Chapter 12
Different Music to the Same Score: Teaching About Genes, Environment, and Human Performances

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> *What argument against social change could be more effective than the claim that established orders exist as an accurate reflection of innate intellectual capacities?*
>
> Stephen Jay Gould, The Mismeasure of Man

Introduction: Biological Determinism, When Science Meets Ideology

There is agreement within the science education community on the contributions of argumentation about socio-scientific issues (SSI) to scientific literacy and to the development of critical thinking (Kolstø, 2006). SSI involves scientific arguments in addition to political, personal or ethical questions about what action to choose (Kolstø, 2006). It is suggested that argumentation about SSI makes scientific learning meaningful, as it provides a context that connects science with everyday problems where citizens are expected to make decisions, and requires taking an active role to solve controversies. Argumentation in these contexts involves not only applying scientific knowledge, but also developing an independent opinion in order to critically examine scientific claims and arguments, in other words, becoming a critical thinker (Jiménez-Aleixandre & Puig, 2010).

Biological determinism, which is the focus of this chapter, has social relevance because determinist views have been used, and still are used, to support political agendas challenging the notion that all humans are equal. But it differs from other SSI, as for instance cloning (Jiménez-Aleixandre & Federico-Agraso, 2009) where

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the issues at stake relate to genetics but the controversies themselves are ethical in nature. In our unit about gene expression, students need to appeal primarily to causal explanations about genetics, rather than to values, although social representations play a role in the arguments about this issue. The relevance of different contexts (for instance, causal explanations or decision-making) for argumentation and the use of evidence are discussed elsewhere (Jiménez-Aleixandre & Puig, 2011).

The focus of the current study and the embedded teaching unit has ethical, social, and political implications: causal explanations (interaction versus determinism) about gene expression in the phenotype, in particular, about human performances. The current model of gene expression explains the relationships among genotype and phenotype, as for instance human traits and performances, as a consequence of gene-environment interactions. Causal explanations are constructed through social processes of questioning, evaluation, and revision (Berland & Reiser, 2009), meaning that the scientific practices of argumentation and explanation are interconnected. Educational research has examined students' difficulties in the genetic domain (Duncan, Rogat, & Yarden, 2009; Knippels, 2002). Nevertheless, to our knowledge there are no studies that explore the difficulties in the construction of the phenotype notion in connection with human traits and performances and the determinist representations that may be associated with it.

This chapter discusses the design and implementation of a teaching sequence, through a pilot study and two teaching cycles, in five high school classrooms. The topic is the causal model of gene expression and gene-environment interactions. The goals are to engage students in modeling gene expression and in using evidence to build explanations about human performances.

Our aim is to analyze teacher-students interactions or, as Tiberghien, Vince, and Gaidioz (2009) call them, joint productions, to increase our understanding about the challenges in teaching the model of gene expression and its potential interference with determinist views. We seek to explore how meanings about gene-environment interactions are constructed in the class. This analysis is framed in the model of didactical transposition (Chevallard, 1991), characterizing knowledge transformations, from scientific community (reference knowledge) to curriculum and teaching resources (knowledge to be taught), and from these designed instructional sequences to taught knowledge. The objectives, related to these steps in knowledge transformation are:

1. To analyze the process of design of the learning tasks with the purpose of making explicit assumptions and decisions guiding it, that is, the first step in didactical transposition, from reference knowledge to knowledge to be taught.
2. To examine two teachers' actions during the unit about gene expression, in particular how they dealt with the gene-environment interactions, and to characterize the didactical contracts created in both classrooms, that is, the second step in didactical transposition, from designed to taught knowledge.
3. To examine students' difficulties related to the construction of explanations that acknowledge gene-environment interactions.

Rationale: Determinism and Genetics Learning

In this section we will first review the notion of biological determinism and its current resurgence in the context of particular political agendas; then we turn attention to science education studies about genetics learning, in particular about the model of gene expression.

Determinism from Mainstream Science to Support for Racism

Biological determinism is the view that genes entirely determine all individual traits and performances, including intelligence, criminality or academic achievements. In daily life it is commonly expressed in racist and sexist opinions. Determinists attribute social and economic differences among different races or genders to hereditary; they consider these differences to be innate distinctions. These views were part of mainstream science; for instance, a hierarchy was established distributing human races from "superior" (white) to 'inferior', according to features such as skin color. Cuvier (1817) "studied" the body of Saartjie Baartman, known as the Hottentot Venus, concluding that she was a proof of why these (black) races were "condemned to eternal inferiority".

Nowadays "human race" is not accepted as a biological notion, much less as a hierarchy of "superior" and "inferior" people. Determinist views have been replaced by a consensus on the interaction between genes and environment. As Lewontin (1991) points out, although there is a large amount of variation from one individual to another from the same ethnic group, accounting for 85% of all genetic variation, there is remarkably little variation on average among major groups (7% of all genetic variation). The remaining 8% of variation is found between ethnic groups within a race. However, as with other socially constructed representations (Moscovici, 1961–1976) determinist views, explicit or implicit, continue to exist in society. The persistence of these views is reflected in the media, literature or jokes. Biological determinism cannot be justified on the basis of current scientific evidence, such as genome research. Then, why is this view still circulating? Who legitimizes it?

A particularly disturbing occurrence is that of political discourses that relate issues such as alcoholism, violence or suicide to genetic determination. We illustrate this trend with two statements of European politicians: first, the French president Sarkozy, in an interview: "Every year about 1,200 to 1,300 young people commit suicide in France. It is not because their parents do not care about them, but because, genetically they had frailty, a previous pain" (*El País*, September 10, 2009). The second example is taken from a newspaper article by Mariano Rajoy, current leader of the conservative party (Partido Popular), which has been alternating in the Spanish government with the socialists since the late 1970s. The article, entitled *Human equality and models of society* questions the "cliché of human equity":

> Natural inequality among men is written on the genetic code, where the roots for all human inequalities are found: in it are transmitted all our conditions, from physical, health, color

> of eyes, hair, corpulence… to the ones that we call psychical, as intelligence, disposition for arts, studies or business. (Faro de Vigo, March 4, 1983)

Although this text was written years ago, this author has never distanced himself from the positions offered in this and a later article on the same issue.

Determinism explains social inequalities as a result of biology. Its message, as point out, is that all social phenomena are rooted in human nature. This reductionist view on human beings may be comforting for individuals because it provides an explanation for inequalities. If genes were responsible for determining exactly who each person would become and individuals do not have control over the outcome, then there would be no social responsibilities. The resurgence of determinism has been related to conservative proposals for reducing investments in social programs (Gould, 1981). It is used to support political agendas seeking scientific justification for reducing support for deprived segments of society; poverty, unemployment, and educational exclusion are interpreted as a result of innate features rather than social conditions (Kaplan & Llomovatte, 2009). In other words, responsibility is placed on individuals and on genetic traits, not on society (Lewontin, 1991).

Contemporary determinism asserts for instance that the differences in intelligence between blacks and whites are due to genetics (Herrnstein & Murray, 1994; Jensen, 1969). On October 14, 2007, in an interview for the *Sunday Times*, the Nobel laureate James Watson, talking about Africa, said that "all our social policies are based on the fact that their intelligence is the same as ours – whereas all the testing says not really." Watson went on to argue that people who employ black workers challenged the notion of equality. Watson's claim is a statement with political implications, which may be used to justify the reductions of investments in African countries. Racism is a target for educators, but we have not located any studies, besides Levy, Selles, Ferreira's (2008) exploration of textbooks, about determinism in the science classroom. In this study we focus on the students' positions between acknowledgment of interactions and determinism.

Teaching and Learning About Phenotype-Genotype Relationships

Research shows that genetics is one of the most difficult topics for students (Duncan & Reiser, 2007; Knippels, Waarloo, & Boersma, 2005; Lewis & Wood-Robinson, 2000), so the challenge for science educators is to develop learning environments that promote students' scientific literacy in this topic. This chapter deals with the model of gene expression and its application requires an appropriate understanding of the phenotype notion and of the influence of environment in gene expression. Given the complexity of these ideas and the lack of resources, as evidenced by the analysis of textbooks below, our goal was to develop a sequence supporting students' appropriation of this model. We agree with Gelbart and Yarden (2006) about the need to provide students with a context giving opportunities to apply genetics concepts, develop new knowledge, and present it in different ways. Tasks set in real life and SSI constitute appropriate contexts for this purpose.

Why is it important to understand this model? There are two primary reasons: first, it explains the relationships among genotype and phenotype accounting, for instance, for human traits as height and performances such as athletic achievements or intelligence. Without understanding these relationships students may not be able to reason about how the environment influences some phenotypic traits, for instance, why nowadays people are taller than several generations ago. Although phenotype is sometimes defined as the "visible" manifestation of genes, it needs to be noted that some traits, like blood type, are detectable rather than "visible."

Second, understanding this model is necessary for a critical evaluation of determinist views. Although there are studies showing that students have poor understanding of the relationships between genotype and phenotype (Tsui & Treagust, 2007; Venville & Donovan, 2005), they do not deal with biological determinism. For instance, Lewis and Kattmann (2004) have reported students' difficulties in distinguishing between genotype and phenotype, and as a result, in considering the microscopic and molecular causal mechanisms of genetic phenomena. Duncan et al. (2009), in their proposal of a learning progression in genetics, suggest that one of the core ideas of students' understanding in genetics is related to the interaction between genes and environment, but that this set of ideas is often entirely missing from the genetics curriculum. They indicate that the risk of developing a deterministic view is greater when students lack explanatory mechanisms that link genes to traits, being unaware of what organization level the genetic information specifies.

In a previous study (Puig & Jiménez-Aleixandre, 2010a), we suggested that students' difficulties in identifying data related to the model of gene expression and using them to evaluate a determinist claim may be influenced by social representations of human races. Artistic skills, human performances, and health conditions are sometimes presented as genetic traits without any environmental influence, misinterpreting an individual's genetics endowment as predestination. The fact that these ideas are still circulating makes it difficult for students to understand what phenotype actually is and what influences it. We think that understanding the model of expression is a necessary but not sufficient condition to evaluate determinist claims and that students need to develop critical thinking. In our characterization of critical thinking (Jiménez-Aleixandre & Puig, 2010), there is a component related to social emancipation and the capacity to develop one's own opinion as opposed sometimes to the mainstream ideas of a community or society.

Methods and Educational Context

Methodological Framework: Didactical Transposition

Our methodological approach is framed by the theories of didactical situations (Brousseau, 1998) and *didactical transposition* (Chevallard, 1991) based on the assumption that there are social conditions required for knowledge to exist, as knowledge can only stay alive if it is studied, used or both.

Didactical transposition characterizes the process of transformation of knowledge from one community, scientists (reference knowledge), to another, classrooms (taught knowledge). As Tiberghien et al. (2009) point out, there are two steps in the transposition: (1) from the reference knowledge to the knowledge to be taught and (2) from the knowledge to be taught to the taught knowledge. The knowledge to be taught consists of official curricula, textbooks, and other resources and the taught knowledge is related to the way a teacher enacts it in a particular class.

For objective 1, the analysis of the design process is based on Tiberghien et al. (2009), who propose a framework to develop research-based design, relating decisions to theories about knowledge, teaching, and learning. For objective 2, the analysis of the teachers' actions is based on the work of Sensevy (2007). Sensevy characterizes the "didactical action" (*action didactique*) as a reciprocal action based in communicative processes between the teacher and the students. This approach is based on the assumption that knowledge shapes the teaching and learning practices and that didactical action is a joint action between teacher and students. For analyzing these interactions between teacher and students, we adapted Mortimer and Scott's (2003) tool.

The analysis of teachers' actions is framed in the notion of *didactical contract* (Brousseau, 1998), which characterizes the teacher's expectations about students and the students' expectations about the teacher. As Tiberghien et al. (2009) discuss, the didactical contract constitutes a system of norms, some of which are generic and will be lasting, while others are specific to elements of knowledge and need to be redefined with the introduction of new elements.

For objective 3, the examination of students' difficulties in explaining phenotype as a result of the gene-environment interactions, instead of seeing it as depending only on genes (biological determinism), the students' wrote reports and the transcriptions of their talk were analyzed, and categories constructed in interaction with the data.

Context and Data Collection

This is a multi-case study conducted through a pilot study and two research cycles in five classrooms from three public (state) secondary schools in Galicia, the northwest region of Spain. All of the students involved in the research ($N=127$) were native Spaniards. The teaching sequence was carried out in several (ranging from three to five) sessions, each lasting 50 min except the pilot study that was developed in two sessions. The full study including the pilot and research cycles extended over a 3-year period. All the teachers, identified by pseudonyms, are male and hold a degree in Biology. In this section, we outline the specific context of each case study and the data collected. Table12.1 summarizes this information.

Students worked in small groups and each group was audio and video taped. The researcher (first author) took notes about teacher-students interactions. All drawings

Table 12.1 School context in the pilot study and research cycles

		First research cycle	Second research cycle	
	Pilot study	Case study 1	Case study 2	Case study 3
School and location	School A city	School A city	School B town	School C small village
Grade and age	9th grade (14–15)	10th grade (15–16)	10th grade (15–16)	11th grade (16–17)
Course	Biology & geology	Biology & geology	Biology & geology	Science for the modern world
Number of classes and students	1 (24 students)	2 (50 students)	1 (18 students)	1 (35 students)
Number of sessions	2	3	5	4

and diagrams used on the blackboard or electronic board were also registered. Sometimes, at the request of the teachers, the researcher engaged in classroom activities to offer guidance with the tasks.

Pilot Study

The pilot study was developed with a group of 9th graders (14 to 15 years old). The students were from middle class backgrounds, and the teacher was a professional with more than 20 years of experience and involvement in inquiry approaches.

Case Study 1

The setting was the same school as the pilot study with two tenth grade biology classrooms (including some of the students from the pilot study). The teacher was a novice, with only 2 years of experience. All tasks were discussed with him, although, due to lack of experience, he offered little input.

Case Study 2

The second case study, conducted in the second research cycle, was developed with tenth grade students from a working class background in a small town. The teacher had more than 15 years of teaching experience, most of it in this particular school. The tasks were discussed with him. Issues related to data collection and students' distribution in groups were also negotiated with the teacher. The scenario was quite different from the pilot study and case study 1 because many of the students involved were not high achieving or expressed little interest in school activities. Seven of the 18 students were repeating the course.

Case Study 3

The third case study was conducted in a rural school located in a remote village where agriculture and roofing slate quarries constituted the main socioeconomic activities. The students and teachers shared particularly strong and trusting relationships in this school. The teacher with whom we worked had been teaching for 10 years. He was involved in research projects related to inquiry and was pursuing a Ph.D. in science education at the time of the intervention.

From Reference Knowledge to the Knowledge to Be Taught: Design of the Teaching Sequence

In this section, we analyze the design process of a teaching sequence (TS) about the model of gene expression for tenth grade. It is a developmental research approach, drawing from theory and practice (Knippels, 2002), and consists of a process of testing the adequacy of learning tasks and design in a classroom setting.

The concept of *didactical transposition* helps to make explicit the process of the development of the teaching sequence. The first step of the didactical transposition consists of how the reference knowledge is transformed into the knowledge to be taught. Figure 12.1 summarizes the different elements, both theoretical (goals, design principles, and literature review) and empirical (textbook analysis, pilot study, and time constraints) that shape this first step.

Reference Knowledge

The reference knowledge is composed of two strands: (1) Genetics, in particular, the model of gene expression and gene-environment interactions, a topic connected to a social issue and biological determinism, and (2) Scientific practices, including

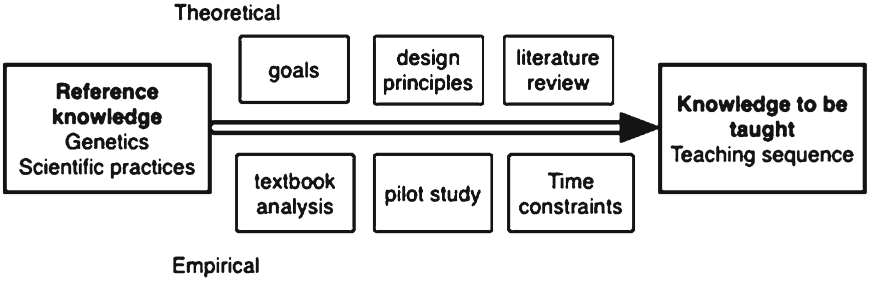

Fig. 12.1 First step in the didactical transposition: from reference knowledge to knowledge to be taught

modeling, argumentation, and the use of evidence. Argumentation and modeling are two central practices in science that are connected in that argumentation is a process that underlies the examination, evaluation, and revision of models (Berland & Reiser, 2009).

Goals and Design Principles

The transformation of reference knowledge into knowledge to be taught does not involve a simplification. It is a process of knowledge transformation expressed in the choice of learning tasks for students supporting the appropriation of the model of gene expression and its application to different contexts. As Tiberghien (2008) indicates, elaborating the knowledge to be taught that leads to scientific culture and to citizenship education, necessarily goes beyond disciplinary goals. Therefore, this sequence has three goals for students, the first two related to science education and the third to citizenship: (1) to be able to apply the model of gene expression to real life contexts; (2) to develop the competency of using evidence and building arguments; and (3) to be able to develop a critical stance toward biological determinism.

How did we use these goals and design principles in order to transform the reference knowledge? The consequences of the goals were first that tasks 2 and 3 required students to apply the model of gene expression to everyday contexts. Secondly, these tasks engaged students in the practice of selecting and using evidence in order to support a claim. Finally, the tasks, particularly numbers 2 and 3, addressed biological determinism. It has to be noted that this is not the standard way of transformation of reference knowledge, as illustrated by the textbook analysis reported below.

The choice of the design principles related to these goals draws from Jiménez-Aleixandre's (2008) proposal for learning environments that support argumentation. We briefly discuss how three of these design principles, role of students, of teachers, and learning tasks, influenced the decisions made in the design.

- *Active role of the students*: The tasks were designed in order to actively engage students in the scientific practices of modeling and use of evidence. For instance, in task 1 adapted from "Take two people" (Dixon, 1982), students worked on the construction of a model about relationships between genotype and phenotype. In task 2, students needed to relate pieces of evidence to claims about causes for the achievements of black sprinters.
- *Learning tasks set in real life contexts*: The learning tasks were drawn from real life. For instance, the second task ("Athletics"), related to the use of evidence, provided a context where students were asked to build arguments about black athletes' achievements. In task 3 ("Watson"), students had to evaluate a determinist claim. In terms of classroom organization, the tasks used cooperative learning strategies and required students to pay attention to different points of views within their groups.

- *The role of the teacher*: According to Sensevy (2007) didactical action is a joint production of teacher and students, which means that the teacher should act as a knowledge mediator. The teachers' actions and interactions with students are discussed in the section about taught knowledge.

Literature Review

The literature review about genetics learning, discussed in the rationale, was used first to identify learning problems that needed to be addressed such as understanding the genotype – phenotype relationship and second to locate proposals for tasks that were incorporated into the sequence such as the modeling activities designed by Dixon (1982) and Johnson (1991). This first step in the didactical transposition was also influenced by empirical elements: the analysis of school textbooks and the development of a pilot study as well as the time constraints, which were a chief concern for the teachers.

Analysis of Textbooks

We wanted to check how school textbooks introduced the model of genotype expression and whether they dealt with biological determinism. For this purpose, the contents of genetics chapters in five tenth grade textbooks were analyzed. Tenth grade is the first year in which genetics is a part of the Spanish curriculum. The four teachers involved in the study used two textbooks (TB1 and TB2), which are the most widely used in Spain. We decided to examine three more textbooks in order to have a representative sample, providing an overview of how this topic is typically presented in schools. Four dimensions of textbook presentations were analyzed: (a) the definition of phenotype; (b) examples of the influence of the environment on gene expression; (c) questions and activities requiring the application of the phenotype notion; (d) references to determinism or "race." The findings are summarized in Table 12.2.

Table 12.2 Summary of the textbooks analysis. N = 5 textbooks, TB1 to TB5

Dimensions	Number of textbooks $N=5$
Definition of phenotype	
Phenotype as a result of interactions gene-environment	4
Phenotype solely as the expression of genes	1 (TB3)
Examples of the influence of environment	
Two different examples	3 (TB1, TB3, TB4)
One example	2 (TB2, TB5)
Questions and activities requiring the application of the phenotype notion	1 (TB2)
References to determinism and race	2 (TB2, TB3)

- *Definition of phenotype*: We examined first whether textbook authors defined phenotype as the result of interactions between genes and environment or just as gene expression. Second, we examined whether authors discussed the idea that some phenotypic traits are detectable but not visible. Four textbooks defined phenotype as the result of an interaction between genotype and environment and one as solely gene expression: "The genes contained in one individual for a specific character constitutes his/her genotype (AA; Aa or aa) and the expression of that genotype is called phenotype" (TB3). This narrow definition, not consistent with the reference knowledge, revealed determinism. All five textbooks defined phenotype as the "set of visible characters in any individual" (TB2), without mentioning that some characters, like blood types, are detectable but not visible.
- *Examples of the influence of environment on gene expression*: Little space was devoted in the textbooks to explanations or examples of the influence of the environment on gene expression. Three presented two examples, and the other two just one. In all, only four different examples were found: Human height, muscles, hair color in animals, and obesity. Two textbooks (TB1, TB2) presented height as an instance of influence of environmental factors, in particular of nutrition: "Human height is an inherited trait, parents that are tall usually have children that are tall too, but alimentation does definitely influence this trait" (TB2). The development of muscles is explained in two textbooks (TB1, TB3) as a consequence of training.
- *Questions and activities requiring the application of the phenotype notion*: There were only eight questions or activities related to genetics in the five textbooks. Five were problems of Mendelian genetics requiring the use of the Punnett square and did not demand applying the model in different contexts. As Stewart (1983) pointed out, solving this type of problem does not necessarily require an adequate understanding of genetics' content knowledge. We found only one question in TB2 that required applying the notion of the influence of the environment in the genotype expression: *Can two individual with different phenotype exhibit the same genotype?* The others were related to the transmission of human traits from parents to offspring.
- *References to determinism and the "race" issue*: The analysis revealed that while all textbooks addressed some of the social implications related with biotechnology and genetic engineering (transgenic organisms, cloning, DNA tests, etc.), only two (TB2 and TB3) mentioned races and racism. However, neither text explicitly addressed biological determinism and the underlying misunderstanding of the model of gene expression. TB2 mentioned the genetic similarity of humans, using it to justify the lack of a scientific base for the notion of human "races": "Human beings are very similar from each other. 99.9% of the genetic data is common to every person, therefore it does not exist a genetic base for the notion of race."

TB3 discussed three issues in a section entitled "Diversity and racism": First, the old idea of "races" as categories to classify human beings. Second, it emphasized that all individuals are different from each other, highlighting it in bold type: "There are not two people totally identical although neither completely different in everything." Third, it claimed that racism is a social but not a scientific problem. Although raising the issue of races is interesting, the text did not explicitly discuss that races, as hierarchical categories, do not exist in a biological sense or make connections to biological determinism.

In summary, the analysis of these five textbooks indicated that all but one provided an adequate definition of phenotype. It is worth noting that in all books, there was little space devoted to explanations or examples of the influence of the environment: a small number of examples per book and only one question about the explanation of the influence of environment in gene expression. For Toulmin (1972) we only understand the scientific meaning of words and notions when we learn to apply them. If students are not required to transfer the model of gene expression to different contexts we cannot know whether they understand it. Concerning biological determinism, two textbooks mentioned the question of races but did not relate it to the model of gene expression.

Analysis of the state-approved curriculum for tenth grade biology (MEC, 2007) revealed little attention to the notion of phenotype. The evaluation criteria emphasized the student ability to distinguish among primary genetics constructs and to solve Mendelian genetics problems. Concerning the social implications of genetics, the curriculum highlighted the capacity of students to analyze critically "the benefits and risks related to modern biotechnology (genetic therapy and transgenic food)." Therefore, it is not surprising that textbooks did not address biological determinism.

The consequences of this analysis for the didactical transposition were that it can be assumed that if teachers rely on textbooks as a primary resource for teaching, as happens in most cases, they will likely find adequate definitions of phenotype but very little help in terms of activities that support student application of this notion. So the teaching sequence needed to include these types of tasks.

Results of the Pilot Study

The pilot study was developed with a group of ninth graders with the purpose of examining the use of evidence and the students' positions toward Watson's claim about genetic differences in intelligence between blacks and whites (Puig & Jiménez-Aleixandre, 2010a). Grade 9 was chosen as it is the last year when science is compulsory for all students and therefore is the highest level of science for about half of the Spanish population. The purpose was to better understand how the general public would critically analyze a determinist claim. The results revealed that students experienced difficulties in recognizing evidence, as for instance the influence of training or other environmental factors. The students demonstrated problems understanding the influence of the environment in gene expression.

How did we use the results of the pilot study to go from the reference knowledge to the teaching sequence? First, the results highlighted the need for devoting more time to developing the model of gene expression, including a detailed explanation of the phenotype notion and examples of the influence of the environment on gene expression in different contexts. Second, the results suggested the need for learning activities that engage students in modeling the relationships between genotype and phenotype and in using evidence. Third, they revealed a need to modify the items in the Watson task that proved the most difficult for the students to interpret.

Time Constraints

The third empirical element that influenced the transposition was limitations in the time available in classrooms. Our initial draft consisted of six to eight sessions to be delivered over 2–3 weeks but after negotiations with the teachers, it was apparent that they were only ready to devote four or five sessions to this issue. As Jiménez-Aleixandre and Sanmartí Puig (1995) pointed out, the reduction of one-third in the number of science hours in the Spanish curriculum in the last decades was not accompanied by a parallel reduction in expected content coverage. Teachers felt that it was difficult to cover all the topics and to attain all the objectives in so little time. Therefore, it was necessary to adapt the tasks to the number of sessions available for each teacher.

The Knowledge to Be Taught: The Designed Sequence

Taking into account the theoretical and empirical elements and the time limitations, the first decision was to devote session 1 to an explanation of genetics concepts and the remaining four sessions to different tasks, two adapted from previously developed materials (tasks 1 and 4), and two designed by us (tasks 2 and 3). Table 12.3 summarizes the tasks and concepts in the full sequence with an indication of the tasks developed in each case. The development of session 1 is discussed in the next section.

- *Task 1* "*Take two people*": The first task, designed for the second session, was adapted from previously developed materials (Dixon, 1982). It provided opportunities for student groups to create models of inheritance. The objectives of the task were to help students: (a) visualize relationships between phenotype and genotype, and (b) reveal the role of chance in the formation and combination of gametes.
- *Task 2* "*Athletics*": The second task required students to establish relationships between eight pieces of information and three different explanations about the

Table 12.3 Tasks and activities in the teaching sequence

Session/case study	Genetics concepts	Type of task/activity	Content and source
1 Case 2, 3	Gene, alleles, dominant, recessive, phenotype, genotype, heterozygote, homozygote	Lecture	Teachers' explanation of genetic notions
2 Case 1, 2, 3	The same as in session 1	Students' perform a modeling task	Task 1: take two people; adapted from Dixon, 1982
3 Case 2,3	Phenotype-genotype relationships, gene-environment interactions	Students are asked to select and use evidence in the context of choosing a causal explanation	Task 2: athletics achievements of black sprinters
4 Pilot study Case 1, 2, 3	Phenotype- genotype relationships, determinist claim	Students are asked to use evidence to evaluate a scientific claim	Task 3: Watson claim about blacks being less intelligent than whites
5 Case 1, 2, 3[a]	Phenotype- genotype relationships	Students are involved in a modeling activity	Task 4: the doughnuts analogy; adapted from Johnson, 1991

[a] In case study 3, the contents of sessions 4 and 5 were collapsed into a longer session

causes of the outstanding achievements of black sprinters. The prompt highlighted the fact that black athletes have placed in the top three positions at each Olympics and World Championship sprint competitions since 1987. The objectives of this activity were to (a) identify evidence for a given claim and connect evidence and claim through justifications for argument building; and (b) apply the model of gene expression in a real-life context. It had originally been designed for at least two sessions, so we had to simplify it in order to meet the teacher's needs in terms of timing.

- *Task 3* "*Evaluation of Watson*'*s claim*": The third task was tested in the pilot study and modified accordingly (Puig & Jiménez-Aleixandre, 2010a). A new item was introduced with data showing the increase in height of Galician men in the last 70 years. Human height is one of the most frequent phenotype examples in textbooks, but some authors (Diehl & Donnelly, 2008) explain it as a consequence of evolution. In another study with eleventh graders (Puig & Jiménez-Aleixandre, 2010b), we found that a 17% of the students considered this increase as an evidence of evolution.
- *Task 4 The doughnuts analogy*: This modeling activity was adapted from Johnson (1991). The activity used something familiar to students (in our case doughnuts, a traditional Spanish sweet) to explain the unfamiliar (phenotype and genotype). The goal was to help students construct meanings for genetics' concepts and to visualize the influence of environment on the phenotype, as doughnuts made with the same recipe could look quite different.

Two classroom cycles comprising three case studies were implemented in order to test and improve the sequence.

From Knowledge to Be Taught to Taught Knowledge

The second step of the didactical transposition consists of how the knowledge to be taught is transformed into the taught knowledge. Figure 12.2 summarizes the different elements that shape this second step, influencing the different forms of the taught knowledge.

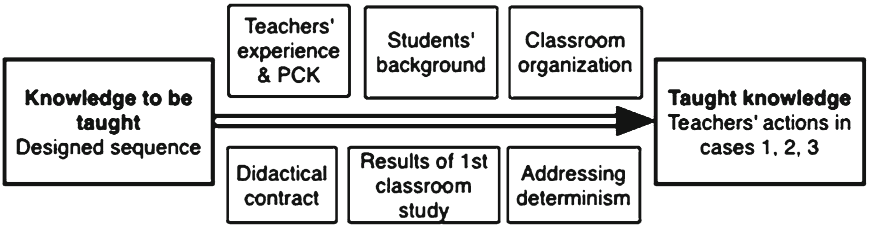

Fig. 12.2 Second step in the didactical transposition: from knowledge to be taught to taught knowledge

Teachers' Experience and Pedagogical Content Knowledge

As discussed in the methods section, the three teachers had different levels of teaching experience and expertise. We framed teacher expertise in terms of Pedagogical Content Knowledge (PCK; Shulman, 1986) or subject matter knowledge for teaching, which includes an understanding of typical student learning difficulties and a repertoire of teaching strategies. The analysis focuses on two teachers Mr. Val (case 2) and Mr. Quiroga (case 3). (Both names are pseudonyms.) Although Mr. Val had more teaching experience, Mr. Quiroga had more sophisticated PCK. Both teachers used TB1.

Students' Background and Previous Experience

Several differences existed among the students in terms of socioeconomic backgrounds and cultural capital (Bourdieu & Passeron, 1970), a notion explaining how social inequalities are reproduced through differences in cultural or symbolic capital (language, accent, dress), influencing academic opportunities and success of students from different backgrounds. There were qualitative differences among the three schools in this dimension, as the cultural capital of students in school A (case study 1) is higher than those from schools B and C (case study 2 and 3). There were also differences in students' experiences working in small groups and engagement in inquiry: the students in case 3 had this experience, while the others did not. In other words, their roles (as perceived or expected by the students) were different. This had consequences for the development of the sequence, as discussed below.

Classroom Organization

The learning environments designed by each teacher differed in their organization (which overlaps with the didactical contract) as seen in the analysis of the teachers' actions. This became especially apparent in task activities that called for cooperative learning and work in small groups.

Didactical Contract

The didactical contract constitutes the reciprocal expectations between teacher and students, the system of norms jointly created in the class. It includes the (usually implicit) roles of students and teachers and classroom management. Although the sequence's design assumed that the students had the responsibility for building models (tasks 1, 4) and arguments (tasks 2, 3), it was also framed in an approach where the teachers supported these practices. The teachers' scaffolding presented a number of differences, discussed below.

Results of the First Classroom Study

The evaluation of case study 1, in two tenth grade classes, helped to identify design problems. An instance was students' difficulties to use evidence, which lead to modifications in the tasks. Therefore, a new version of the sequence (TS2) was developed, to be used in cases 2 and 3. The teacher in case 1 did not consider it necessary to spend one session explaining the genetics concepts including phenotype. Instead, before task 1, "Take two people," he reminded students of the main concepts. Some results of this case study, and consequences for the design were:

- Structure of the sessions: the students could not complete the modeling task "Take two people" because part of the time was used to review genetics' notions. This confirmed our initial design and the need for two sessions, one for explaining the concepts and one for the task.
- Task comprehension: students had some difficulties understanding what they were asked, particularly in one item about black sprinters in the Watson task. The task was split in two, and a new one ("athletics," session 3) was designed, initially for two sessions, including a range of data to illustrate the role of both genes and environment in athletics achievements.
- Use of evidence: as in the pilot study, students struggled to identify the model of genotype expression in the items featured within the Watson task. For instance, some students interpreted human height as an instance of evolution due to mutations.

In summary, the main modifications from TS1 to TS2 were: devoting the first session to instruction about genetics concepts and splitting Watson's task in two, one about athletics, and the other a revised version of the evaluation of Watson's claim, asking students which evidence would be needed to support or rebut it.

Addressing Determinism: Social Implications of Gene-Environment Interactions

One of the three goals underlying the teaching sequence was the development of a critical stance toward biological determinism. Although this dimension was embedded in the design, in particular in tasks 2 and 3, Mr. Val and Mr. Quiroga addressed it differently. Only Mr. Quiroga dealt with it explicitly, first in his presentation in session 1, then in the classroom debate after task 3. Time constraints influenced the two steps in the didactical transposition. In the second step, negotiation with the teachers resulted in four sessions for Mr. Quiroga and five for Mr. Val.

Taught Knowledge: Teachers' Actions

The second objective of the study is the examination of two teachers' actions during the unit about gene expression: in terms of the didactical transposition, the taught knowledge, which is associated with a particular classroom (Tiberghien et al., 2009). This section analyzes the didactical actions focusing on teachers in cases 2 and 3 who taught the same version of the sequence.

First, we examine the teachers' actions and their modes of interaction with students in the first session, during which the teachers directed instruction. Second, their guidance of the students during the tasks in other sessions is analyzed. Third, we examine how they dealt with gene-environment interactions and its social implications. We outline the session development and then analyze the teachers' actions through a revised version of Mortimer and Scott's (2003) scheme. It should be noted that this is not an evaluative analysis; we consider both of these teachers as professionals. The purpose of the analysis is to examine how the same teaching sequence comes to be taught in different ways, thus becoming two different types of taught knowledge.

The Development of Session 1 in Two Classrooms

The development of this 50 min session can be divided into five episodes for Mr. Val and six for Mr. Quiroga, according to the content and the type of discursive moves. The episodes followed a pattern of the consecutive discursive moves of textualization (Mortimer, 2000): *description* as a first approach to a system, object or phenomenon, in this case its definition; *explanation*, which establishes relations between entities and concepts, importing a model to give sense to a specific phenomenon; and *generalization* involving explanations independent from a specific context. To these we add *application*, when the notion is transferred to a new context. The episodes and discursive moves are summarized in Table 12.4.

Episode 1 Introducing the lesson: Definitions. In the case of Mr. Val the episode was primarily a teacher's lecture, with students listening. The predominant discursive move was description or definition. He addressed a question to one student: *Felisa: Would one person be homozygote or heterozygote for all his or her genes? What do you think?* The student answered "No"; but instead of waiting for her justification, he offered an extended explanation.

Mr. Quiroga began by connecting genetics with evolution. He introduced the lesson showing the students a picture of Mendel and a few of Mendel's peas brought from a visit to his laboratory. Then he wrote on the electronic board six terms: genotype, phenotype, allele, homozygote, heterozygote, dominant, recessive. He emphasized the importance of understanding rather than memorizing as they would need to use these ideas to explain different phenomena. Students worked in pairs for 5 min on the definition of the six terms.

Table 12.4 The taught knowledge in session 1: summary of episodes and discursive moves

	Mr. Val	Mr. Quiroga
Episode 1	*Introducing the lesson: Definitions* Teacher defined 14 genetics terms. He asked one yes/ no question to one student.	*Introducing the lesson: Definitions* Teacher contextualized the unit, wrote on the board seven genetics terms and asked the students to work in pairs on their definition.
Episode 2	*Explanation about phenotype* Teacher explained the concept of phenotype with six examples. He addressed two questions to two students, plus one yes/no question, Q3. Students listened; one answered “no” to Q 3.	*Explanation about genotype* Extended dialog (16 turns) among teacher and students about the definition of genotype, with seven questions posed to students. Six students participated in the dialog.
Episode 3	*Genes-environment interaction: Explanation, generalization, and application* Teacher explained the influence of environment in genotype expression, providing six examples. He posed two yes/ no questions, and asked for more examples about gene expression. Students offered three examples.	*Gene-environment interactions: Explanation, generalization, and application* Extended dialog (73 turns) among teacher and students about whether genotype is always manifested in the phenotype. Teacher used two analogies: building drafts and music scores. He asked 30 questions and introduced a metacognitive reflection. Twelve students participated and offered examples about how environment can modify gene expression
Episode 4	*Other genetics concepts* Teacher explained the relationship among dominant/ recessive alleles and phenotype, providing three examples. He asked two questions. Students answered the questions.	*Other genetics concepts* Three teacher-student dialogs of 12, 11, and 14 turns about alleles, homozygote/ heterozygote, and dominant/recessive. Teacher asked 15 questions. Six students replied to the questions.
Episode 5	*Wrapping up and checking questions* Researcher solicited instances of phenotype. Four students answered; they provided the same examples used by the teacher.	*Wrapping up and checking questions* Researcher solicited examples of phenotype. Teacher asked three questions. Eleven students answered the questions.
Episode 6	–	*Social implications of gene-environment interactions* Teacher explicitly addressed determinist views. He asked nine questions about whether traits and behavior depend from genes or from environment. Extended dialog (30 turns) teacher - students.

Episode 2 Explanations about genotype/phenotype: Mr. Val began by asking one student to define phenotype, and followed the same pattern of explaining without waiting for her answer. Mr. Val provided three examples of phenotypic traits, observable (eye color), behavior (mice), and biochemical (lactose intolerance). He explained why phenotypes do not always exhibit in identical ways in parents and offspring. He posed a question about whether phenotype is inherited, to which the students answered "No." Mr. Quiroga initiated a dialog with the students about these terms beginning with genotype after the students finished working on the definitions. He picked up their responses asking about where genes are located and the origin of the genes in our body.

Episode 3 Explanation, generalization, and application about gene-environment interactions: This was the longest episode in both classes, taking about half of the session's time. As gene-environment interactions are the focus of this study, the way each teacher dealt with them are subjected to a detailed analysis in the section about students' processes of construction.

Episode 4 Other genetics concepts: Mr. Val explained the relationship among dominant/ recessive alleles and phenotype, providing three examples. There was a brief dialog initiated by the teacher asking questions related with the concepts of homozygote and heterozygote. Mr. Quiroga and the students reviewed the same concepts, in a Socratic dialog.

Episode 5 Wrapping up and checking questions: In both cases, the researcher asked students about the differences between genotype and phenotype and solicited instances of phenotypic traits. The students of Mr. Val offered the same examples used by the teacher. The students from Mr. Quiroga offered other examples.

Episode 6 Social implications of gene-environment interactions: Mr. Quiroga explicitly addressed determinist views about behavior. In an extended dialog (30 turns) the teacher probed students' understanding with questions about whether traits and behavior depend on genes or come from the environment. There was substantial teacher feedback regarding student answers.

Teachers' Guidance of Students in Tasks in Sessions 2, 3, 4, and 5

There were some general differences related to the didactical contracts in both classrooms. For instance, in Mr. Quiroga's class it was apparent that students were used to working in small groups and were expected to express their opinions and to participate in the debates, whereas these activities were not apparent in Mr. Val's class. Mr. Val's students had difficulties in understanding the purpose of some of the tasks. They needed more support and the researcher had to step in more times as compared to Mr. Quiroga's class. A second difference was that in Mr. Quiroga's class all the students were required to carry out inquiry projects in small groups about their own questions (Jiménez-Aleixandre & Fernández, 2010). There had been much explicit talk in the classroom about working as scientists do, and as a result they were familiar with notions related to scientific work.

Task 1 Take two people: The approaches to introduce this activity were noticeably different. Mr. Val explained what students needed to do, but he did not establish links to the concepts from the first session. Students did not complete the task within the allotted class time, so there was no opportunity for debriefing. Mr. Quiroga began by relating the task to some concepts from the previous session, highlighting genotype-phenotype relationships, and gene-environment interactions.

Task 2 Athletics: Mr. Val read the handout aloud, without clarifying the meaning of each question. He assisted two of the small groups that specifically requested clarification of question 2. Mr. Val highlighted the importance of listening to all views and reaching consensus before writing the report.

Mr. Quiroga began by relating the task to the notion of phenotype and some of the concepts from session 1. He and the researcher cooperated in clarifying question 2. Mr. Quiroga framed the task in scientific practices, making explicit the similarities between this task and scientists' practices, in particular the process of decision making through the use of evidence. Twice during the session Mr. Quiroga initiated a whole class discussion. At the end of the session, he recontextualized the task, asking students about the concepts important for carrying it out.

Task 3 Evaluation of Watson's claim: Mr. Val's students answered individually during session 4 and held a debate in session 5. Mr. Quiroga asked students to briefly discuss the task in small groups and then to write their conclusions. Then he initiated a whole-class debate about the influence of environment on intellectual achievements. He introduced a metacognitive reflection: "We are discussing a definition that is in textbooks and sometimes is not understood: the phenotype is the result of the interactions genotype-environment."

Task 4 The doughnuts analogy: This task was reduced to a part of the last session in both cases. The students brought doughnuts that they had baked. The main difference was that at the end of the session Mr. Quiroga asked students again about the meaning of phenotype and solicited more examples; Mr. Val did not.

How Teachers Dealt with Biological Determinism

The teaching of gene-environment interactions and the process of students' construction of explanations about it, that is teacher-students joint productions, are analyzed in the section about students. It should be noted that the ways both teachers addressed biological determinism were very different. Mr. Val highlighted the influence of environment in the phenotype, providing many examples. However, he never explicitly addressed biological determinism.

Mr. Quiroga explicitly addressed biological determinism in episode 6 of the first session. He mentioned social views about the genetic bases for alcoholism or aggressive behavior. He probed students about this issue, but at this stage he refrained from making explicit his own views about gene-environment interactions. In task 3 he initiated a discussion about intelligence and its basis. Mr. Quiroga also made references to the influence of the environment in gene expression in all the other sessions. He followed up this issue along the sequence, making explicit the continuity of the different tasks and sessions.

Characterization of Didactical Contracts and Their Relevance for SSI-Based Education

For the purpose of characterizing the didactical contracts created in the classroom, an adaptation of Mortimer and Scott's (2003) scheme was used. The scheme addressed two dimensions: the content knowledge including not only genetics but also scientific practices and the communicative approach. It is summarized in Table 12.5.

Table 12.5 Summary of the analysis of the classrooms joint productions in session 1

	Mr. Val	Mr. Quiroga
Content knowledge		
Genetics		
Conceptual load	More concepts (14)	Fewer concepts (7)
Progression of knowledge: how are concepts introduced	All concepts defined and explained by the teacher	Concepts developed through interactions
Genetics knowledge context	Mainly scientific	Combination of scientific and everyday contexts
Use of analogies	–	2 (building drafts, music score)
Use of examples	Teacher provided 17 examples	Teacher asked students for examples
Scientific practices (sessions 2 to 5)	– Students' lack of experience in scientific practices – No references to the role of evidence	– Students' previous experience in inquiry – References to the role of evidence
Communicative approach		
Questions posed to students	$N=12$	$N=65$
Rhetorical	6	7
Application and extension	4	20
Evaluation	2	38
How the teacher took into account students' answers	Teacher answered the questions for students; he did not change his discourse	Teacher developed students' answers; he changed his discourse in some cases
Interaction patterns	Less dialogic, less interactive	More dialogic, more interactive
Teacher's turns	31	86
Students' turns	19	84

Content Knowledge

As the reference knowledge, the content knowledge is composed of two strands: genetics and scientific practices. The first strand explores (a) the conceptual load, (b) how did genetics knowledge progress in session 1, (c) in which context, and (d) the use of analogies and examples. The second strand examines how the development of scientific practices proceeded in other sessions.

As seen in Table 12.5, there were substantial differences between both classrooms. Mr. Val explained more genetics concepts, all of them introduced by him. In contrast, Mr. Quiroga addressed fewer concepts, developing them in interaction with students, so the progression of knowledge took place through social discourse. Concerning the context of the explanations and the use of analogies and examples, Mr. Val focused on the scientific meaning of the genetics notions offering many examples. Mr. Quiroga connected these notions with real-life situations and asked students for examples. He used two analogies in order to clarify the model of gene expression and the relationships between genotype and phenotype.

The development of the scientific practice of using evidence is analyzed as a joint production of teacher and students (Tiberghien et al., 2009). Work on the tasks was influenced by students' previous experiences in the classroom. Mr. Quiroga's students had experience working in small groups, carrying out inquiry projects requiring them to collect and evaluate evidence, and participate in debates. In contrast, Mr. Val's students did not have these experiences; therefore, the level of support required in the two contexts was different. Learning scientific practices combines elements of practice and metaknowledge. Mr. Quiroga explicitly framed the tasks in scientific practices and the use of evidence, for instance, in task 3.

Communicative Approach

The analysis, focusing on session 1, attended to three interrelated aspects, (a) the type and number of teacher questions; (b) how the teachers account for students' answers; and (c) the interaction patterns. There were differences in the number and type of questions: Mr. Quiroga asked five times more questions than Mr. Val, and most of them were either evaluation or application and extension questions. Half of the questions posed by Mr. Val were rhetorical or confirmation questions that did not require elaboration from the students.

There were even greater differences in how the teachers reacted to students' answers: Mr. Val gave very little time for students' responses; on five occasions he answered his own questions, and in the others he did not develop on students' answers, solicit extended explanations, or explore their meaning. Mr. Quiroga developed students' answers, taking some time to discuss them. While Mr. Val's discourse did not experience any change due to interactions with students, Mr. Quiroga modified his explanations when he detected problems, as for instance when the students were not able to give an example of genes not being expressed in the phenotype. He then presented a second analogy, a music score, which was more successful.

Concerning the interaction patterns, Mr. Quiroga interacted more with students as seen in the number of students' turns, 84, while Mr. Val did not provide many chances for students to participate: there were 19 students' turns in session 1. A second aspect in the interaction patterns is whether the approach is dialogic or not. According to Mortimer and Scott (2003) who draw from Bakhtin, what makes talk functionally dialogic is the fact that more than one point of view is represented and ideas are developed, even when this talk is produced by an individual. It is in this sense that Mr. Quiroga's approach was more dialogic because he took into account students' answers to carry out the lesson. An example is presented in the following excerpt that was taken from episode 3 after the introduction of the music score analogy and the question about what influences gene expression. Mr. Quiroga presented the example of a plant that could reach 8 m, but not in an inadequate environment:

Mr. Quiroga: If I would plant it there: What would happen?
Students: It would not grow.
Mr. Quiroga: It would never grow up to eight meters. Why not?
Students: Because of the environment.
Mr. Quiroga: Because the environment does not allow it […] Look, give me another example about plants, animals or people.
Cristina: Someone who is prepared to be muscular, but for instance is born in an underdeveloped country.
Mr. Quiroga: When there is not enough to eat…
Cristina: … is not going to develop the musculature.
Mr. Quiroga: A good example. The environment, in this case not enough food to eat, is preventing the development of the amount of proteins that was planned in his or her genes. Good. Another example? One that is not about humans.

In this instance, the teacher built on students' answers to develop the target concepts. We can summarize the classroom discourse patterns in this first session, by saying that in the case of Mr. Val it consisted of detailed explanations interrupted by short question-answer exchanges. The teacher retained the responsibility of the progress of knowledge; he was more concerned about students' understanding of the meaning of genetics notions than about engaging them in its construction. In the case of Mr. Quiroga, there was little time devoted to the teacher lecturing and students listening. The students participated in the definition of each concept and discussed its meaning with the teacher. The teacher modified his discourse when he perceived problems in understanding or applying it, as seen with the first analogy. The progression of knowledge took place through interactive processes between teacher and students. The task of knowledge construction was shared with the students.

Didactical Contracts

As a consequence of these differences, the didactical contracts were very different in the two classes. The didactical contract is the set of teacher behaviors that are expected by students and vice-versa. As Sensevy (2007) points out, this notion positions educational actions as essentially communicative because the actions are grounded in students' interpretation of the situation.

We interpret that, in Mr. Val's case, the students expected the teacher to explain without being interrupted, and sometimes they did not even attempt to answer his questions. They seemed to perceive their own role as one of reproducing the notions and examples presented rather than one of producing new examples or applying the concepts. For instance, when asked about phenotype examples, they offered the same ones presented by the teacher. In Mr. Quiroga's case, the students expected the teacher to interact with them. They answered all the questions posed, sometimes with errors or advancing inadequate examples. The students did not exhibit apprehension in the expression of ideas even when those ideas were contradictory to their teacher's comments. When asked about examples, they knew that they were expected to produce new ones and to apply the concepts, as the teacher explicitly said, in a reflection reproduced above, and they attempted to do so.

The analysis of the development of the tasks in sessions 2, 3, 4, and 5 shows differences in the systems of norms in each classroom: Mr. Quiroga's students perceived their roles to include work in small groups, discussions of different pieces of evidence, and participation in debate. By contrast, for Mr. Val's students these types of tasks seemed not to be part of what they were expected to do, so they asked for clarification more times and required more guidance.

The Relevance of Different Didactical Contracts for SSI-Based Education

In this section we have examined how different the taught knowledge, the instructional approaches, and the didactical contracts can be in two classrooms working with the same teaching sequence and using the same textbook. The question now is: What is the relevance of these differences for SSI-based education? In particular: Are these differences significant for the goals of supporting students in (a) building arguments about the influence of environment in gene expression, and (b) the development of a critical stance toward biological determinism?

In order to answer it in full, it is necessary to analyze how students used the knowledge in making sense of the tasks, which is the focus of the next section. However, drawing from what has been discussed so far, we suggest that the differences have significance for teaching socio-scientific issues in three interrelated dimensions:

1. *Students' autonomy and empowerment*: Goals of SSI-based education include taking an active role to solve controversies, or developing an independent opinion.

As Tiberghien (2008) points out, when introducing SSI in the classroom, we are concerned both with scientific literacy and with citizenship education. In this sense, we interpret that the didactical contract created in Mr. Quiroga's classroom promoted development of students' autonomy to a higher degree. The students' expectations about their own role were to participate in the discourse, to advance their own opinions, and to express their ideas. Developing an opinion and the capacity to participate in society requires having the opportunity to make public positions, to discuss them with others, and to evaluate the evidence supporting them. The students in Mr. Val's classroom had few opportunities to do so.

2. *Students' construction of meanings about the topics discussed*: SSI have social relevance but are also scientific in nature. In order to criticize determinist views, students need to understand causal explanations about phenotypic traits, the influence of the environment in gene expression, and its implications for human performances. This may require conceptual change, modification or refinement of their previous ideas. For this purpose, it is necessary that students' ideas be elicited and that, when made public, the teacher takes them into account. In this dimension, Mr. Quiroga's approach was more aligned with strategies seeking to promote students' construction of their own meanings. He developed ideas suggested in students' answers and changed his discourse, when needed, to address them. In his classroom, work in small groups provided a context for developing and applying ideas. In Mr. Val's classroom the discourse was dominated by the teacher.
3. *Students' acknowledgment of the existence of two views with different social implications*: Working with SSI in the classroom involves, in many cases, supporting students in the acknowledgment of the existence of two positions on a dilemma, two different courses of action, and two views about one issue. In the case explored in this paper, biological determinism and gene-environment interaction are opposing views with divergent social implications. For students, it may not seem contradictory to learn that environment influences gene expression while retaining a view explaining all traits and performances as a consequence of genotype. We suggest that, in order to support this acknowledgement, the opposing views should be explicitly addressed in the classroom. In our case, this means talking explicitly about biological determinism. Only Mr. Quiroga did so.

In summary, we interpret that Mr. Quiroga's didactical contract was more adequate for the specific goals related to teaching about one issue with social implications.

Students' Construction of Explanations Acknowledging Gene-Environment Interaction

The third objective of our study was to examine difficulties students had with the construction of explanations acknowledging gene-environment interactions. We sought to document the meanings that students gave to phenotype and to the model of interaction taught in the sequence and the difficulties encountered in the application of this model to real life contexts. For this purpose, we examine here (a) students' difficulties evidenced during the introduction of the influence of environment on gene expression in the first session; (b) students' application of this knowledge to explanations about human performances, like athletics in task 2; (c) the written results of a retest administered 5 months after. We focus on the students of cases 2 (small groups 2F, 2G, 2H, 2I) taught by Mr. Val and 3 (small groups 3A, 3B, 3C, 3D, 3E) taught by Mr. Quiroga.

Discursive Moves and Obstacles in Gene-Environment Interactions in Session 1

The analysis of teacher-students interactions in the context of the introduction of the influence of environment on gene expression (episode 3 in session 1) showed quantitative and qualitative differences. In Mr. Val's case, the input from students was minimal: six turns of speech out of 17. In Mr. Quiroga's case, about half (36) of the 73 speech turns corresponded to the students.

In the case of Mr. Val's classroom, episode 3 can be divided into three teacher discursive moves following the pattern definition – explanation – application. First, he defined genotype emphasizing heritability and summarized the differences with phenotypes and provided an example (Drosophila). The second move, explanation, began with Mr. Val showing students two photographs of a well-known Spanish politician before and after a period of physical training and asked students whether his genes had changed. After they answered "no," he stated that *His genotype did not change, but his appearance, his phenotype, did change*. Mr. Val posed a second question: *Could the phenotype change without changes in the genotype?* This confirmation question was answered with a simple "yes," and the teacher extended the notion himself, explaining the influence of environment in the expression of genes and offered six examples, two of which are presented here: the lack of vitamin D as a causal mechanism for rickets, and the effects of temperature of incubation on the sex of crocodile hatchlings. In the third move, Mr. Val asked students about other cases of environmental influence, and four students provided examples including obesity and tanning.

Mr. Quiroga and his students engaged in an extended dialog, which can be divided into four discursive moves, which revealed students' difficulties, summarized in Fig. 12.3. The teacher began the first move, definition, by asking students about phenotype. One of the students suggested that phenotype is "what is manifested." Mr. Quiroga followed up with this idea and extended the discussion by asking students about differences between genotype and phenotype. A second student proposed eye color as an example of phenotype "because it is what comes out outside, in our physic." We interpret these statements (and others during task 2) as representative of understandings of genotype–phenotype relationships as making visible or external ("coming out outside") what is invisible and internal ("in the cells"). This is associated with a notion of the genes as entities whose expression is fixed, not modulated.

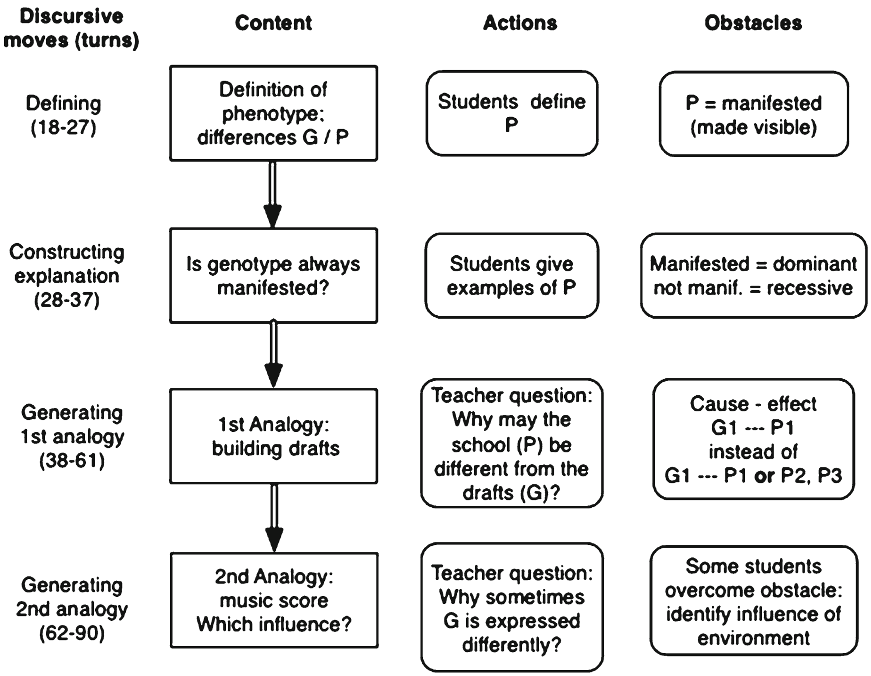

Fig. 12.3 Discursive moves and obstacles about the model of gene-environment interactions in Mr. Quiroga's classroom (*G* Genotype, *P* Phenotype)

The second move, intended to support construction of an explanation about environmental influences, began when the teacher asked if the genotype is always manifested or expressed in the phenotype. Although the students answered "no," their examples (eye color and recessive diseases) it was clear that the only mechanism they could postulate for the nonexpression of a gene was through a recessive allele. They framed the teacher's question in terms of dominant (expressed) versus recessive (not expressed) alleles. Although Mr. Quiroga clarified that the genotype would be constituted by both alleles, they continued giving this type of examples. We interpret that the students gave to "manifested" or "exhibited" the meaning of "dominant" because it corresponds to Mendelian genetics notions.

When Mr. Quiroga saw that the students did not understand his question, he began a third move, using his first analogy: the coincidence or lack of coincidence between the building drafts of a school and the actual school. He asked about possible reasons for the discrepancies, encouraging students to establish correspondence between source and target: *So, which one is genotype and which one phenotype?* He solicited examples from biology, to which students offered mutation, and again the presence of two alleles (blue and brown) in a genome. Extending

Fig. 12.4 Two models of causal correspondence between genotype (*G*) and phenotype (*P*)

his analogy, he said that in a building draft there could be a room painted brown over a previous blue color: *What I am saying is something that was in the draft but then is not coming out.* We interpret these difficulties to apply the concept of phenotype to a simple, straightforward causal correspondence where one cause produces one given outcome (1), as opposed to the notion of gene-environment interactions, which is more complex in that one causal factor may produce multiple outcomes (2) (see Fig. 12.4).

The awareness of these difficulties led to a fourth move, introduced by a metacognitive reflection by the teacher: *See, this is an instance about how you can clearly define a concept, but you don't understand it. Because until you are able to give me an example, it means that you have not internalized the concept. It is not the same to memorize it than to understand it.* Mr. Quiroga then presented a second analogy, a music score. He asked whether the sound would be the same if a music score was played by different people. This second analogy was more successful, and then he arrived at the episode's central question: *What is this (factor), which has influence and is not in the genes?* After the students answered "environment," Mr. Quiroga offered one example of how plants would not reach its regular height in inadequate conditions and asked students for other examples. Interestingly, the first suggested by Cristina was: *Someone who is prepared to be muscular, but for instance is born in an underdeveloped country.* Some turns of this episode were reproduced in the previous section.

From the analysis of this session, three interrelated problems emerged: (a) an understanding of a genotype being expressed as simply "coming out"; (b) a confusion between "expressed" and "dominant"; and (c) a simple causal correspondence, one cause – only one possible effect. Perhaps Mr. Val's students had similar problems, but there were not enough opportunities for them to become apparent. The analysis of the subsequent sessions, particularly when students were discussing the tasks in small groups, shed light on how in some cases the students overcame these problems, while in others the difficulties persisted.

Explanations About Human Performances in Task 2 "Athletics"

As discussed above, in the description of the teaching sequence, the "Athletics" task asked small groups of students to align eight different sets of information with one of three explanations for the achievements of black sprinters: (A) genes; (B) influence of factors as food or training; (C) a combination of A and B. After considering the information, students were asked to select one of the options. It was expected (a) that students would recognize some pieces of evidence as supporting the influence of genes, for instance the R allele of the ACTN3 gene in chromosome 11, related to fast twitch fibers; (b) that they would recognize other pieces as supporting the influence of environment, such as a table showing race and place of origin for recent medal winners. We distributed the explanations of the nine small groups (noting students with diverging positions) into three categories or stages in the acknowledgment of gene-environment interactions.

Category 1. Genes Are Solely Responsible for the Performances

Two groups, 2H and 2I did not progress beyond this stage in task 2. Group H2 was composed of five students. Although two of them, Hilario and Henrique, mentioned environmental influences at the beginning of the exchange, Hector and Hugo dominated the debate:

Hugo: Is this one [option A, genes], I believe, because it says that all of them [Olympic medalists] are blacks, but not all were born in the same country. They may be from the US, from England.
Hector: It doesn't matter, as they have the genes of blacks…
Hugo: Blacks are better than whites because it doesn't matter where they were born; they always will arrive first.
Hilario: I believe that being black does help, but it also depends on where do you train because it is not the same to train in Africa than in the US.
Hector: Training sometimes does not [influence], because it may be the case that Usain Bolt runs without training and he wins as well.
Researcher: And why it is so?
Hector: (…) It is because of the genes, Usain Bolt's genes.

Group 2I was composed of four students, with two of them, Iolanda and Irma, dominating the debate and the other two speaking very little. The idea of environmental influences was mentioned, but the group ultimately settled on the genes-only explanation.

Irma: It is A, the genes.
Iolanda: And they are all born in the region of… out of Africa, in the US.
Researcher: And, what does that mean for you?
Iolanda: That they are not from Africa!
Isabel: That… it has to do also with climate.

Iolanda: That it has nothing to do with climate! It has to do with genes!
Alba: Why are all of them black and why does not win a white?
Irma: Because they have it in their genes! And whites do have other genes!

Hugo and Iolanda interpreted the information of the table about Olympic medalists, not as a conspicuous absence of African-trained athletes (although the teacher highlighted this absence at the beginning of the task), but as evidence for the preeminence of genes over environment, “it doesn’t matter where they were born.” Hector in group 2H as well as Irma and Iolanda attributed the performances only to genes. We suggest that these problems are related to three issues: (a) to social representations about deep genetic differences between blacks and whites; (b) to a confirmation bias, in which individuals attend only to aspects of available information that supports a particular hypothesis; (c) to a greater difficulty in perceiving something missing (black sprinters from Africa) than something added (Jiménez-Aleixandre & Pereiro, 2002); (d) to difficulties in making sense of information presented, for instance, some students did not identify the country where an athlete was raised/trained as an environmental factor.

Category 2. Genes and Environment Influence Separately, but Genes are More Relevant

Two groups, 3A and 3C recognized that environment has an influence, but they treated genes and environment as separate factors with genes dominating over environment. One excerpt from group 3C, composed of five students, illustrates this type of explanation.

Roi: I think that it is A [genes]. Because a white may train too, whites eat too, man. Then it has to be because of genes […]
Bernal: But on this ground [the information], then, I don’t know…
Roi: It means that on equal terms, blacks are better.
Rosendo: I think that it is A because on equal terms black people are very superior to white people, and this is due to their genes, because food and environment could be made equal both for blacks and whites, so the only remaining difference would be the genes.
Bernal: Yes, I agree.
Roi: It has to do with genes.
Cristina: And, how do you know that the food is the same?
Roi: Look, if they are going to compete, they would strive to eat as best as they can.

It seems that for these students environmental circumstances, food or training, may be modulated, modified, and “made equal.” On the other hand they neither accept a modulation in gene expression, nor the existence of unequal environmental circumstances that may modify performances. For them genes and environment seem to have different status.

Category 3. Combined Influence of Genes and Environment

Five groups, 3B, 3D, 3E, 2F, and 2G, acknowledged the combined influence of genes and environment in their explanation, although they arrived at this conclusion through different processes. Groups 3B and 3E derived their explanation from data while groups 3D, 2F, and 2G chose an explanation before discussing the significance of each piece of information. This is demonstrated in the excerpt below from group 3E:

Roman: It has to be both [genes and environment], because here [Olympic medalists] it talks about their nations, US, US, Jamaica… And that is environment! Because of the place where they are raised. Besides, it is also genetics, because their skin color is black, black, black. And they are all trained in English-speaking countries, except the Jamaican one and that is environment.

Ernesto: I believe that it is both. Yes, because even if you are very good, you need to eat and to train.

Estrela: Besides, they all are in locations where everybody can work and to develop that…

Rexina: Look, I think that it is [option] C.

In this group, students accept the role of genes, and they also identify the relevance of the environment particularly in terms of diet and training, using the data from the table as evidence to support their choice.

In summary, not all small groups progressed to the stage of acknowledging the influences of both genes and environment in their explanations. In two groups, both from Mr. Val's class, the predominant discourse was an attribution to genetics as the only determinant on athletic performance. Two other groups, from Mr. Quiroga's, class recognized the role of environment, but saw it as subordinate to genes. Five groups, three taught by Mr. Quiroga, and two by Mr. Val, arrived at a combined explanation, although they did not express it in terms of interaction. The small number of groups prevents any generalization; however, the fact that both groups that selected the gene-only explanation came from the same class may support a link between this outcome and the teaching approach. In this class, students had few opportunities to develop their ideas and there was no explicit discussion of determinist views.

The analysis of the oral discussions about task 3, "Watson" which asked students to evaluate a claim about differences in intelligence among races showed that almost all groups maintained positions coherent with their explanations in task 2. All explanations and student statements acknowledged the role of environment in intelligence, except those from group 2H, which claimed that intelligence depended only on genotype. When asked to justify that claim, Henrique said, "You are born with a capacity," and Helena added "You may do as much as you can, but you cannot develop it more than what you have." It seems that Henrique changed her position, which, in task 2, acknowledged the influence of environment. This may be related to the group leadership by Hugo and Hector who strongly supported the genetics-only option.

Table 12.6 Categories in the answer to the retest

Categories	Case 2 ($N=15$)	Case 3 ($N=31$)
3. Gene-environment interaction	1	3
2. Influence of environment	14	27
1. Genes only	–	1

Written Results of a Retlest

Five months after the completion of the unit, at the end of the school term, a question about identical twins raised in different countries was included in a final written test. The item asked whether at 16 both twins would have similar or different height and muscles and would develop similar or different reading and mathematical skills (see Table 12.6).

All students but one in both classes acknowledged the influence of environment in physical traits, as well as in intellectual achievements. However, only four of them integrated both genotype and environment in their responses, for instance:

> Braulio (3D): No [it would not be the same], because departing from the same genotype it would not be equally developed in favorable conditions than in precarious circumstances. They would not be identical because their phenotype is different; in B [raised in a developed nation] it could be developed optimally and in A [raised in an underdeveloped nation] would be limited.

The majority of students acknowledged the influence of environment, but did not mention genes or genotype. We interpret that they took for granted the role of genes, as the question was about identical twins. There was only one student, Camilo (3A), who had supported in all the tasks the notion that only genotype mattered, and continued supporting it:

> Camilo: The physical traits would be the same for A and B, because environmental conditions cannot alter their genes.

In summary, it seems that all students but one took into account environment in their explanations. This may suggest that the teaching sequence was successful in both classes in overcoming initial explanations that in some cases were close to determinism. However, we also need to consider that the academic context, a final examination, may prompt some students to give the answer that they believed that the teacher expected.

Discussion and Implications

Most topics in genetics are difficult for students, but some of them have received greater attention in the literature. Our work seeks to add to this knowledge about genetics teaching and learning an examination of the challenges posed by the model of gene expression, in particular, the interactions between genotype and environment, resulting in the phenotype traits. This model has social implications as biological determinism ignores environmental influences presenting human traits and performances as solely determined by genes, a view lending support to political agendas that challenge notions of equity.

This chapter presents a developmental study in five classrooms, framed in Chevallard's (1991) notion of didactical transposition, or transformation from reference to taught knowledge. First we discussed the process of transformation of the reference knowledge, including genetics and scientific practices, into the knowledge to be taught. This transformation draws from goals related to science and to citizenship education, and from an analysis of textbooks, revealing little attention to the application of the model. Second, we analyzed how this designed sequence was transformed in two different types of taught knowledge in two classrooms. Third, we examined the process of construction by students of explanations taking into account gene-environment interaction.

The analysis of the taught knowledge is characterized through the notion of didactical contract (Brousseau, 1998), students' expectations about the teacher and teacher's expectations about the students. The examination of several dimensions, collapsed in content knowledge and communicative approach, showed substantial differences between the didactical contracts in both classrooms. In the case of Mr. Val's class, students expected the teacher to be in charge and lecture, and they perceived their own role as one of reproduction. The students requested more guidance when they were required to engage in modeling and using evidence because they usually were not expected to collaborate in group work. The expectations of the teacher seemed to be that the students would listen to him and respond "yes" or "no" to his questions. On the other hand, he is a good professional, holding students' attention all the time, and providing a structured explanation.

The case of Mr. Quiroga was different, both in content knowledge, as he was guiding the concept development trough interactions and in the communicative approach which was more dialogic and interactive than Mr. Val. A relevant dimension is how he took into account students' answers, changing his discourse in reaction to students' problems with the notion of phenotype. He expected students to participate and the students' expectations were to be engaged in all the textualization moves: they defined concepts, explained their meaning, and tried to apply them, although not without difficulties. They seemed to feel comfortable openly expressing ideas even when those ideas contradicted the teacher because there were no negative academic consequences when they said something wrong.

An important question is the relevance of the two different teaching approaches for the goals of SSI-based education. We suggest that didactical contracts like the one Mr. Quiroga created in his classroom may support (a) students' autonomy and the development of independent opinions; (b) students' acknowledgment of the existence of two views with different social implications; and (c) the construction of appropriate meanings for the conceptual topic underlying the SSI. While the two first dimensions are common to all or most SSI, our topic, biological determinism, may be different in requiring mastering the model of gene expression. However, we believe that most SSI also require a deep understanding of the concepts involved and, for this purpose, engaging students in active participation is an important feature of teaching.

The analysis of discourse in both classrooms enabled identification of student difficulties. These difficulties included meaning construction for phenotype and application of this concept to real life contexts. The discursive moves used by Mr. Quiroga and his students illustrated both the students' difficulties for constructing appropriate meaning about one notion (that genotype can be sometimes expressed in different ways due to environmental factors) and the changes introduced by the teacher in his discourse for overcoming them. We interpret that these difficulties, and the students' confusion between "not manifested genotype" and "recessive alleles," are related to the fact that the linear causal correspondence, G1–P1, is more intuitive than the idea of a complex correspondence where one genotype may yield several potential phenotypes, G1– P1 or P2, or… Pn. This may be related to epistemological assumptions about causal mechanisms and to difficulties in accepting uncertainty. The findings suggest that this complex question needs to be taught through application in different settings and that a simple lecture is not sufficient.

These epistemological assumptions may be the reason why the first analogy (building drafts) was not successful, as usually there is only one building corresponding to one draft. The second analogy, music score, helped students to understand and apply the notion, probably because they saw that a score could be played differently by different people. This may suggest features for successful analogies when teaching this issue.

The analysis of small group discussions during completion of tasks revealed variance in the application of the notion of interplay among genes and environment to a real context. Five groups acknowledged that both genes and environment had an influence on performances, but for two other groups genes would dominate over environmental influence. The remaining two groups (as well as some individual students, disagreeing with their group) accepted only the effect of genes, a position that closely approximates biological determinism. We suggest that these difficulties may be related to social representations that assume deep genetic differences between blacks and whites, as well as to a high status of genetics in the social imagery. Genetics is equated to "scientific"; therefore, the influence of genes is not to be doubted.

The initial design of the teaching sequence contained more time and tasks related to the use of evidence. It is a complex scientific practice that scarcely could be developed in a few sessions. The students' difficulties with the Athletics task points to the need to devote more sessions to engage students in selecting and using evidence. Educational authorities, in Spain and elsewhere, need to be aware that introducing recommendations about argumentation and use of evidence in the curriculum is not enough when teachers have too much content to be covered.

A final remark concerns the potential utility of didactical transposition and didactical contract to frame analysis of teaching sequences and teachers' actions. It is important to make public the goals and decisions underlying particular tasks and activities. To reflect about how reference knowledge is transformed in a teaching sequence may help teachers to decide which issues need more time and emphasis. An instance could be the scientific practices of modeling and using evidence, which make part of the reference knowledge in this sequence. Didactical contracts conceive educational actions as essentially communicative, and in this sense are aligned with current attention to communication in the classrooms and to the development of the scientific practice of knowledge communication.

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