors with regard to performance. Possession of these rules is related to some characteristics of the exhibits and of the students, and to the learning context. Further studies are necessary to clarify this relationship.

Although the analyses generally revealed changes in concept understanding, from entry to exit, a more detailed analysis revealed that gains were not evenly distributed across all eight students. More detailed studies are necessary to clarify our findings and help understand how students with different characteristics learn from exhibits, especially the most socioeconomically disadvantaged students.

We identified three characteristics of exhibits that influence students' learning; these relate to their design, the set of mechanisms inherent to the function of the exhibit, and the evaluation criteria. These are characteristics that can be analyzed in future studies and they may contribute to science educators' understanding of students' behavior, learning, and interactions with the exhibits.

With regard to exhibit design, analysis of the results suggests that distinct parts of exhibits, essentially those related to the knowledge to be learned, must allow students to easily associate them with the objects they are supposed to represent. For example, if the designers want students to think that an object simulates a rocket, then the object must have characteristics that easily allow its association with a rocket, not leaving it to the students' imagination. Text in the exhibit label must contain words or expressions that help students to construct the relevant scientific concepts.

The mechanisms and facts that students need to learn to understand a given concept must be made clear. This was not the case in the exhibits evaluated in this study, particularly the hydrogen rocket. Teachers and science centers' educational teams must consider these aspects.

Evaluation criteria showed similar values for both exhibits, but the values differed between the two microcontexts: students' procedures and students' concept understanding. These distinct values seemed to explain the distinct performance levels observed in each microcontext. If the evaluation criteria are not explicit, how can the principles that allow recognition of the context and production of the expected text be acquired? We believe this is an important aspect to be explored in the conception of exhibits. If we intend to help students understand scientific concepts we must construct exhibits that explicitly offer such a possibility. The evaluation criteria affected the relation between what students do (procedures) and what students learn (concept understanding). We can conclude that good performance in both microcontexts requires explicit evaluation criteria; that is, students must know what is expected from them in relation to what they need to do (procedures) and in relation to the facts or concepts they are expected to learn (concept understanding).

Another contribution of this study is its innovative form of analysis of student–exhibit interaction and student learning. Bernstein's theory made it possible to identify some important sociological aspects of the exhibit–student relation and to associate these with performance. This theory has shown much potential in the study of learning contexts, and we suggest this can be applied to science centers. It makes possible the understanding of what students do and learn and how they do this. According to Bernstein, the acquisition of recognition and realization rules is a function of the classification and framing principles. In this study, the classification between contexts (between common-sense and school concepts at the microcontext of the concept understanding and between the various exhibit parts at the microcontext of the procedures) made it possible for students to manifest recognition rules for both microcontexts. With respect to framing—that is, the nature of the control upon selection, sequence, pacing, and evaluation criteria—we conclude that its values for both microcontexts, except in the case of the evaluation criteria, made it possible for students to show passive realization. This means that students could identify the correct answer to school concepts (at the microcontext of concept understanding) and identify the correct behaviors (at the microcontext of the procedures). This critical point is related to evaluation criteria as discussed earlier. At the microcontext of concept understanding, a weak framing value (F^{--}) did not seem adequate for the acquisition by students of a correct understanding of concepts. We strongly suggest that exhibits at a science center make it clear what students are to learn.

This study has contributed some knowledge about science centers' learning and provides some paths for future research. The results and their discussion suggest important aspects that both designers and science center educational teams must take into account when devising interactive exhibits directed to visitors in general and to students in particular. In this case, the role of the teacher, who might be considering incorporating the informal learning setting into their school's curriculum, is also important. If teachers spend time and energy to take students to science centers and expose them to a set of exhibits, then what are the returns the teacher might expect in terms of students' increased understanding of scientific concepts? There are also implications for teachers' action related to the fact that lower socioeconomic status students may experience a novelty factor in visits to museums, whereas other students may not.

From these data we see that interactions with exhibits may influence the development of misconceptions. This finding may be useful to consider in future investigations.

In conclusion, we suggest that future efforts to investigate learning at science centers should consider characteristics of students' achievement and family socioeconomic status. Similarly, we suggest that they should consider exhibit characteristics, at least the set of mechanisms that students must learn in the interaction and the evaluation criteria concerning the text to be learned.

Notes

[1]For example, some science centers are organized to have rooms for physics and rooms for biology. In this case, there are strong boundaries between discourses. In other science centers, there are rooms where biology and physics topics are explored simultaneously. Here there are blurred boundaries between discourses.

[2]For example, if we consider the exploration of space by students, teachers can control that exploration or leave it to the students themselves. In the first case the framing is strong, but it is weak in the second case.

[3]Selection refers to knowledge and competence to be learned; sequence is the order in which learning takes place; and pacing is the expected rate of acquisition and evaluation criteria to the correct/legitimate text to be acquired and produced.

[4]The ESSA Group (Sociological Studies of the Classroom) at the Department of Education of the School of Science, University of Lisbon, carries out research on science education, within a fundamentally sociological approach and an interface with other approaches.

[5]In this study, socioeconomic status should be understood as nominal, descriptive, and not as an analytical concept, and should be used to make evident its role as a regulative category of the differential codes of family and school.

[6]We constructed a 1–6 scale for both the mother's and father's occupation and academic qualifications. The maximum number of points obtained would thus be 24.

[7]We used a four-degree scale because we had a 100% value. According to Del Rincón, Arnal, Latorre, and Sans (1995), the best way to determine the number of degrees on a scale is to make its points equidistant.

[8]We used a three-degree scale because the total value was 11. According to Del Rincón et al. (1995), the best way to determine the number of degrees on a scale is to make its points equidistant. However, it is impossible to make a scale of 11 points where points are equidistant. Thus, we decided to create a three-point scale.

[9]The results obtained at the level of socioaffective dispositions are shown in Appendixes A–C. Space limitations required us to take them out of the "Results" section, where they could be described in detail. A description can be found in the study by Botelho (2001).

Appendix A

During the time that you interacted with the exhibit, you

(a) enjoyed yourself; (b) had fun yourself; (c) played; (d) learned new things; (e) felt it was useless; (f) felt it was annoying; (g) understood what was happening; (h) felt it was very complicated

(*Indicate yes or no; you may signal more than one sentence*)

STUDENTS' FEELINGS DURING INTERACTION

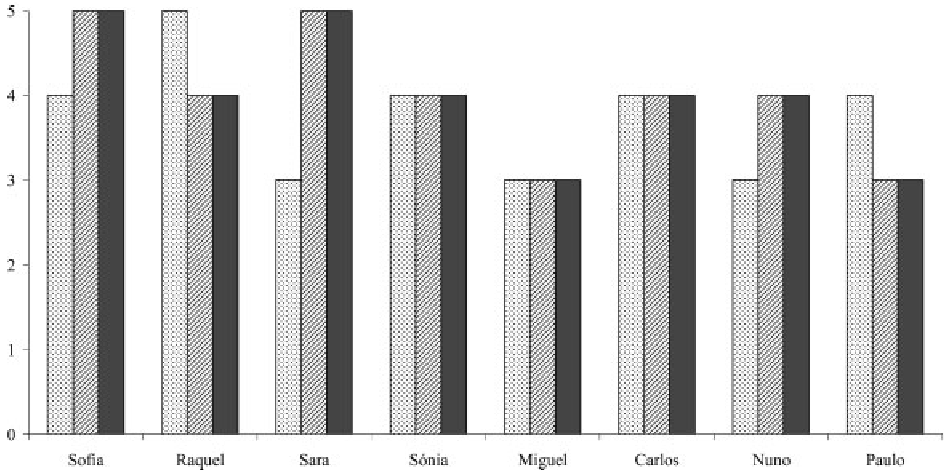
During the time that you interacted with the exhibit, you	Sofia		Raquel		Sara		Sónia		Miguel		Carlos		Nuno		Paulo	
	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
HOT AIR BALLOON																
Enjoyed yourself		●		●	●		●			●		●	●		●	
Had fun yourself		●		●	●			●		●		●	●			●
Played		●		●	●		●			●		●	●			●
Learned new things		●		●		●		●		●		●		●		●
Felt it was useless	●		●		●		●		●		●		●		●	
Felt it was annoying	●		●		●		●		●		●		●		●	
Understood what was happening		●		●		●		●		●		●		●		●
Felt it was very complicated	●		●			●	●		●		●			●	●	
HYDROGEN ROCKET																
Enjoyed yourself		●		●	●		●			●		●	●		●	
Had fun yourself		●		●	●			●		●		●	●			●
Played		●		●	●		●			●		●	●			●
Learned new things	●			●		●	●			●		●		●		●
Felt it was useless	●		●		●		●		●		●		●		●	
Felt it was annoying		●	●		●		●		●		●		●		●	
Understood what was happening	●		●		●		●		●		●		●			●
Felt it was very complicated	●		●			●	●		●		●			●	●	

Appendix B

Students' opinions about Hot Air Balloon looking/design and time spent in interaction

1. I think the exhibit was:
   (5) very pretty; (4) pretty; (3) normal; (2) ugly; (1) very ugly
   (5) very funny; (4) funny; (3) normal; (2) not funny; (1) not at all funny

2. From the moment I started working with the exhibit until it went up, I think it took
   (5) too much time; (4) much time; (3) enough time; (2) little time; (1) much little time

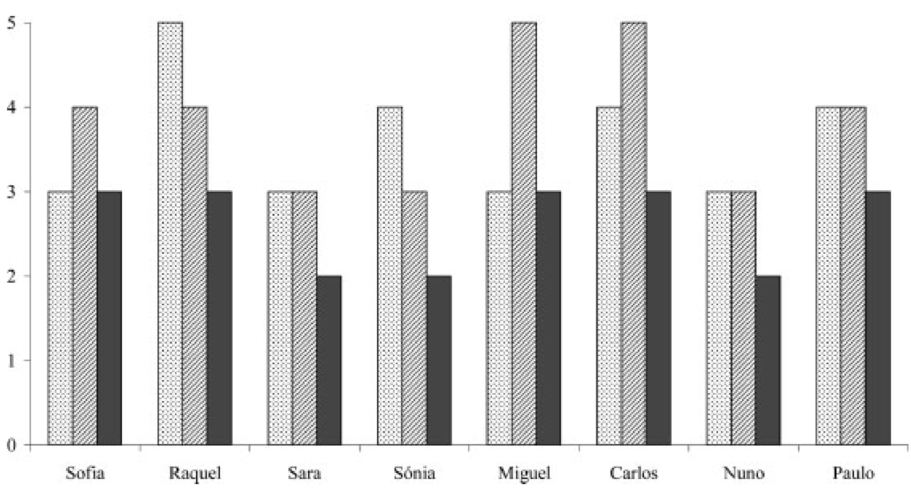


Appendix C

Students' opinions about Hydrogen Rocket looking/design and time spent in interaction

1. I think the exhibit was:
   (5) very pretty; (4) pretty; (3) normal; (2) ugly; (1) very ugly
   (5) very funny; (4) funny; (3) normal; (2) not funny; (1) not at all funny

2. From the moment I started working with the exhibit until it went up, I think it took
   (5) too much time; (4) much time; (3) enough time; (2) little time; (1) much little time



References

Afonso, M. (1995). Concepções alternativas em ciências e orientação especifica de codificação—Influência da família e da escola nas concepções dos alunos e na mudança conceptual. Unpublished master's thesis in Education. Lisboa: Faculdade de Ciências da Universidade de Lisboa.

Anderson, D., & Lucas, K.B. (1997). The effectiveness of orienting students to the physical features of a science museum prior to visitation. Research in Science Education, 27, 485–495.

Bernstein, B. (1990). Class, codes and control. Vol. IV. The structuring of pedagogic discourse. London: Routledge.

Bernstein, B. (2000). Pedagogy, symbolic control and identity: Theory, research, critique (rev. ed.). Oxford: Rowman & Littlefield.

Boisvert, D., & Slez, B. (1994). The relationship between exhibit characteristics and learning-associated behaviors in a science museum discovery space. Science Education, 79, 503–518.

Botelho, A.J. (2001). Museus de Ciência e Desenvolvimento Científico. Estudo sociológico de desempenhos e aprendizagens dos alunos. Unpublished master's thesis in Education. Lisboa: Faculdade de Ciências da Universidade de Lisboa.

Botelho, A.J. (2004). Experiências de integraço de actividades de aprendizagem formal, não formal e informal: reflexões sobre a sua implementação no âmbito do estágio pedagógico. In A. Estrela & J. Ferreira (organizers), Regulação Educação e Economia (pp. 263–272). Lisboa: Association Francophone Internationale de Recherche Scientifique en Education—section portuguaise.

Botelho, A.J., & Morais, A.M. (2003). O que fazem os alunos num centro de ciência: Uma análise da interacção com módulos científicos participativos. Revista Portuguesa de Educação, 16, 157–192.

Botelho, A.J., & Morais, A.M. (2004). A aprendizagem de conceitos científicos em centros de ciência: Um estudo sobre a interacção entre alunos e módulos científicos participativos. Revista de Educação, 12, 5–24.

Busque, L. (1991). Potential interaction and potential investigation of science center exhibits and visitors' interest. Journal of Research in Science Teaching, 28, 411–421.

Carlisle, R.W. (1985). What do schoolchildren do at a science centre? Curator, 28, 27–33.

Carr, M., & Barker, M. (1994). The constructivist paradigm and some implications for science content and pedagogy. In P. Fensham, R. Gunstone, & R. White (Eds.), The content of science: A constructivist approach to its teaching and learning (pp. 147–160). London: Falmer Press.

Cone, C.A., & Kendall, K. (1978). Space, time, and family interaction: Visitor behavior at the science museum of Minnesota. Curator, 21, 245–258.

Del Rincón, D., Arnal, J., Latorre, A., & Sans, A. (1995). Técnicas de investigacion en ciencias sociales. Madrid: Editorial Dickinson.

Driver, R., & Asoko, H. (1994). Constructing scientific knowledge in the classroom. Educational Researcher, 23, 5–12.

Escot, C. (1999). La culture scientifique et technologique dans l'éducation non formelle. Paris: editions UNESCO.

Falk, J. (1997). Testing a museum exhibition design assumption: Effect of explicit labeling of clusters on visitor concept development. Science Education, 81, 679–688.

Falk, J., & Dierking, L. (2000). Learning from museums. Visitor experiences and the making of meaning. Walnut Creek, CA: Alta Mira.

Falk, J., Koran, J., Dierking, L., & Dreblow, L. (1985). Predicting visitor behavior. Curator, 28, 249–257.

Falk, J., Moussori, T., & Coulson, D. (1998). The effect of visitors' agendas on museum learning. Curator, 41, 107–120.

Feher, E. (1990). Interactive museum exhibits as tools for learning: Exploration with light. International Journal of Science Education, 12, 35–39.

Fensham, P., & Gunstone, R. (1994). The content of science: A constructivist approach to its teaching and learning. London: Falmer Press.

Gilbert, J.K., & Stocklmayer, S. (2001). The design of interactive exhibits to promote the making of meaning. Museum Management and Curatorship, 19, 41–50.

Hein, G.E. (1991). Constructivist learning theory. ICOM CECA Conference: The museum and the needs of people. Jerusalem: ICOM.

Hein, G.E., & Price, S. (1994). Active assessment for active science. Portsmouth, NH: Heinemann.

Henriksen, E. (1998). Environmental issues in the museum: Applying public perceptions in exhibition development. Curator, 41, 90–105.

Jackson, R., & Hann, K. (1994). Learning through the science museum. Journal of Education in Museums, 15, 11–13.

Kubota, C., & Olstad, R. (1991). Effects of novelty-reducing preparation on exploratory behavior and cognitive learning in a science museum. Journal of Research in Science Teaching, 28, 225–234.

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

Lemke, J. (1990). Talking science. Norwood, NJ: Ablex.

Miles, R.S. (1987). Communicating science to the public. Chichester, UK: Wiley.

Morais, A., Neves, I., Medeiros, A., Peneda, D., Fontinhas, F., & Antunes, H. (1993). Socialização primária e prática pedagógica. Vol. 2. Análise de aprendizagens na família e na escola. Lisboa: Fundação Calouste Gulbenkian.

Morais, A., Neves, I., Antunes, H., Fontinhas, F., Medeiros, A., Peneda, D., & Reis, E. (1996). Práticas pedagógicas e aprendizagem científica: um estudo sociológico. Revista de Educação, 5, 69–93.

Morais, A., & Neves, I. (2001). Pedagogic social contexts: studies for sociology of learning. In A. Morais, I. Neves, B. Davies, & H. Daniels (Eds.), Towards a sociology of pedagogy—The contribution of Basil Bernstein to research (pp. 185–221). New York: Peter Lang.

Morais, A.M., Neves, I.P., Rocha, M., Afonso, M., Câmara, M.J., Ferreira, L., et al. (2000). Estudos para uma sociologia da aprendizagem. Lisboa: Centro de Investigação em Educação da FCUL e Instituto de Inovação Educacional.

Reid, B. (1997). Interactives: Popular but unproven? Museum Practice, 2, 12.

Rogoff, B., & Lave, J. (1984). Everyday cognition: Its development in social context. Cambridge, MA: Harvard University Press.

Russell, T. (1995). The enquiring visitor: useable learning theory for museum contexts. Journal of Education in Museums, 16, 19–21.

Serrel, B. (1997). Paying attention: Duration and allocation of visitors' time in museum exhibitions. Curator, 40, 108–125.

Symington, D., & Boundy, K. (1986). Prior knowledge and primary pupils' interaction with a museum display. Research in Science Education, 16, 55–62.

Swift, F. (1997). Time to go interactive? Museum Practice, 2, 12–15.

Thier, H.D., & Linn, M.C. (1976). The value of interactive learning experiences. Curator, 19, 233–245.

Tulley, A., & Lucas, A.M. (1990). Interacting with a science museum: Vicarious and direct experience and subsequent understanding. International Journal of Science Education, 13, 533–542.