Contributions from Science Education Research 2

Nicos Papadouris
Angela Hadjigeorgiou
Constantinos P. Constantinou *Editors*

Insights from Research in Science Teaching and Learning

Selected Papers from the ESERA 2013 Conference

Springer

Contributions from Science Education Research

Volume 2

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Foreword

I was delighted when I received a request to write a brief foreword for this volume, which brings together 18 selected, peer-reviewed contributions to the 10th European Science Education Research Association (ESERA) Conference which was held in Nicosia, Cyprus, in 2013. This is the second book in a series entitled *Contributions from Science Education Research*, published by Springer.

The biennial ESERA Conference since its inception in 1995 has become an important event in the field of science education. The Nicosia ESERA Conference 2013 was a successful and memorable event, with interesting presentations from researchers from all over the world, fruitful conversations among colleagues, and unforgettable moments.

The set of papers included in the book addresses a range of important topics within science education. Among others, they reflect on different approaches to enhancing our knowledge of learning processes and the role of context, designed or circumstantial, formal or nonformal, in learning and instruction. Looking through this magnificent volume, I would like to congratulate the editors, Nicos Papadouris, Angela Hadjigeorgiou, and Constantinos P. Constantinou, but also the group of reviewers, who have collaborated to put this collection of papers together.

Manuela Welzel-Breuer
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Part I
Overview of the Book

Chapter 1
Introduction

Angela Hadjigeorgiou, Nicos Papadouris, and Constantinos P. Constantinou

1.1 Context of the Book: The ESERA 2013 Conference

The European Science Education Research Association (ESERA) is an international organisation of researchers and science educators, which aims at (a) enhancing the range and quality of research and research training in science education, (b) sustaining a forum for collaboration in science education research, (c) representing the professional interests of science education researchers, (d) identifying and elaborating connections between research and policy or practice in science teaching and (e) fostering links between science education researchers in Europe and similar communities elsewhere in the world. The biennial ESERA conference is the main forum for direct scientific discourse within the community and for the exchange of insightful practices.

This book is the second volume in the Contributions from Science Education Research series, published by Springer in partnership with the European Science Education Research Association (ESERA). This volume comprises a selection of papers presented in the 10th ESERA Conference, which was held in Nicosia, Cyprus. It consists of 18 representative, high-quality contributions chosen out of the proposals that were presented in the conference, either in the form of oral presentations, papers in symposia or posters. Overall, these proposals were organised into a total of 16 different strands that covered the diverse research areas within science education. In addition to the contributed proposals, the conference also hosted four invited, plenary talks given by prominent scientists in the field.

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1.2 Overview of the Procedure for the Selection of the Papers

1.2.1 Preliminary Selection

After the conference, each strand chair was asked to propose two papers from his/her strand, which he/she deemed most appropriate for inclusion in this book. They were informed that the book would include selected papers that are innovative in either, the issues they explore, the methods they use or the ways in which emergent knowledge in the field is represented, and they were asked to identify the papers that were more likely to fit this description. The various recommendations were collected and processed to narrow down the list so that it included no more than three proposals from each different strand. In doing so, we also took into account, and weighed, the variability in the number of proposals in each strand. We then extended to the authors of the selected proposals a formal invitation to submit a paper to be considered for publication in the book. As a result of this process, we received a total of 22 submissions.

1.2.2 Final Selection

The submitted papers were subjected to blind, external review by scholars within the Science Education community, who accepted to voluntarily contribute to the preparation of the book by undertaking this task. Each paper was evaluated by at least two reviewers. All papers went through at least one round of review, whereas most were also subjected to a second round. As a result of this process, we ended up with 18 papers which achieved eventual acceptance status and were therefore included in this book.

1.3 Structure of the Book

The 18 papers, which include both empirical and theoretical contributions, have been organised under five parts, each reflecting a different thematic category. Each paper appears as a separate chapter under one of these parts. Next, we briefly present these parts and the chapters included in each.

1.3.1 Science Teaching Processes

This part includes five chapters. The study reported in the first chapter, by Tiberghien, presents and discusses concepts that could help researchers characterise a class as a group. It presents examples of how to use the notions of didactic contract and milieu, to analyse two classroom situations in the context of a teaching sequence in mechanics, at grade 10. The author also introduces the concepts of identity and normative identity as a means to characterise the class in the framework of socio-cultural theories. The author discusses how this analysis of concepts drawn from different theoretical frameworks strives, on the one hand, to promote a better understanding between researchers in our international community and, on the other hand, to offer insights into classroom practices that could inform the design of resources for teacher education and science teaching.

The second chapter by Schreiber, Theyßen and Schecker sets out to compare (a) a process-oriented approach to the assessment of experimental skills, based on videos of students' actions in a hands-on test and their lab sheets, with (b) a product-oriented approach that solely focuses on the lab sheets. Data analysis revealed high correlations between the outcome of the two approaches on certain aspects but yielded low correlations on others. The authors discuss the implications that stem from these findings.

Bungum, Esjeholm and Lysne, in chapter three, report on a video study of three design and technology (D&T) projects, conducted in different schools in North Norway. It reveals that disciplinary knowledge of mathematics and science did not appear prominently in student projects, even though they had been explicitly designed to illustrate these connections. The authors offer evidence-based interpretations for students' tendency to avoid drawing on disciplinary knowledge and discuss the ensuing implications.

The next chapter, by Rollnick and Mavhunga, investigates the possible transferability of the principles of topic-specific PCK (TSPCK) across science topics. The authors report results from an empirical study aiming to explore the extent to which the principles of pedagogical reasoning about one topic can be transferable to other topics as well.

The last chapter of the first part, by Jones and her colleagues, investigates the efficacy of a real-time, interactive, visuohaptic simulation to teach students particulate motion and the concepts of thermal energy, pressure and random motion. It involved 78 middle school students who investigated particle motion using either the visuohaptic or a visual simulation (control group). Even though the results showed that there were no significant differences in post scores between the students in the two groups, students in the visuohaptic group reported that the investigation was highly interesting and enabled them to better understand particle motion as well as visualise movement. The authors offer a discussion of the role of haptic instructional technologies as tools to teach micro- and human-scale phenomena.

1.3.2 Conceptual Understanding

This part comprises two chapters. The first, by Guisasola and his colleagues, summarises the key ideas discussed in a symposium organised by the Groupe International de Recherche sur l'Enseignment de la Physique (GIREP), on content-focused research and research-based instruction. The chapter reports a synthesis of results from studies in physics education, carried out in different countries, including Belgium, Germany, Italy, Spain and the United States. It also conveys a sense of the variability in terms of research questions, methods, interpretative frameworks and the role of specific research findings in driving educational innovation.

Callinan, in the last chapter of this part, reports on a study, which explored the gestures used by children during discussions of their ideas about electricity. This chapter discusses how gestures can be categorised according to content and how content of gestures can reveal elements of knowledge that is not verbalised in speech.

1.3.3 Reasoning Strategies in Science Learning

This part consists of four chapters. Fotou and Abrahams, in the first chapter, present a cross-age study, involving 41 participants, which was designed to investigate students' predictions in novel situations and the role that analogies play in their reasoning. The findings of the study suggest that teachers need to be more aware of the nature of the analogies used and how, and why, reasoning on the basis of such analogies can, in many cases, lead students to make incorrect predictions.

The second chapter, by Redfors, Hansson, Hansson and Juter, presents a framework for analysing the role of mathematics during physics lessons in upper secondary school. It departs from the premise that the connections made during physics lessons between *Reality*, *Theoretical models* and *Mathematics* are of paramount importance. The framework was developed to analyse the communication during physics lessons. The authors describe this framework and demonstrate its use in the context of selected results from a physics class. The chapter also shows how students' and teachers' usages of links between the three entities, i.e. *Reality*, *Theoretical models* and *Mathematics*, can be brought to the forefront in an analysis of complex physics teaching situations.

The next chapter, by Zoller, focuses on assessing college science students' problem-solving capability in the context of "traditional" chemistry teaching. It reports on a case study that explores the extent to which contemporary/traditional university/college chemistry teaching contributes to the development of students' problem-solving capability and views concerning higher-order cognitive skills (HOCS)-type questions. The chapter offers insights into what can be learned from students' responses to HOCS-requiring problems that can be used for promoting both their generic and disciplinary problem-solving capabilities.

The next chapter, contributed by van Lacum, Koeneman, Ossevoort and Goedhart, elaborates a novel model, the Scientific Argumentation Model (SAM), for analysing original scientific articles. This model draws on ideas from argumentation theory and genre analysis and seeks to support students in acquiring the ability to productively and meaningfully engage with the process of reading original science texts. The authors also report preliminary results on the validation of this model.

1.3.4 Early Years Science Education

This part contains two chapters. The first, by Russell and McGuigan, reports on an iterative design- based research approach used to inform instructional design sequences in early years science. The main thrust of this approach involved the postulation of developmental trajectories through which children move incrementally across the age range 36–84 months. In this chapter, the authors report on how the addition of a programme of qualitative research with early years practitioners allowed them to collaborate to describe hypothesised developmental sequences, relating to conceptual development, enquiry skills and science as discourse.

The second chapter, by Stylianidou, Glauert, Rossis and Havu-Nuutinen, reports results from the European, FP7 project *Creative Little Scientists*, which concentrates on the synergies between early years science and mathematics education and the development of children's creativity. The authors discuss how the findings across the varied contexts in partner countries indicate potential for enquiry and creativity but also suggest a number of areas for policy development in early years teacher education.

1.3.5 Affective and Social Aspects of Science Teaching/Learning

This last part includes five chapters. In the first of these chapters, Kudenko and Gras-Velázquez examine secondary pupils' views on different aspects of learning STEM subjects and on STEM careers. The areas covered in the study include pupils' interest in science and technology, their views on school teaching of STEM subjects, social attitudes to the STEM sector as well as pupils' inclinations towards STEM-related careers. Findings suggest that when information about the modern state of STEM jobs and real-life applications is blended in STEM education in a meaningful way for young people, it can trigger important changes in career choices.

The next chapter, by Le Hebel, Montpied and Tiberghien, explores the answering strategies adopted by low achievers while solving PISA items. They report on an empirical study with video data, aiming to analyse the mental and behavioural processes in which students engage for solving PISA items. The authors discuss the facility of PISA items to accurately assess the competences of low achievers.

Adesokan and Reiners, in the next chapter, investigate what specific learning difficulties and special needs students in chemistry may have and what teaching concepts can be used in an inclusive setting. The aim of their project is to develop a teaching material on the topic of scientific reasoning and working, which is adapted for the needs of deaf and hard-of-hearing (DHH) students. The authors discuss implications for the development of inclusive chemistry education.

The fourth chapter, by Walper, Pollmeier, Lange, Kleickmann and Möller, seeks to track German students over the key period of ages 10–14, in order to longitudinally describe the changes in physics-related instruction from the students' perspective as well as the changes in their physics-related interests. They report results from a cross-age study, which confirm that the students' physics-related interest dropped after transition from primary to secondary school and indicate that students perceived significant declines in various aspects of the quality of physics-related instruction when they entered secondary school.

Finally, the last chapter of this part, but also of the book, by Kollas and Halkia, reports on a study situated in the context of *Second Chance Schools*. These are intended to promote the reintegration of adult school dropouts who have not completed their compulsory education, into society. The study sets out to investigate Greek science teachers' views about the meaning of the notion of students' scientific literacy and focuses on science teachers' practices when developing a curriculum to achieve the goal of reintegrating second chance schools' students. The data reported suggest that the ability to design scientific literacy curricula, which meet their students' needs, is not related only to their teaching experience. Rather it requires the science teachers' enculturation into their students' worlds and a paradigm shift in science teachers' own ideology of science teaching.

Part II
Science Teaching Processes

Chapter 2
How Does Knowledge Live in a Classroom?

Andrée Tiberghien

2.1 Introduction

The title of this chapter, emphasising knowledge and the classroom instead of students and the teacher, or learning and teaching, may seem surprising. This focus highlights the social goal of schooling, learning what is involved in the curriculum (knowledge, value). Here knowledge takes a larger meaning; it does not only include conceptual knowledge but also skills, competences, etc.

This chapter will present and discuss concepts that help researchers to *characterise a class as a group*. We present first the Joint Action Theory in Didactics (JATD) (Sensevy 2011) which derives from previous theories, developed in France, called "theory of didactic situations" (Brousseau 1997) and "anthropological theory of the didactic" (Chevallard and Sensevy 2014) with two conceptual elements characterising classroom practices, the didactic contract and the milieu. Then we illustrate the use of these concepts to analyse two physics classrooms and characterise them. In order to develop a better understanding of these didactics theories and other theories much more known and shared in the science education community, we discuss this approach with regard to the concepts of model of identity and normative identity developed in the framework of social practice and sociocultural theories in science and mathematics education.

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2.2 Point of View on Knowledge

Knowledge is associated with human actions like producing, using, teaching and learning which always involve a communicative process. Moreover, knowledge is specified by words like everyday, scientific, curriculum and also classroom to indicate the type of knowledge. In fact, these words give the place where the knowledge "lives", more specifically the community of practices or the institution. It means that people shape knowledge, organise it and give specific meaning depending on the group they belong to.

The metaphor of "life of knowledge", introduced by Chevallard (1991), is well expressed by Edward and Mercer in their book (1987) concerning the way knowledge is shaped in a classroom:

> Knowledge is presented, received, shared, controlled, negotiated, understood and misunderstood by teachers and children in the classroom. (ibid, introduction)

This implies that the *life of knowledge is specific to the group in which it lives*. Each group or community of practice shares knowledge in a specific way and constructs specific meanings. However, at the same time, each community shares a greater or lesser part of their knowledge with other groups. Let us take examples of two types of knowledge. In the case of scientific knowledge, members of the same research unit share specific experiences, practices and ways of discussing and thus construct specific components of knowledge. Visiting a research unit is an enriching experience for a researcher; it is a way of developing his/her knowledge by acquiring a part of the specific knowledge of the group. Similarly, each classroom has its own characteristics and develops some part of specific knowledge, and at the same time, these groups can share knowledge with other groups.

Scientific knowledge is particularly standardised, as underlined by Luke (2011):

> Modern science is predicated upon the establishment of *uniform systems* of measurement, common technical nomenclature, and replicable procedures. (p. 370)

The International System of Units has been established for a rather long time. The first attempts for length and volumes started in the middle of the seventeenth century and the creation of a coherent system of units by an international organisation (General Conference on, International Committee for, International Bureau of Weights and Measures) in 1875. The standardisation of scientific knowledge may sometimes lead us to forget that it is associated with groups of people and that its meaning depends on them.

The standardisation of curriculum knowledge is currently increasing. International evaluation like TIMSS and PISA and intergovernmental organisations like the European Union contribute to sharing some common orientations for school curriculum. In the case of science education, the emphases on inquiry and competences – even if the meaning of such ideas is not always the same – are largely shared in many countries.

Thus, knowledge is associated with groups; parts of knowledge are largely shared, whereas each group constructs and shares specific parts of knowledge. This is the case for the classroom. How each class constructs and develops knowledge is determinantal to relating teacher practices and students' learning. That is the focus of this chapter.

2.3 Joint Action Theory in Didactics (JATD)

In the joint action theories, human action is thought of as a *joint action*; in the case of didactics, teaching and learning are two joint actions. In JATD, following Bourdieu on one hand (e.g. 1987) and Wittgenstein and Anscombe (1997) on the other hand (language game), the game is considered as a relevant model to bring out certain aspects of the social world of human activity; it reflects the logic of the practice (Sensevy 2007). A game is defined by what is at stake and the rules to carry it out. Two main concepts define the game: the didactic contract and the milieu. The *contract* is defined as the strategic systems used by the teacher and the students to play the game. The *milieu* consists of the elements of the material and communicational situation that allow the players to construct or modify a new strategic system.

Let us note that these two concepts first emerged in the 1970s in the theory of didactic situations (Brousseau 1997) and have more recently been developed in the JATD.

The strategic system to play the game includes the reciprocal expectations between the student and the teacher. Some of the components of this system are generic and will be lasting such as, for example, the habit of working in small groups; the fact that during classroom discussion an idea is taken into consideration if it is supported by an argument, whether it is correct or not from a physics perspective; others are specific to current elements of knowledge and need to be redefined with the introduction of new elements. For example, when students have to construct the notion of objects in physics which differ from the everyday meaning, since in physics a small piece of paper and the planet Earth are objects modelled the same way in basic mechanics (mass and position), the idea of objects evolves in the classroom (Tiberghien and Malkoun 2009). Gradually, it begins to belong to the class's common knowledge and to acquire a status of certainty (Tiberghien et al. 2014). When later on the students work with diverse objects and it is no longer necessary to discuss that all objects are modelled in the same way, we can say that the didactic contract has evolved for this element of knowledge. When the notion of object belongs to the common knowledge of the class, then it becomes a generic element of the contract, whereas during its construction by the students, this knowledge was a part of the contract that evolves: it is specific to a period of time and to some elements of knowledge.

The milieu is associated with the notion of affordance. The potential milieu includes all aspects of the environment, in particular the institutional one, the "state of affairs" and the material world. The effective milieu is what the teacher and/or the students really take into account in their strategy, while what is available is the "potential milieu": thus, the milieu can be different for the teacher and a student.

The didactic contract, which is strongly related to the milieu, allows us to make sense of the teacher's and students' actions. Their strategies to select and use elements of their environment are directly linked to the meaning construction. In the following section, we present two phenomena already well identified in the framework of the theory of didactic situations (Brousseau 1997). These phenomena characterise types of didactic contract where a teacher negotiates knowledge in a specific way.

2.3.1 Two Phenomena Historically Associated with the Didactic Contract: The Topaze and Jourdain Effects

Brousseau developed his theory not only on the basis of general theories of epistemology, sociology and psychology but also in very close relation to empirical studies. Brousseau and his colleagues collaborated with teachers in a primary school associated with didactic research. This work on the didactic contract started around 1978 with a first publication in 1983. At this period, classroom videos were already recorded as data of research studies. We briefly present these two phenomena that show how the meaning of the classroom knowledge depends on the strategic systems of the teacher and the students.

2.3.1.1 The Topaze Effect (Pagnol's Play: Topaze)

The paradigmatic situation of this phenomena is the following: at primary school during a dictation, the teacher dictates *les moutons* (*the sheep* with an "s" in the plural), and the students do not write the "s" to indicate the plural (in French the s is not pronounced); then the teacher says *les moutonSSES* (Brousseau 1983). With this transformation, the teacher intends to bring success to the students. This transformation changes the meaning of the knowledge involved; the teacher *transforms a spelling problem into a phonetic problem.*

In this paradigmatic situation, *the teacher's intention is no longer the students' understanding but the students' success*. The teacher modifies the milieu by modifying the pronunciation; the sounds are different, and the students' task is to adopt a phonetic spelling. This case emphasises that a main component of teacher activity consists of transforming or adapting knowledge to help students to develop understanding and/or students' success.

2.3.1.2 The Jourdain Effect (From Molière's Play: Le Bourgeois gentilhomme)

Monsieur Jourdain's philosophy teacher tells him that when we speak, we can only do it in verse or prose. Thus, Monsieur Jourdain recognises that he uses prose and that he knows what prose means, whereas prose has a meaning which is not acquired by him. This effect can easily be found in the classroom. For example, when a student makes a force diagram of a motionless object with two force vectors equal and opposite, the teacher can tell him that it is very good and let him believe that he knows the principle of inertia. However, the student's interpretation is very likely motivated by everyday knowledge or simple causality (motionless then no force, motion then force). To understand a physics principle, one needs to be aware of its status and generality, which is not easy to acquire. This can have consequences in the classroom development of knowledge, if after that the teacher proceeds as if the students knew this principle while this is not the case, then the expectations of the teacher and the students will not match at all. This gap can create difficulties in students' learning. The milieu designed by the teacher will be no longer adapted to the students as it will not offer relevant affordances. In this Jourdain effect, the teacher, in order to avoid a debate on knowledge with students or to avoid acknowledging a failure in the students' learning, recognises science knowledge in the students' productions, whereas these productions are, for example, everyday knowledge.

2.4 Examples of Classroom Practices Analysis in Terms of Contract and Milieu

We present a comparison between two classes at grade 10 in mechanics (Malkoun 2007). To illustrate it, we analyse the introductory part on dynamics after kinematics teaching. The two teachers are experienced. Teacher 1 (class 1) follows a teaching sequence designed by a group of teachers and researchers (Tiberghien et al. 2009), whereas teacher 2 (class 2) follows his own sequence; both sequences are consistent with the official curriculum. These classes were analysed during all the teaching sessions on dynamics (respectively, 7 sessions with class 1 and 6 with class 2). Our interpretations are based on the whole analysis.

This introductory part on dynamics has about the same duration in the two classes, between 18 and 20 min. Table 2.1 gives the structure in games for this part in each class.

2.4.1 Class 1 Analysis

During this introductory part, the classroom organisation changes; first, it operates as a whole class, then in small groups, and again as a whole class.

This part deals with the introduction of the notion of action. It lasts for about 20 min. Our analysis at the mesoscopic level (about 10 min) leads to structuring it into three games (Table 2.1).

Table 2.1 Structure in games of the introductory parts of dynamics in two classes (in *parentheses* the social organisation of the classroom followed by the duration of the game)

Class 1	Class 2
Game 1. (Whole class) time length: 0:05:10	*Game 1. (Whole class) time length: 0:01:29*
Introducing the notion of action and preparing to carry out the associated activity	Becoming aware of the purpose of the work: introduction of the effects of force and of two experiments: throwing the sponge and the balloon
Game 2. (Small groups) time length: 0:08:31	*Game 2. (Whole class) time length: 0:01:13*
Carrying out the activity on the introduction of action	Describing what happens when you hit the balloon
Game 3. (Whole class) time length: 0:05:30	*Game 3. (Whole class) time length: 0:04:23*
Reviewing/discussing the interpretations of the studied situation (stone-elastic band) and institutionalising the notion of action	Interpreting in terms of force what happens when you hit the balloon
	Game 4. (Whole class) time length: 0:04:35
	Carrying out and interpreting the fall of a steel ball on an inclined plane
	Game 5. (Whole class) time length: 0:06:44
	Review of interpretations and institutionalisation

Game 1 begins with the teacher's introduction of the notion of action and the associated activity. This introduction illustrates the implicit use of the generic rules of the didactic contract by the teacher and the students (in the following the transcripts include punctuation in order to make them easy to read):

T So we have finished the first chapter, and you have noticed we have established a number of tools and vocabulary, circular motion, uniform motion, rectilinear motion, what is a trajectory, what is a referential, […] and now we are going to part 2, **so as usual** you take a sheet (*T hands out the text of the activity*) (*a few students ask the teacher where to stick the paper*)

[…]

you will work in groups of 4, you have in front of you a stand on which you will attach a piece of elastic, a stone is attached to the elastic […] (*the teacher reads the activity statement and asks some questions*)

The teacher indicates the number of students by group but leaves implicit the ways of working in groups, of using the assignment and of answering the questions, by saying "as usual". The rapidity with which the students start working in groups confirms that these implicit rules are shared in the classroom.

Game 2. At the beginning of this game, the students work in small groups, with the text of the activity (Fig. 2.1) and the device. They play the game of constructing interpretations of the situation during the discussions. This is confirmed by the videotaped group and by the students' questions when the teacher intervenes in their group (the teacher discusses with 7 groups out of 15). The students' difficulties foreseen by the designers of the teaching sequence occurred in most of the groups. All the groups that interacted with the teacher recognised that gravity and/or weight could act on the stone but that they are not "objects" (material) and cannot be

You have at your disposal: a stand, a piece of elastic, a stone. The stone is hanging from a piece of elastic. It is motionless.
Questions
a) What are the objects which act on the stone?
b) On what objects does the stone act?

Fig. 2.1 Text of the activity given to the students together with the device

considered as the answer. Most of the time, the teacher's help consisted in asking with what object gravity is associated, for example (T is teacher, S1, S3, S4 are students):

1. T But is there only the elastic that acts on the stone?
2. S4 As an object, yes
3. S2 As an object, yes
4. T As an object, yes, because there are other things than objects that act?
5. S1 There is gravity
6. T Ah, and gravity – what is it?
7. S3 Ah, the force acting
8. T Is it a force? What is a force?
9. S1 Something which is not an object and which acts on
10. T Ah, ah, this is something which, and *bah* in fact in physics what it acts on are the objects, then this something that acts and that you call gravity, gravity is the result of the action of which object?
11. S1 Of the Earth
12. P Thus, what is the other object?
13. S3 Earth
14. P There you are

The next example also illustrates that students deal with the knowledge involved in the task, working on the construction of an understanding (C and M are the students video recorded)

1. C (*reads text*) (on which objects) the stone acts ah yes, think, the stand because it holds the elastic if you move it it's (*C touches the stand*) going to move because it means that the weight of the stone acts on the elastic which acts itself on the stand
2. M Hm hm
3. C So, obviously, there is the stand
4. M Yes, but it does not act directly; you understand what I mean?

In *game 3*, the organisation is as a whole class. There is a discussion/review of most of the ideas involved in the small group work. The teacher emphasises the necessity of giving argument to back up a statement. In the discussion/review, this type of request explicitly appears twice in a short period of time (about 5 min). In the last case, the teacher asked (M and N are for students):

5. T Is there another object other objects that act on the stone MIC [name of a student]?
6. M Er, the Earth
7. P The Earth, indeed what allows us to say that?
8. N Er, because if you cut the elastic, the stone falls

In this extract, the teacher is not satisfied by a direct answer, she asks for reasons. More generally, the necessity of giving arguments belongs to the generic part of the didactic contract in this classroom, and it is regularly recalled.

These examples illustrate the milieu and the didactic contract involved in this introductory part. The milieu offers different affordances for the development of knowledge. In particular, the text of the activity, the device and the work in small group allow students to develop their understanding of the task and come up against understanding difficulties. Moreover, there is continuity in knowledge development between small group and whole class work to the extent that most of the understanding difficulties which appeared in the small groups are introduced in the whole class discussion. At the end of game 3, the teacher's institutionalisation officialises elements of knowledge as physics knowledge.

In the didactic contract, the teacher expects the students to take responsibility for developing ideas relevant to the activity even if they are not correct from the physics point of view. The choice of this task, where the students can develop ideas that are not correct but relevant for a future discussion, is coherent with a review/discussion at classroom level. In other terms, *the status of knowledge is such that, at a certain step of its construction, it can be wrong, but proposals should be supported by arguments and should be debated. The* teacher's *institutionalisation constitutes a step in the classroom knowledge development*; elements of physics knowledge are officialised and serve as a reference in the classroom later on.

In this classroom, illustrated by the analysis of the introductory part:

- The students' strategic system of developing ideas *corresponds to the teacher's expectation.*
- There is a *continuity between the small group work and* the whole class discussion. This continuity depends not only on the types of interactions in the classroom but also on the relevancy of the content in the sense that the students can manage the activity and the social classroom organisation, with small group work followed by a review/discussion as a whole class and frequently concluded by an institutionalisation of the main components of the knowledge involved.

2.4.2 Class 2 Analysis

During this introductory part, the classroom organisation does not change: the work is done as a whole class.

Here is the way the teacher starts this part in the middle of the session (T for teacher, S, GA, AM for students):

1. T Shhh. I would like to begin with you the introduction of velocity, uh, excuse me
2. S Force
3. T Force OK well, thus this notion you already know it since college [lower secondary school], but we will try to review first the effects of forces. We'll first experiment. Uh, very simple. If you take an object, so I always have one on hand, if we take an object and you throw it (*T throws the sponge he had in his hands*)

[…]

4. T So this object here (*T shows a balloon*) has a movement (*T holds the balloon in his hand and pulls his arm up*). First, I will release it and then with a little luck I'll not miss it (*T releases the balloon that goes down and then hits it, the balloon goes horizontally towards the students*)

[…]

5. T Thus, the second thing. So before moving on to other examples, this one to start the phenomenon, there, what happens when I hit the balloon? What happens I will listen to you, and then we'll see GA [name of a student]
6. GA The movement is accelerated
7. T Firstly, which object are you considering the movement of?
8. GA The balloon

[…]

9. T It was modified. Therefore, if we pronounce the word force AM [name of a student] in one of those beautiful sentences that you hold the secret to, what would you say here about what we have just seen?
10. AM Uh, uh, the trajectory

This excerpt illustrates the way the teacher introduces knowledge. He shows an experiment and asks questions that necessitate short answers and goes on. However, as we see in turn 9, sometimes the teacher does not get any answer so he often asks the same question again, as in this case, where 50 s later he says:

1. T Shhh, well if we use the word force in the sentence since you studied force at school [in the previous year] VIN [name of a student]

Again, no student gives the expected answer, so the teacher gives the answer:

1. T The force of the hand or the force exerted by the hand on the balloon we agree the force exerted by the hand on the balloon changed the trajectory of what object?
2. S The balloon
3. T The balloon

About one minute later on, the teacher asks another question on the relation between the modification of the trajectory and the force:

1. T Well, in this case in the case of the parabolic trajectory of the sponge, do we have a phenomenon of this kind there?

2. S No
3. T STE [name of a student] did the trajectory of the sponge change under the influence of a force?
4. S (No answer)
5. T I'll do it again and I'll get it this time (*T throws the sponge*).
6. S Wow.
7. S No.
8. T The trajectory is not changed under the effect of a force (*T shows by his tone that he disagrees*).
9. S Well, no.
10. T Well.
11. S Yes, the force of the yes yes the force of the the the force of the Earth.

This excerpt illustrates again that when the teacher obtains an answer that is not expected, he shows that it is not the right answer to the students, often indirectly, here by his intonation. If like here, a couple of seconds later, a student gives the right idea, he goes on developing knowledge on the relations between force and trajectory. In other cases, like in the previous example, he gives the right answer.

In these excerpts, the interaction pattern is very usual: IRE. This type of lecture is called in French "cours dialogué" in the sense that the teacher, like in a lecture, presents new knowledge in a very structured way, but instead of speaking alone, the teacher asks questions that engage students in the development of the course. However, since the wrong answers should not change the structure of the lecture planned by the teacher, he gives the right answer.

In this introductory part, the teacher uses experiments, and the milieu offers affordances. For example, as he said later on, he chose a balloon and not a basketball or football because its form is clearly modified when it is hit. Moreover the objects chosen by the teacher (sponge, balloon, steel ball) are familiar to the students; they can easily say something about them.

These excerpts also show that the teacher introduces knowledge with several supports allowing easily observable events (sponge thrown, balloon thrown in the air and hit) by the whole class. These events are directly related to the taught knowledge; one can consider that the physics concepts are presented as if they were directly connected to observable events. Moreover, the teacher accepts only the correct students' contributions.

2.4.3 Comparison of the Two Classes

Our analysis in terms of the contract and the milieu and their relationships leads us to state that each teacher develops knowledge differently. Table 2.2 presents the main elements of the milieu and the contract of the introductory parts.

In this introductory part, our analysis leads us to consider that in class 1, *correct or incorrect students' ideas* mainly constructed during group work contribute to the

Table 2.2 Main elements of the milieu and the didactic contract during the introductory part for dynamics in a mechanics teaching sequence (grade 10)

Class 1	Class 2
Milieu (small group work)	*Milieu* (whole class)
The text, the associated device, the working group situation, the possible teacher's help	Teacher experiments with a sponge and a balloon include affordances: e.g. the direct observation of the effect of a 'slap' on a balloon: changing its trajectory and its shape
The text and the associated device include affordances. The contradiction with the students' everyday knowledge: *objects act in a motionless situation*	
The request to differentiate phenomenon and object	Teacher discourse associated with the experiments and students' contributions to this discourse
Milieu (whole class)	
The teacher's discourse and students' contributions. Ideas including arguments both correct and incorrect involved in the discourse	Writings on the blackboard
The knowledge institutionalised by the teacher (at the end)	
Didactic contract	*Didactic contract*
To play the game the students develop a strategic system:	To play the game the students develop a strategic system to participate in the teacher's discourse by:
Constructing new interpretations including ideas with arguments during the discussions in groups (small group)	Answering the teacher correctly with a single word or short sentence
Contributing to the classroom review/discussion by giving arguments when proposing an idea (whole class)	Finishing a sentence begun by the teacher
Accepting the institutionalised knowledge	The teacher plays the game by showing the students experiments to keep their attention, make relevant events visible and describe to them with relevant physics words
The teacher plays the game by helping student groups to be aware of the main points (the differentiation gravity-Earth, etc.) and to construct arguments. The teacher plays the game by reviewing and discussing students' proposals The teacher institutionalises knowledge, which thus is supposed to be shared in the classroom	

development of knowledge in the classroom; knowledge is *debated and constructed* with rational arguments. In class 2, knowledge is constructed from correct elements only and in direct relation with observable events of experiments. Students contribute to this construction by observing the experiments and answering the teacher. In both classes, the teacher's *institutionalisation constitutes a step in the classroom knowledge development*; elements of physics knowledge are officialised in the class.

More generally, we consider that the main tendency in both classes is for good students to participate in the classroom discourse but differently; if we take the two extremes, we consider that the good students in one case construct proposals with arguments, correct or not, and in the other case give a correct answer. In the two classes, *knowledge has a different status*; it can be much more questioned and debated in class 1 than in class 2.

2.5 Relationships Between Concepts: Joint Action Theory in Didactics and Social Practice Theories

The main aim of establishing relationships between the concepts of didactic contract and milieu of the Joint Action Theory in Didactics and the concepts of model of identity and normative identity developed in sociocultural theories is double. On one hand, the similar aspects of these concepts show a convergence in the conceptualisation of classroom phenomena, which involves the way knowledge is introduced or used by the teacher and the students. This convergence is mainly based on empirical analyses of classrooms with different theoretical approaches leading to phenomena that we consider as similar. On the other hand, relating different theoretical approaches on empirical bases help the science education community to better understand each other and to further develop new research on the basis of previous shared work.

2.5.1 Concepts of Identity and Normative Identity

Before moving on to discussing the relationships between concepts of different theories, we will briefly present how these concepts are situated in sociocultural and social practice theories. As introduced before, we chose theories used in science education which conceptualise the class as a group and not only students as individuals in interaction. Moreover, we have only selected some studies where the role of the taught knowledge in the classroom is analysed to the extent that in the JATD as in theory of didactic situations, knowledge is at the heart of the relation between the teacher and the students and thus the evolution of the class with that of the taught knowledge is the social *raison d'être* of a class.

As clearly analysed by Shanahan (2009), studies on identity can be situated according to their emphasis on three orientations: personality, social structure and interaction. She stated that until recently, most of the studies were mainly focused on two levels of analysis – personality and interactions – and one of her interpretations was that communities of practice perspective (Lave and Wenger 1991), which has had a wide influence in science education research, emphasise these two levels and to a far lesser extent the social structure which is considered to be rather stable:

> From this perspective [communities of practice], identity is defined as who one is and who one wants to be and learning is viewed as identity transformation – transformation into who we want to become. This focus on transformation places the communities of practice framework squarely in the transitions between personality and interaction. Through interaction, individuals learn about the community of practice and what is expected of its members.

> These expectations are internalised and the individual can make choices to act in a way that will gain them membership in the community. (p. 57)

Here, we only refer to studies on identity that include social structure perspective (Wortham 2006; Cobb et al. 2009) in order to situate them with regard to the concepts of the Joint Action Theory in Didactics. Cobb et al. (2009), who are researchers in mathematics education, give a clear definition of "normative identity" where the term "scientific" can be substituted for their use of "mathematical":

> Normative identity as we define it comprises both the general and the specifically mathematical obligations that delineate the role of an effective student in a particular classroom. A student would have to identify with these obligations in order to develop an affiliation with classroom mathematical activity and thus with the role of an effective doer of mathematics as they are constituted in the classroom. Normative identity is a *collective or communal notion rather than an individualistic notion*. (pp. 43–44) (our italics).

Similarly, Wortham (2006), who works mainly in anthropology of education, specifies what he means by model of identity and then, in reference to Hacking (1990) and Foucault (1966), discusses the rather recent construction of model of identity:

> By "model of identity" I mean either an explicit account of what some people are like, or a tacit account that analysts can infer based on people's systematic behaviour toward others. Models of identity develop historically. (p. 6)

But Wortham goes further:

> Models of identity are contingent not only at the level of sociohistorical epochs, but also at more local levels. We must explore the local "spaces" (Blommaert et al. 2004) and shorter "timescales" (Lemke 2000) in which widespread practices and categories get contextualized. (p. 8)

The contingency of model of identity is closer to "normative identity" presented by Cobb et al. (2009); it allows the researcher to investigate how a class as a group constructs models of identity in relation to the taught knowledge. As a matter of fact, the role of academic teaching in classroom practice in relation to non-academic processes is the focus of Wortham study (2006):

> This book describes one way in which academic and non-academic activities can overlap in classrooms. It focuses on social identification and academic learning, sketching an account of how these two processes can overlap and partly constitute each other. (p. 1)

2.5.2 Similar and Different Views of JATD and Sociocultural Theories

A first major common view of these theories is their focus on a *class as a group* and not only on students as individuals.

The concepts of normative identity or model of identity and didactic contract, together with the emphasis on the role of knowledge, allow the researchers to share the common focus on the class as a group and better understand classroom practices. For example, these concepts allow the researcher to give the characteristics of a "good student" of a given class.

Other common aspects are the evolution over time of the didactic contract and the normative identity or model of identity and their respective relationships with the milieu of the setting.

Since in these studies didactic contract or the normative identity is contingent to the situations, timescales should intervene (Lemke 2000). In the didactic theories, considering generic and specific components of the contract implicitly involves timescales; studies involving several timescales have started to be developed (Tiberghien and Buty 2007; Tiberghien et al. 2009) but need further investigation in particular into the methodological component. The situation seems to be similar in the socio-cultural theories in science education. This is not surprising in that analysing over several weeks, months or years and also at the level of minutes and seconds requires collecting data over a long period, and consequently analysing them is extremely time-consuming. There is a common methodological challenge.

Among the differences, we note the following.

The first one is situated in the *historical evolution of the view of the class as a group*. In France, since the 1960s–1970s, a group of researchers in mathematics education has been developing a theoretical approach aimed at understanding how mathematics is involved in the teaching processes. This trend was influenced by a Marxist approach and also a sociological approach; moreover, Piaget's works were also known and played a role. Thus, with these influences, it is not surprising that the theoretical approach emphasises the "social structure" to guide the conceptual construction. Brousseau theorised the didactic contract in very close relationships with empirical studies. Brousseau and his colleagues collaborate with primary teachers in a school associated with didactic research. This work on a didactic contract started around 1978 with a first publication in 1982. Thus, in this theorisation, the contingency of the didactic contract to specific classroom situations was essential.

In the USA mainly, the research focus shifts from individual to group seems much more recent (for example, Varelas, 2012). For example, Carlone recently (2012) discussed this shift and in particular the changing types of research questions (Carlone 2012) (Fig. 2.2).

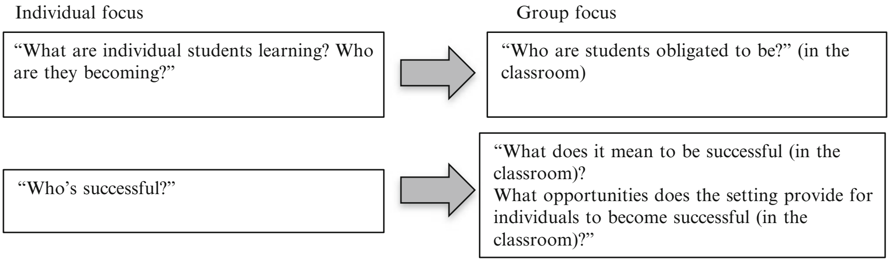

Fig. 2.2 Different research questions according to the research focus, individual or groups (From Carlone 2012, p. 12)

Carlone (2012) also discusses the individual and social approaches. For her, the dialectic between agency and social structure should be respected. She found that:

> … the structure/agency dialectic, as Shanahan (2009) argued, "poses methodological problems" (p. 46) and, in sociocultural studies, often veers too far over on the "agency" side to over-emphasize the freedom individuals have to shape their own destiny, to make their own meanings. (p. 11)
>
> […]
>
> Though we gain solid insight from examining and theorizing moments of agency, creativity, and improvisation, science education needs more accounts of the ways group-level meanings–heavily influenced by larger social structures, history, and politics–emerge and enable and constrain individuals' subject positions. (p. 11)

The second difference concerns both *the basis of the theories and the results of the analysis*.

The sociocultural theories give more general orientations; they are "grand theories" (Cobb et al. 2003; Tiberghien et al. 2009), whereas JATD and theory of didactic situations are specific to didactic situations. Even if didactic situations do not only take place in the classroom, they are specific to situations where somebody wants his/her interlocutor to learn something and the reverse. Such a situation can happen anywhere, for example, in the street when somebody asks his/her way of a person who indicates how to find it or at home when an adult explains to a young child what to call something. These situations are characterised by the actors' intention to teach and learn something; this something is not at all limited to academic knowledge. The sociocultural theories do not limit the type of situations, like sociology or anthropology. They give typical models like "Loud black girls", "Resistant black males" and "Disruptive students" (Wortham 2006) which are not specific to teaching-learning phenomena.

The JATD is based on the "didactic triangle" or in other terms on the ternary relations between teacher, students and knowledge. In the JATD, the game model respects this holistic view; there are transactions between the teacher and the students of which the object is knowledge. As we presented above, this theory and the theory of didactic situations lead the researchers to characterise the statuses of knowledge in a classroom or typical phenomena like the Topaze and Jourdain effects. These characterisations are associated with didactic situations where knowledge is specifically shaped according to the intention of the teacher and/or students.

2.6 Perspectives

The concepts that we studied – didactic contract, milieu, normative identity and model of identity – help the researchers to make implicit classroom practices visible, making the familiar strange. This better understanding of classroom practices can contribute to teacher education. As proposed by Lampert (2010), teacher education should be organised around *a core set* of teaching practices. Developing characteristics phenomena of classroom practice, based on analysis of classroom as a group, is essential since the teacher has first to manage a group and not a sum of individuals, even if it is not the exclusive teacher's activity who has also to work with students as individuals. Thus, the shift in focus from individual to group allows the researchers to contribute in a determinant way to teacher education. This development can include teaching education and teaching resources designed based on research and professional practices.

Moreover research processes characterising science classroom phenomena can be developed. These phenomena could be debated, confronted in different cultures and then would constitute a common knowledge of science education research community. This perspective goes hand in hand with that of developing a better understanding of theoretical and methodological approaches among science education researchers and then establishing relationships between concepts.

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Chapter 3
Process-Oriented and Product-Oriented Assessment of Experimental Skills in Physics: A Comparison

Nico Schreiber, Heike Theyßen, and Horst Schecker

3.1 Background and Framework

The acquisition of experimental skills is widely regarded as an important part of science education (e.g., AAAS 1993; NRC 2012). Thus, there is a demand for assessment tools that allow for a valid measurement of experimental skills. In our study, we developed and compared two types of assessing students' performances in hands-on tests: a process-oriented and a product-oriented approach.

3.1.1 Modeling Experimental Skills

In the literature, there is a broad consensus about the major experimental skills. Typical skills include creating an experimental design, setting up an experiment, observing, measuring, and interpreting the results (e.g., DfEE 1999; KMK 2005; NRC 2012). These skills can be assigned to three dimensions: *prepare*, *perform*, and *evaluate*. Models of experimental skills usually differentiate between these three dimensions (Hammann 2004; Klahr and Dunbar 1988; for an overview, see Emden and Sumfleth 2012). In most models, setting up an experiment, observing, and measuring are assigned to the dimension *perform*.

In the HarmoS hands-on test (807 students, grades 6 and 9), the dimensionality of experimental skills was investigated. The best model fit is a two-dimensional one

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(Gut et al. 2014) that differentiates between a cognitive-manipulative dimension (e.g., set up an experiment and measure) and a mere cognitive dimension (e.g., develop the experimental design). However, the poor EAP/PV reliabilities gained from Rasch model analyses (.55 for the cognitive-manipulative and .56 for the mere cognitive dimension) and the high correlation between both dimensions ($r = .99$) are arguments against a two-dimensional construct of experimental skills.

3.1.2 Product-Oriented and Process-Oriented Assessment of Experimental Skills

There is a need for test instruments that support a valid assessment of experimental skills – in particular for large-scale and high-stakes testing. Since abilities to actually perform an experiment represent an important dimension of experimental skills (e.g., NRC 2012), assessment should take into account processes like setting up the apparatus and making measurements.

There are written tests to assess experimental skills. However, especially with regard to the *perform* dimension, their validity is questioned (e.g., Shavelson et al. 1999). Other approaches for the assessment of performance skills seem to be necessary (Garden 1999; Ruiz-Primo and Shavelson 1996; Stebler et al. 1998). Here, hands-on tests show their potential. Students' experimental skills can either be assessed product-oriented or process-oriented. A product-oriented assessment evaluates what students document in their lab sheets. This approach is typically used in large-scale studies like TIMSS and the Swiss HarmoS (e.g., Gut 2012; Ramseier et al. 2011; Stebler et al. 1998). Also in lab courses for university students, lab sheets are usually analysed in a product-oriented way. Here, rubrics are often used as scoring guides (cf. Vogt, Müller, Kuhn in Theyßen et al. 2014, 326). The analysis of lab sheets neglects process aspects of experimenting, e.g., students' strategies for setting up the apparatus and data acquisition. These processes are taken into account by a process-oriented assessment. Walpuski (2006) analysed videos of students' experimenting, according to the three dimensions *prepare*, *perform*, and *evaluate*. His focus was on the sequence of experimental actions and their technical correctness. Neumann (2004) applied a scheme developed by von Aufschnaiter and von Aufschnaiter (2007) that distinguishes between explorative, intuitive rule-based, and explicit rule-based modes of experimenting. Both methods evaluate the communication between members of small groups working on tasks collaboratively. They are not applicable to single-student assessment. There is still a lack of test instruments for a process-oriented assessment of individual students' experimental skills.

3.1.3 Reliability of Performance Assessments

The measurement of experimental skills is confounded by personal and external variables. Shavelson et al. (1999, 64–65) found that the {person x task x occasion} component explains the largest portion of variance in students' performances in hands-on experiments. At different occasions, students perform differently on different tasks, but aggregated over several tasks, the {person x task} component is zero. This leads to the conclusion that a reliable measurement of experimental skills demands the use of several tasks (see also Stecher and Klein 1997).

Shavelson et al. (1993, 1999) examined the exchangeability of assessment tools for experimental skills. 186 students from fifth and sixth grades carried out mystery hands-on investigations. They had to set up electric circuits and identify the contents of mystery boxes (e.g., battery, bulb, or wire). The students documented their investigations in a prestructured lab sheet. On the one hand, students' performances were assessed by direct observation (DO). The observers assigned score 1 if the content of the box was correctly identified and a suitable circuit or sequence of circuits was used to identify the content; otherwise, score 0 was assigned (Baxter and Shavelson 1994). On the other hand, the prestructured lab sheets were analysed according to the same criteria (LS). Shavelson et al. report a correlation of $r = .84$ between both scorings. In this case, both scorings were based on the same performance ("occasion"). For correlating scores obtained from two different occasions, Shavelson et al. retested a random sample of 29 students from the original sample. The correlations between both scorings went down to $r_{\mathrm{DO1,\,LS2}} = .48$ and $r_{\mathrm{DO2,\,LS1}} = .56$ (Shavelson et al. 1999, 69).

3.2 Rationale and Methods

According to Ruiz-Primo and Shavelson (1996), a science performance assessment is constituted by a task, a response format, and a scoring system. Our study compares two scoring systems, while task and response format are kept constant. Both scorings refer to students working on a hands-on experiment on their own.

A process-oriented assessment of students' actions in hands-on experiments usually demands for the analysis of video data. Compared to product-oriented assessments, this approach is very resource-consuming. The effort is only necessary and justified if a process-oriented approach yields an added value for the diagnostics of experimental skills. The aim of our study was to clarify this question, especially in the dimension *perform an experiment*.

According to the results of Shavelson et al. (1999), a reliable measurement of experimental skills would demand the use of several tasks for each individual. In our study, we do not aim at reliable scores for students' experimental skills but at a comparison of two scoring systems. As a consequence, we keep the task and the occasion constant for our comparison. Each student only works on one task, and both scorings are based on data from the same occasion. The process-oriented assessment takes the students' actions (video analyses) and their experimental results (lab sheets) into account. The product-oriented approach only uses the lab sheets for scoring. Thus, our findings cannot be confounded by the task or the occasion of data generation.

3.2.1 Hypotheses

In our study, we investigate the exchangeability of a product-oriented and a process-oriented assessment of students' performances in hands-on tests according to six assessment categories (s. Fig. 3.2). As the analysis of processes includes much more information about what students actually do when they experiment than only looking at the products, we take the results of process analyses as benchmarks. The question then is: Do scores gained from product analyses sufficiently overlap with scores from the more time-consuming process analyses? To answer this question, we correlate scores from both forms of assessment. Our first hypothesis is:

H1: Concerning the dimension "perform an experiment", scores gained from the analysis of products are <u>not</u> highly[1]correlated with scores from the analysis of processes.

Experimental pathways of different quality can lead to the same result. When students perform an experiment, they receive immediate feedback from the experimental setup. A nonfunctional electric circuit, e.g., may lead to a series of changes, until the setup finally works. The lab sheet will only show the final result. Similar processes of problems and refinements may occur during measurement. A product-oriented assessment only evaluates the documented (i.e., usually the final) results, while a process-oriented approach can also take the sequence of students' actions into account.

Interactive feedback as mentioned above does hardly occur when students plan an experiment or work on data. Students prepare the experiment and evaluate their data mostly in written form (e.g., sketches, calculations) without handling experimental devices. We thus assume a close relation between what students actually do and what they document. Thus, our second hypothesis is:

H2: Concerning the preparation and evaluation of the experiment, scores gained from the analysis of products are highly [1] correlated with scores from the analysis of processes.

3.2.2 Design

Figure 3.1 shows the design of the study. It was embedded in a more extensive study concerning the exchangeability of written tests, tests with computer simulations, and tests with hands-on experiments in the assessment of experimental skills (Schreiber 2012; Schreiber et al. 2014).

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[1] As a high correlation, we define a correlation above 0.7 (Kendall-Tau b).

pretest – cognitive skills, content knowledge, self-concept		**45 min**
training – introducing the hands-on tests		**20 min**
Hands-on tests		
group 1 and task 1 Find the bulb with highest power	group 2 and task 2 Find the best conductor	**30 min**

Fig. 3.1 Design of the study

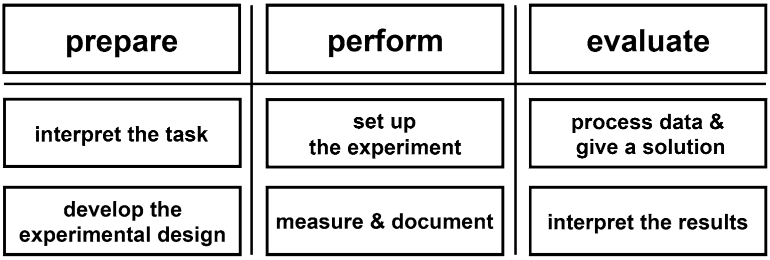

Fig. 3.2 Model of experimental skills (adapted from Schreiber et al. 2009, 2014)

138 upper secondary students, aged 16–17, took part in this study. In a pre-test, we surveyed background variables that are supposed to influence students' test performances: cognitive skills, self-concepts concerning physics and experimenting in physics, and the content knowledge in the domain electric circuits. Established tests and questionnaires were adapted for this pre-test (Brell 2008; Engelhardt and Beichner 2004; Heller and Perleth 2000; von Rhöneck 1988).

In a training session, the students were made familiar with the structure of the tasks and the handling of the devices. The training task was also about electric circuits (measuring the current–voltage curve of a bulb). In the hands-on test, each student worked on one of the two tasks (s. Sect. 3.2.4). The use of two different tasks was necessary for the more extensive project into which this study was embedded. In the context of this study, it allows for first conclusions concerning the generalizability of the results. The students were assigned to one of the two groups in a way that secured a sufficient and similar variance of the background variables in both groups.

3.2.3 *Model of Experimental Skills*

Task development was based on the model of experimental skills that is presented in Fig. 3.2. In contrast to other models (Hammann 2004; Mayer 2007), the model particularly accentuates the dimension "perform" with two skills that refer to the processes *set up an experiment* and *measure and document*.

An expert panel (science teachers and teacher educators; Nawrath et al. 2011; Schreiber 2012, 39f) confirmed the relevance of the model components for the description of lab work in science teaching and its focus on performing experiments. Students mostly work on topics and questions prepared by their teachers. But they still have to interpret the specific task for themselves: What exactly is the question to be answered? In more open-ended situations students have to work out the experimental design themselves. Performing an experiment means to set up the apparatus, conduct measurements, and document data. Data evaluation often includes the processing of raw data. Finally, students have to interpret the results and formulate an answer to the experimental question. This description might suggest a linear order of steps as an ideal experimental process at school. However, this is not intended. During experimentation, the six steps can reoccur in different orders and can be repeated with or without improvement.

3.2.4 The Hands-On Test Scenario

Based on the model shown in Fig. 3.2, we developed two experimental tasks for the domain of electric circuits in secondary school curricula (Schreiber et al. 2009, 2014; Theyßen et al. 2014). In task 1, the students have to find out which of the three given bulbs has the highest electrical power input when supplied with 6 V. In the second task, six wires made of three different metals and with different lengths are provided. The students have to find out the metal that is the best conductor.

Both tasks are unguided. The students have to work out their own solutions, starting from planning the experiment up to evaluating data from own measurements. There is no further assistance except from written information about the necessary physics content knowledge (e.g., the definition of "electrical power"). For task 1, this information is: "The electrical power is the product of current and voltage. The current in a bulb is determined by the voltage applied and the electrical properties of the bulb itself."

A comparative analysis of the content of the tasks confirmed that the necessary experimental actions are very similar and that these demands can be assigned to the six skills in our model (Fig. 3.2) (Schreiber 2012, 81f). The content validity of both tasks was underpinned by an expert panel and an analysis of syllabi. The results indicate that students aged 15 to 16, i.e., students even younger than our participants, should be able to understand and solve the tasks.

The students worked with a set of electric devices and a prestructured lab sheet (see Fig. 3.3). In the situation shown in Fig. 3.3, the student documents his (inadequate) setup using two multimeters, a battery, and a bulb. The prestructured lab sheet requests the students to clarify the question, i.e., to write it down with their own words; to document the setup, the measurements, and the results; and to interpret the results with regard to the question. Students can choose when and in which order they fill out the sheet. It does not give any hints for a particular solution or approach. Students' actions were videotaped and the lab sheets were collected.

Students' test performances were scored by a product-oriented as well as a process-oriented scoring system. For the product-oriented scoring, only the stu-

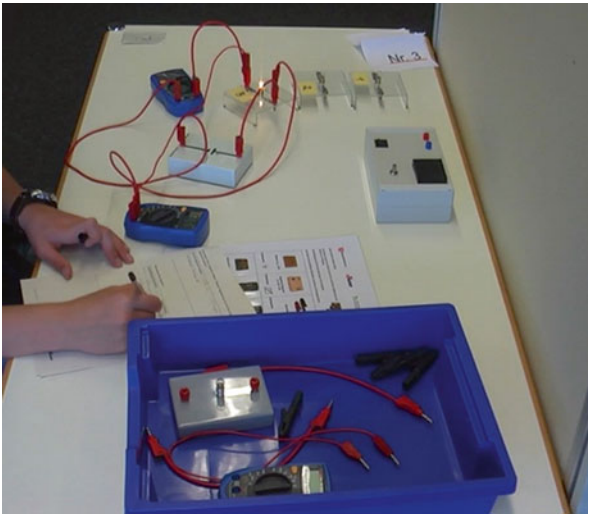

Fig. 3.3 A student performs task 1

dents' documentations in the lab sheets are analysed with regard to the same six model skills (see Fig. 3.2). Each entry in the lab sheet is associated with an assessment category. The single criterion is the correctness of the entry. We used partial credits: correct, imperfect (suitable in principle, but with minor mistakes), or wrong (not suitable). In the assessment categories *measure and document* and *process data and give a solution*, the coding can only be correct or wrong. In a detailed coding manual, these levels are defined for each category. 16 double encodings, eight per task, were carried out. Inter-rater reliability was satisfying in each assessment category (Cohen's Kappa > *.62)*. In the following, the process-oriented scoring is laid out in more detail.

3.2.5 Process-Oriented Analysis

Our process-oriented scoring system relies on an analysis of the sequences of a student's actions. It is a low-inference method using video data of students working on the experiment (setting up the apparatus, making measurements, filling out the lab sheet). The collected lab sheets are also included in the analysis, because the resolution of the videos does not always allow a detailed view of what students write down or sketch.

3.2.5.1 Gaining the Scores

The first step of evaluation is time-based coding. Each 5 s interval of the video is assigned to one of the six experimental skills (see Fig. 3.2). In this step the two categories *process data and give a solution* and *interpret the results* had to be aggregated because, due to the specific tasks, the processing of data only occurred in very short intervals. Figure 3.4 visualizes an exemplary result. This description contains information about the order of occurrence and the iterations of students' actions. As typical steps in experimenting (e.g., setting up the apparatus) take much longer than five seconds, we define *processes*. A process ends when there is a change in the assigned category. For example, a change from *set up the experiment* to *measure and document* determines the end of a setup process. Figure 3.4, e.g., contains three setup processes, indicated by rectangles.

After identifying processes, the quality of students' actions can be determined, for example, whether an experimental setup is suitable to solve the task or not. The quality of a process is rated according to its completion. As in the product-oriented scoring, we use partial credits for most categories: correct, imperfect, or wrong. In the category *process data and give a solution*, the coding can only be correct or wrong. A detailed coding manual defines levels for all the categories. For scoring entries in the lab sheet, it is largely identical with the manual for the product-oriented analysis.

Students' experimental skills are scored in similar ways for each of the six skills. As an example we describe the scoring of *setup* skills. The coder rates each setup process that was identified (three setup processes in Fig. 3.4) as correct, imperfect, or wrong. Based on these codes, a final *setup* score is assigned according to the flow diagram shown in Fig. 3.5. If only one setup process is detected, a score is assigned according to its quality. If several setup processes occur, the scoring takes into account the quality of the final setup and additionally determines whether the setups improve from the first to the last setup process. In short, this analysis looks at the *development* of quality. The flow diagram in Fig. 3.5 shows how five levels are assigned to the eight possible paths. Level five represents the highest quality, level one the lowest. The assignment of the five levels is in agreement with an expert panel, that ordered the eight paths according to their quality. In cases in which a student is not able to finish any setup of the experiment, score 0 is applied.

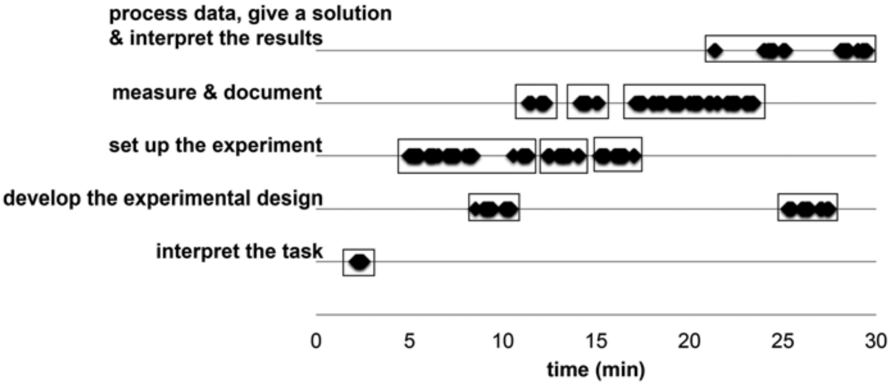

Fig. 3.4 An example of a sequence description of students' actions (The categories *process data and give a solution* and *interpret the results* are not distinguished here)

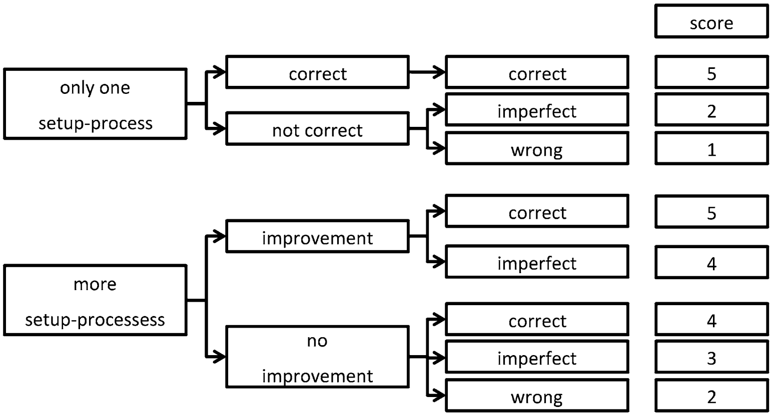

Fig. 3.5 Formal analysis scheme of the process-oriented scoring specified for setup skills

In product-oriented scoring (see above), a development cannot be assessed since in most cases only one result is documented in the sheets. Thus, using the formal analysis scheme (Fig. 3.5), only the upper part applies, and levels 1, 2, and 5 can be scored in the product approach.

3.2.5.2 Quality of Process Assessment

As the analysis of processes is a rather new and challenging approach to score students' experimental skills, we performed several semiquantitative and qualitative studies to assure inter-rater reliability and criterion validity of the process-oriented assessment. We give a short overview of some results.

Inter-rater Reliability Two trained coders interpreted students' actions in 5 s intervals and assigned them to the five categories (*process data and give a solution* and *interpret the results* aggregated; s. Fig. 3.4). 3722 5 s intervals (about 310 min of video) from four students working on both tasks were analysed. Cohen's Kappa (κ-value) for inter-rater agreement was .84.

The same two coders analysed 14 videos based on the existing time codings of students' actions. The coders had to identify *processes*, i.e., chains of actions belonging to a specific skill (with start time and end time). Additionally, they had to rate the quality of these processes (correct, imperfect, or wrong) for each of the six assessment categories (s. Fig. 3.2). In this sample of 14 students, all processes occurred more than once per student, especially the setup. All the agreements ($.67 \leq \kappa \leq .90$) are above the critical κ-value of .60 (Bortz and Döring 2006, 277; Landis and Koch 1977).

Criterion Validity We compared the results of the process-oriented assessment with high-inference expert ratings (Dickmann et al. 2012). Since our model (Fig. 3.2) emphasizes the performance dimension of experimenting, the criterion validation was restricted to the scores of setup skills and measuring skills. The dataset consisted of twelve videos showing students working on one of the experimental tasks and on the corresponding lab sheets. For the high-inference rating, two experts who were familiar with the model of experimental skills but did not know the process-oriented scoring system holistically rated the students' performances. By means of pairwise comparisons, the experts decided for six pairs of students, who performed better. A third independent trained person applied the process-oriented scoring and also rated these twelve videos (and corresponding lab sheets).

The two experts agreed in 17 of 18 pairwise comparisons (94 % relative agreement). Expert 1 and the process-oriented analysis coincided in 16 of 18 pairwise comparisons, expert 2 and the process-oriented analysis in 17 of 18 comparisons. The results support criterion validity of the process-oriented analysis.

3.3 Results: Comparison Between Product- and Process-Oriented Analyses

To test our hypotheses (Sect. 3.2.1), correlations between the performance parameters gained from the product-oriented and the process-oriented scorings were calculated for each of the six experimental skills (Table. 3.1). As the five levels are graded on an ordinal scale (see Sect. 3.2.5.1), we chose rank correlations (Kendall-Tau b, τ). Since generalizability across tasks was questioned, the correlations were calculated for each task and for the aggregated sample.

The correlations calculated for tasks 1 and 2 throughout confirm the hypotheses. In the dimension "perform", the correlations are lower than .70. In the "prepare" and "evaluate" dimensions, the correlation is above .70 with one exception: a medium correlation in the assessment category *creates the experimental design* for task 2 (r=.657). With regard to the aggregated sample (tasks 1 and 2), the correlations are high ($r \geq .728$) in all assessment categories belonging to the dimensions "prepare" and "evaluate." In the assessment categories in the dimension "perform", correlations are low or medium ($r = .221; r = .499$) . Thus, our hypotheses are confirmed. The very similar results for both tasks indicate that this applies independent of the special task, but further investigations concerning the generalizability of the results are necessary.

The bubble diagrams in Figs. 3.6 and 3.7 show distributions of the scores students achieved in the assessment categories "set up the experiment" and "measure and document". The diagrams allow for a qualitative interpretation of the low correlations. With regard to the process-oriented scoring as the benchmark, the product-oriented scoring seems to underestimate students' skills in the assessment category *set up the experiment* (Fig. 3.6) and to overestimate them in the category *measure and document* (Fig. 3.7) (Table 3.1).

Table 3.1 Correlations (Kendall-Tau b, τ) between the product-oriented and the process-oriented assessment

		Task 1		Task 2		Tasks 1 and 2	
Dimension	Assessment categories	τ	N	τ	N	τ	N
Prepare	Interpret the task	.894	70	.862	68	.877	138
	Develop the experimental design	.782	70	.657	68	.728	138
Perform	Set up the experiment	.637	64	.380	66	.499	130
	Measure and document	–[a]	60	.323	62	.221	122
Evaluate	Process the data and give a solution	.983	60	.930	62	.960	122
	Interpret the results	.771	59	.750	58	.775	117

All the correlations are highly significant ($p<0{,}01$). N: sample size

[a] In the product-oriented analysis, only score 5 was assigned. Thus, no correlation could be calculated. In the process-oriented analysis, students obtained scores from 1 to 5, indicating low agreement between both scorings

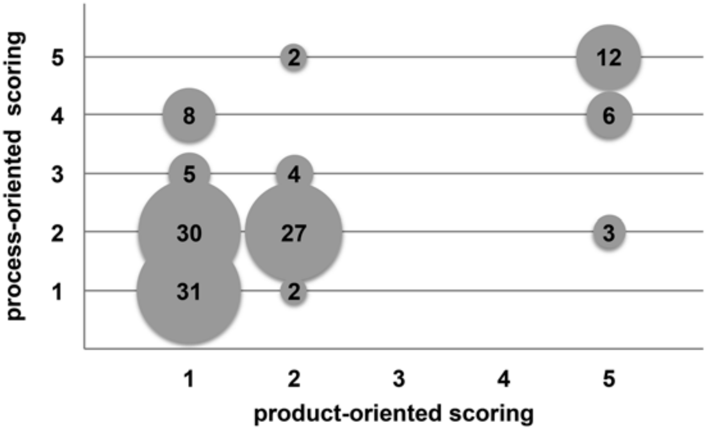

Fig. 3.6 Distribution of the scores students achieved in the assessment category *set up the experiment – tasks 1 and 2*

3.4 Discussion

Qualitative considerations suggest that a process-oriented assessment of experimental skills is superior to a product-oriented assessment in terms of criterion validity because it looks deeper into students' experimental actions. Our results, however,

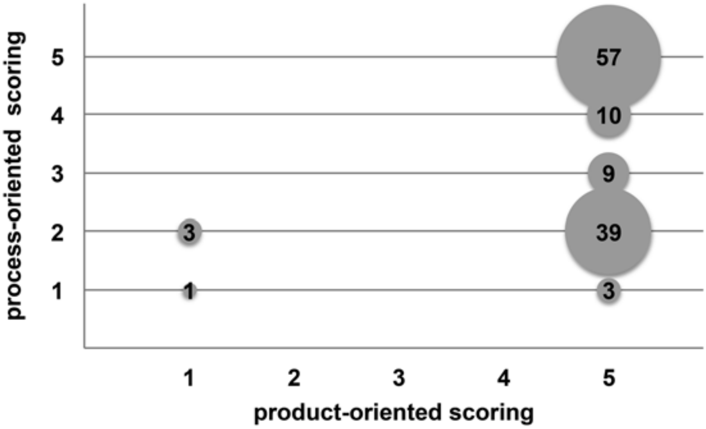

Fig. 3.7 Distribution of the scores students achieved in the assessment category *measure and document – tasks 1 and 2*

show that as far as scoring is concerned, product-oriented and process-oriented assessments are exchangeable for experimental skills in the dimensions *prepare* and *evaluate*. This does not hold for the *perform* dimension; scoring from process analyses only partly overlaps with product-oriented scoring. As scores gained from process analyses can be considered as the benchmark, assessment in this dimension cannot simply be based on product-oriented scoring. As an indicator for generalizability, we found these results for both experimental tasks used in this study.

High correlations in the planning and evaluation dimensions can be explained by a mainly common data basis: In these dimensions, the process-oriented analysis also primarily referred to the documentations in the lab sheets. Only in a few cases, the videos of students filling out the lab sheets provided further information drawn from the iteration and (non-) improvement of processes. Thus, as in the product-oriented assessment, scores 1, 2, and 5 (Fig. 3.5) also predominate in process-oriented scoring.

In contrast, the scoring of skills to actually perform an experiment greatly profited from the video data. The low correlations between the process-oriented and the product-oriented analyses seem to be caused by an information gap if one only evaluates the documented setups and measurements without including the actual setup and measurement *processes*. For example, it turned out that some of the documented setups differed from the ones the students actually used in their real experiments. It could be that students forgot to revise their sketches when they changed (and possibly improved) their real setups in the course of experimenting. Another point concerns the documentation of measured data. Video analysis allows to match documented values with the readings of the multimeter scale, the analysis of the lab sheets does not, so that one has to assume a correct transcript. These examples could also partly explain why we found that a product-oriented analysis overestimates "measure and document" skills while it underestimates "setup" skills. The additional capabilities of process analyses seem to have a relevant effect on scoring abilities to *perform* an experiment, which leads to notably lower correlations with product-oriented scoring than in the dimensions *prepare* and *evaluate*. For an adequate account of skills to carry out experiments, performance assessments with a process-oriented analysis of students' actions appear to be necessary. It is very likely but should be verified by further studies that our results do not only apply to school level but also to lab work at university level. So far, only a few studies evaluating the learning efficiency of newly developed lab courses have used process analyses (e.g., Platova and Walpuski 2013; Niedderer et al. 2002). Typically, the assessment of university students' learning gains from lab courses is based on the analysis of lab sheets. According to our findings, the validity of this approach is in question with regard to setup and measurement skills.

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Chapter 4
Students' Use of Science and Mathematics in Practical Projects in Design and Technology

Berit Bungum, Bjørn-Tore Esjeholm, and Dag Atle Lysne

4.1 Introduction

The knowledge component of technology in the school curriculum remains a contested terrain (see, e.g. Jones et al. 2013). On one hand, technology can be seen as representing a domain of knowledge in itself, while on the other hand technology as a field of activity makes use of and combines knowledge from a range of different areas in order to fulfil specific purposes. In particular, modern technology makes high use of scientific knowledge in its development. This ambiguity is reflected in the challenges represented in defining technology as a school subject worldwide.

The curriculum for compulsory school in Norway places *technology and design* as a cross-curricular field involving the subjects science, mathematics and art and crafts. This chapter presents a classroom video study of practical projects in technology and design developed in line with the curriculum, where we investigate the knowledge content of science and mathematics manifested in the projects in terms of students' actions and teacher-student dialogues. The analysis is done in light of the intention of the curriculum, and the study hence provides an examination of the epistemic foundation the curriculum is built on.

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4.2 Perspectives on Technological Knowledge

In the philosophy of technology, many attempts to capture the nature of technological knowledge have been made, from a philosophical point of view as well as from an educational perspective (see, e.g. Layton 1991; McCormick 1997; Staudenmaier 1985). One reason why technological knowledge is so hard to conceptualise is that technology is highly situated in the practical context and involves knowledge that cannot be understood simply by means of discerning the relevant scientific laws (Boon 2006). To be useful, this knowledge needs to be reconstructed, combined with other forms of knowledge and adjusted to the situation at hand (Layton 1991). The reconstruction often entails that the level of abstraction is reduced but the complexity increased.

This is in line with how Staudenmaier (1985) has provided characteristics of technology as a domain of knowledge, based on his thorough analysis of what constitutes technological knowledge in various domains of the field. He described technological knowledge as combinations of scientific concepts, engineering theory, problematic data and technical skills. This conception of technological knowledge illustrates that even if technology is deeply situated in practical contexts, it also comprises knowledge that is theoretical and generic in nature. Some components of this theoretical knowledge stem from science, while the category engineering theory is theoretical knowledge that is purely technological in nature.

This means that technology is much more than the direct application of pure scientific knowledge. However, science and technology are highly interrelated in their modern form: modern technology builds to a high degree on advanced scientific knowledge, and the advancement of science is in turn highly dependent on technology. Modern science and technology are hence described as a 'seamless web' (Hughes 1986).

Despite this development, science and technology are still seen as different domains of knowledge and activity, and their different *purposes* are often used to make a demarcation between the two areas of knowledge and activity (see, e.g. Ropohl 1997). While the purpose of science is to establish generic knowledge that covers as many contexts and situations as possible with explanatory power, the aim of technology is to develop products and systems with a specific purpose and function. This difference in purpose gives rise to differences in what is seen as progress in the field and what is considered valuable knowledge: progress in science is models that better explain the world while progress in technology is more efficient solutions.

4.3 Representation of Technology in General Education

In education, different perspectives on what technology and technological knowledge mean provide for different positioning of the knowledge domain in the school curriculum. The main challenge is to conceptualise the identity of the subject, its disciplinary content and relationship to other subjects (Jones et al. 2013).

In school science, technological applications have often been presented as part of the science curriculum, not necessarily with a perspective on knowledge but rather in order to make the science content more concrete for the learner and to demonstrate its relevance in society and everyday life. These approaches have been massively criticised as they tend to portray technology as straightforward applications of science and hence do not do justice neither to technology nor to science (e.g. Boon 2006; de Vries 1996; Gardner 1994; Layton 1991).

Other traditions of technology education place the domain within craft and vocational training, often associated with less able students and with a low social status (see, e.g. Hansen 1997). In recent decades, however, technology has emerged as a subject in its own right and for all students in several countries. The subject has been modernised and broadened to include design and notions of technological literacy (Jones, et al. 2013).

While technology as a subject for all students makes technology more visible in the curriculum, many have pointed to that the close relationship that exists between science and technology should be represented in how students engage with science and technology in their general education (e.g. Barlex and Pitt 2000; Bencze 2001; Petrina 1998; Sidawi 2007). Also for mathematics teaching, studies have pointed to the potential for integration with technology (e.g. Norton and Ritchie 2009). Technology is seen as providing rich contexts for learning and applying mathematics in authentic and relevant contexts, as well as developing more positive attitudes towards the subject.

A curriculum organisation in line with this view was introduced in the current curriculum for Norwegian compulsory school in 2006 (The Norwegian Directorate for Education and Training 2006). The topic *technology and design* is placed across the subjects science, mathematics and art and crafts, with the intention that practical projects in technology and design will provide meaningful and motivating contexts for learning and applying science and mathematics. This explains why mathematics is seen as part of the domain of technology, while, for example, social science is not, despite the importance of technology in human history and in development of society.

Investigations into the implementation of the subject area in schools indicate that even if teachers are positive to technology and design in the curriculum, it gets relatively little attention and teaching time, partly due to practical and organisational reasons (see Dundas 2011).

4.4 A Video Study in Schools: Research Focus and Methods

The study presented in this chapter attempted to support teachers in developing effective and motivating student projects, as well as investigating how conceptual knowledge from science and mathematics come into play when students work with projects in technology and design. Conceptual knowledge is taken to denote declarative, generic knowledge comprising concepts, relationships and principles that may have significance for action (see McCormick 1997). The study is undertaken by analysing how students deal with and communicate knowledge and activities in cross-curricular student projects in technology and design developed and implemented in three different Norwegian schools (year 3–10).

In the research project, six student projects were developed in cooperation with the local teachers at six different schools (see Bungum et al. 2014). In the development, we attempted to create cross-curricular projects with a good potential for incorporating science and mathematics, but also attended to that the projects should be realistic to run in schools with regard to materials as well as teacher knowledge and skills. Analysis of teacher-student dialogues in these six student projects revealed that science and mathematics were virtually absent from dialogues between teachers and students, despite the fact that the projects were designed with the purpose of including these subjects in meaningful ways. The conceptual knowledge addressed by teachers during the technology and design projects was for the most part technological in nature.

In the present study, we investigate the issue further by analysing the material with focus on *why* knowledge from science and mathematics is not addressed to a higher degree in the students' projects. We investigated video material from three of the student projects from the original study. The projects chosen for the deeper analysis were those anticipated to contain most content knowledge from science and/or mathematics. Each project lasted ca 30 h. Members of the research group were present in the classrooms in a substantial part of the project period, but influenced teachers' and students' work to a very limited degree.

Classroom sessions related to the project were videotaped with three cameras recording two selected groups of students and the classroom as a whole, respectively. A fourth camera was used to record other situations of interest that occurred in the classroom. In addition, the main teacher was carrying a wireless microphone throughout the entire project in order to record all teacher-student interactions.

In the earlier study, all dialogues between the teacher and students have been analysed quantitatively with regard to the kind of knowledge represented in the conversation (see Bungum et al. 2014). In the present study, we have analysed selected episodes with regard to why knowledge from science and mathematics is *not* represented in situations considered to have a potential for this. This analysis is interpretative and broader in the sense that it considers not only dialogues but also students' actions in the project and the objects they produce.

Sequences of the video material were purposely selected as they provided illustrative examples of situations where the potential for science and mathematics content was not fulfilled. This selected material was reduced to four episodes that illustrated different aspects of the phenomenon under consideration. From these, we formulated four issues (categories) that have been refined and adjusted through consideration of the video material as a whole and through observer triangulation between members of the research group in interpreting sequences of video data. These categories are presented as results of the study, illustrated by the episode that gave rise to each category.

According to Merriam (1998), categories resulting from inductive analysis should be exhaustive, mutually exclusive, sensitising and conceptually congruent as well as reflecting the purpose of the research in the sense that they provide answers to the research question. The categories developed in this study provide broad answers to the question of why knowledge from science and mathematics is not represented in the student projects. As this concerns an *absence* of something, the formation of categories is inevitably exploratory. The categories are informed by, but not derived from, the theoretical perspectives on technology described in the foregoing. They are mutually exclusive in the sense that they conceptualise distinct issues, but not necessarily exclusive with regard to episodes in the material. This means that events in a project sequence might fit in more than one category. Still, the categories highlight different aspects of why conceptual knowledge in science and mathematics does not come into play when students work with a project on technology and design.

4.5 The Student Projects

The three student projects in this study were as follows:

4.5.1 Models of Playground Equipment

In this project, students in grade 8 designed models of playground equipment by means of the software Google SketchUp and built the models in cardboard and other materials. The software facilitates the making of templates of the individual parts of the construction with accurate measures. Conceptual knowledge from mathematics is involved by the scales students work with in order for the measures to be suitable for the purpose. It could also involve basic mechanics in how the equipment works (Fig. 4.1).

Fig. 4.1 Model of playground equipment

4.5.2 Model of Town with Lights

The project involved building a model of the students' hometown Hammerfest, with streets and buildings and surrounding landscapes including mountains and a fjord. The project was undertaken in a class of grade 10, where students worked in groups performing various parts of a joint model. Students themselves were to decide on what scales to use and what parts of the city and the landscapes that were to be represented in the model. The model was to be enlightened by electric light, making a link to the fact that Hammerfest was the first town in Norway with electric street lights. The project has potential for working with conceptual knowledge in terms of scales in mathematics and principles of electric circuits in science (Figs. 4.2 and 4.3).

Fig. 4.2 Town model

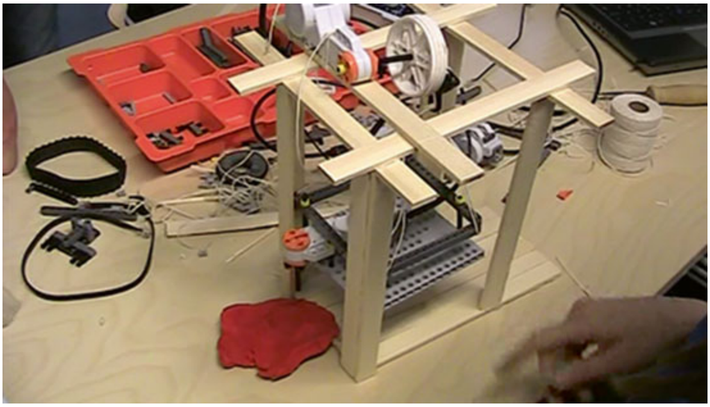

Fig. 4.3 Model of oil drilling system

4.5.3 Model of Oil Rig and Drilling System

The activity was undertaken in grade 8 and formed part of a larger project about oil exploration. Students used Lego Robotics to construct the drill and were allowed to use various materials for making the platform. The main challenge for the students was to design a motor system that allowed the drill to rotate and simultaneously make a vertical movement. The project potentially involves concepts and principles from mechanics, such as force, energy and transformation of movement.

4.6 Results and Analysis: *Why* Is Science and Mathematics Absent from the Design and Technology Projects?

From the data from the three described projects, we have identified four key issues of importance for why the design and technology projects, as they were realised in schools, did not contain any significant component of knowledge from science and mathematics, despite the fact that they were partly designed to do so. The four issues are conceptualised as (1) problem solving by other means, (2) focus on product quality, (3) task requires specialised knowledge and (4) concepts and principles not necessary for the purpose.

In the following these issues are described by means of episodes from the video material. The subsequent discussion relates the findings to how the nature of technology and technological knowledge is described in the literature and then discusses implications in an educational context.

4.6.1 Problem Solving by Other Means

In the projects, students encountered challenges that potentially could invite them to make use of knowledge from science and mathematics to solve the problems and develop their products or to generate a need for attaining this kind of knowledge. The use of scales in making models is an example from several of the projects analysed. The selected episode is from project 2 where students design a model of their hometown and surrounding landscape and where correct scales were essential in order to make different parts of the model fit each other. The project is good in this regard, as correct use of scales is a prerequisite for success, and the challenge is placed in a very concrete context. The task became, however, rather complex due to the irregular shape of the landscape the students were to model and also because students had to move between three representations when calculating scales: the model, the map and the real landscape.

This sequence shows how students arrive at a way of solving the problem of scaling up parts of the map to fit the board where the town model is to be built. The students are discussing and calculating, standing beside the map hanging on the wall:

Student 1: But how on earth can we get this thing onto the board?
Student 2: We just measure in centimetres…
Student 3: What we do is to get this [the map] onto an overhead foil. Then we put the board up towards the wall and move the overhead projector backwards until it fits. And then we just transfer the drawing!

The group of students enters the task with renewed enthusiasm and solves the problem in much more effective and reliable ways than by using scales to calculate measures for each parts of the model. For mathematics content, the student's solution involves understanding of scales in the sense that she was aware of how an overhead projector creates an enlarged image with identical geometry as the original map. Other students might also learn from this experience. However, in the end it did not give the student group as a whole much experience in calculating scales the way they learn, and are tested, in mathematics as a school subject.

4.6.2 Focus on Product Quality

In technology and design, the quality of the final products is more pertinent than in the practical work students usually perform in science and mathematics. The desire for high quality influences the choices teachers and students make and hence the knowledge involved in the activity. In some instances, this means that a considerable amount of time is spent in enhancing the quality in terms of various forms of decoration, which may diminish the focus on technical problem solving. In the projects in this study, we also found examples of how desires for product quality diminished the focus on knowledge components from science and mathematics in other ways.

The selected episode is from student project 2, supposed to entail working with electric circuits, and hence elements from the science curriculum. This could have been done by giving students experience with wiring lights and thereby working with principles such as closed circuits and differences between circuits in series and parallel. Instead, the teacher provided chains of ready-made Christmas lights for lighting up the town model. This makes perfectly sense from a pragmatic point of view, as the light chains are easily available, relatively cheap and make the resulting product of higher quality than letting students wire their own circuits, which would be more time-consuming and probably result in unstable circuits. At the same time, this choice diminished the science component of the project, as there was no need for experimenting with or discussing properties of the electric circuit. The project on creating the town model involved, however, other motivating challenges for the students, and the teacher described the students' learning as 'high-level problem solving' in a heuristic way rather than in terms of specific content outcome from subjects in the curriculum.

4.6.3 Task Requires Specialised Knowledge

In some aspects of the student projects, challenges for students require understanding of general principles in order to accomplish their tasks. The episode selected represents the model of an oil rig students are to construct with Lego systems in project 3. The Lego set contains a great variety of components to be combined in order to construct the desired mechanism. The working principles of the components and their combination can in principle be described by means of concepts from physics, such as rotation, velocity, force and energy transfer. None of these concepts were used by students or the teacher in any scientific way in the project. This is with good reason, since the mechanisms are better described in terms of principles that are technological in nature, more specialised and directly related to the components students are working with. The video recordings of the project revealed that students did not possess this kind of knowledge and that this obstructed their progress in the project. Their work to make the desired mechanisms was hence characterised by trial and error with the available components and heavy guidance by the teacher in order to arrive at the desired movement in the model of an oil rig. The teacher's guidance of one group of students who was to construct a device that can transform rotation into vertical movement involved the following sequence:

Teacher: The point is, how can you make this motor lift this other one? Have you seen this piece? [The teachers show the group of students the Lego brick that works as a rack.]

Student 1: I know it.

Teacher: Yes, is it possible to use this one? (…) Let's say, a cog is assembled to this shaft, for instance… [The teacher puts a shaft in the centre hole of the motor and mounts a cog to the shaft]. The cog will rotate, ok?

Student 2: Yes.

Teacher: So, if you then could mount this part [the rack] perhaps like this [joins the rack and the cog]… do you agree that this [the rack] will move up and down?

Student 3: Wow, that was smart!

The teacher puts the students on the right track by showing them how mechanisms can be used in order to achieve the desired result. The guidance is very visual, demonstrating the teacher's 'know-how' in the particular situation. The use of language is hence limited in terms of concepts. However, the relevant concepts (such as those added in brackets above) are specific technical concepts rather than scientific concepts for how the suggested devices for the mechanism work. The concepts learnt in science can be related to the task, but are too general to be of any practical use.

4.6.4 Concepts and Procedures Not Necessary for the Purpose

In some parts of the student projects, teachers attempted to include concepts and principles from science and mathematics, in line with the intentions of the curriculum. This was not always well received by students, as they did not see it necessary for solving the technology and design task they were working on. They were highly motivated for the practical project, but this did not necessarily motivate them for using the project as context for working with science and mathematics as the task could well be solved with less advanced knowledge that the student already possessed. Our illustrating episode is a situation where a student has used Google SketchUp to construct a model for a playground construction (project 1). This student usually showed low motivation for traditional school subjects and particularly for mathematics. However, in this project he had worked with strong dedication on designing the playground construction on the computer. The teacher saw this as a good opportunity to get the student involved in calculations of scales for his model. Some of the dialogue ran as follows:

Teacher: With this scale, this side becomes 32.42 cm. Is that an appropriate measure for your model?
Student: I *said* it is to be 30 cm!
Student: This side is to be 15 cm.
Teacher: But that is not in accordance with your drawing.
Student: (annoyed) So what?!
Teacher: We have now found two of the sides. Now you can do the rest. You will manage
(student showing reluctance).
Teacher: You don’t seem to agree?
Student: I don’t know, I cannot do math, I hate math!

Not only is this student reluctant to dealing with mathematics as such, he clearly also doesn’t see it as bringing him any further in the practical task of constructing the model. Actually, he is perfectly right in that his rough measure of ‘30 cm’ is sufficient for the purpose and doesn’t need to be further specified by the precise measure resulting from calculation the teacher tries to make him do. In addition, even if the teacher is patient and does an effort to get him involved, the student seems to lose his motivation for the project that he initially enjoyed working with.

4.7 Discussion: Relating Findings to Perspectives on Technology

Our empirical study and analysis have identified key issues of importance for why conceptual knowledge from science and mathematics does not necessarily form part of students’ work in design and technology, even if the subject matter from these subjects seems relevant for the task.

The issue *Problem solving by other means* reflects the nature of technology in the sense that the activity is flexible in use of ideas and materials. Technological activity searches for usable solutions that are optimal in terms of labour, costs and result. When students overcome the problems of calculating scales by utilising an existing technology (the overhead projector) that is more effective and probably more reliable, it resembles to a high degree the way technologists work. The students have many times watched teachers moving projectors back and forth in order to adjust the size of the image it creates. This associative way of solving the problem by imagining how tools can be transferred from one context to another can be seen as an example of technological creativity (see Lewis 2009). From a mathematical point of view, the students' solution clearly involves mathematical thinking, but it does not provide any experience with the kind of calculations students are expected to perform in mathematics and required in the curriculum.

Problem solving by other means based on student initiative is relatively rare in the data material, and this can be explained by the fact that students often lack knowledge about and access to the more effective alternative means. Teachers might also actively restrict students' access to alternative means for the sake of including the basic skills, such as calculating scales by hand, that might form a learning target in the activity. If the aim is to foster technological capability, however, teachers should encourage the alternative technology-based approaches and equip students with knowledge of the relevant effective technological tools prior to the project.

The second category *Focus on product quality* relates to the previous in the way it reflects the nature of technology. The difference lies in that problem solving by other means concerns the work process, while this issue concerns the resulting product. When designing and making a product, students and teachers will value the result of high quality. The industrial designed light chains in project 2 are clearly of higher quality than self-soldered circuits, in terms of aesthetics as well as reliability. McCormick and Davidson (1996) have pointed to what they denote the 'tyranny of product outcome' in design and technology classrooms. They argue that the focus on the final product prevents students from going deeply into the design process. From our study, we can conclude that this also applies to the potential science learning outcome of the activity. Again, the way the teacher and students approached the task of enlightening their town model makes perfectly sense from a technological point of view. In order to integrate content knowledge on electric circuits in the project, the task would need to be more complex, for example, by creating a desire to enlighten all the smaller roads in the town model, where ready-made light chains no longer are suitable. This could alter the conception of what product quality means in the project.

Task requires specialised knowledge involves that the knowledge that potentially could be related to the technological activity is not of an appropriate character for the purpose. The task requires more specialised knowledge that school science offers. In this study, this applies in the project about drilling rigs. Mechanisms for transfer of movement are associated with concepts and principles, but these do not mainly involve the basic concepts of physics. Rather they represent operational principles (Vincenti 1990) and engineering theory (Staudenmaier 1985) more appropriate for this technological domain of knowledge. As Layton (1991) has pointed to, scientific knowledge of physical mechanics is not directly applicable in this context and will have to be restructured according to the specific mechanisms in order to be useful. The problem for students in designing the model of the drill was clearly related to their lack of familiarity with mechanisms and their principles. The problem would not be solved by concepts from physics, but rather by genuine technological knowledge of the various mechanisms' operational principles.

The fourth category, *Concepts and procedures not necessary for the purpose*, relates to how content from science and mathematics is seemingly relevant in the context, but where it does not contribute to the students' activity in the sense of generating a product outcome. The student used as example from the project on constructing models of playground equipment expresses this in very explicit terms, as he refuses to deal with mathematics at all in his work. His arguments are very sensible in the actual context, because the accuracy the calculation of scales provides in this project goes far beyond the required level of accuracy in making the cardboard model. The student realises that the suggested tool (calculating scales) is not well suited for the purpose, in line with how Norman (1998) was warned against a too strong focus on mathematical optimisation during the development of ideas in technology and design. This is only significant when most of the design activity is over and the problem has been reduced to one that is well defined. The student's reaction resembles what constitutes the core of technological activity as dynamic and situated, where knowledge, tools and procedures are chosen in pragmatic ways to fit the desired outcome (Ropohl 1997). If the benefit is negligible, there is no reason to spend the cost of enhanced accuracy.

Clearly, student projects could be better designed in order to incorporate science and mathematics in more direct ways. Other studies have pointed to that also pedagogy and teacher competence are important (McCormick and Evans 1998; Norton and Ritchie 2009; Sidawi 2007). These are all crucial elements in developing high-quality technology teaching. However, our analysis indicates that the challenges are not only a matter of good project design, pedagogy or teacher competence; they are deeply situated in the nature of the knowledge involved. All the four issues identified in this study concern fundamental aspects of the nature of technological knowledge and practice in explaining the lack of content knowledge from science and mathematics in technology projects. Our study suggests that the technological problems students typically encounter in technology projects are not best solved by the conceptual knowledge these subjects offer on school level, unless the project is specifically and carefully designed for this particular purpose. In that case, however, projects would be less authentic as technology and design projects.

4.8 Conclusion: How Can Projects in Technology and Design Serve as Learning Contexts for Science and Mathematics?

The results presented in this chapter suggest that problems of incorporating science and mathematics in technology and design projects are strongly related to fundamental characteristics of technology as knowledge and practice. Concepts and principles from science and mathematics may be relevant in a theoretical sense, but often not of any use for students in performing the technological task. Instead, technological tasks require technological knowledge.

Based on these results we suggest that technology and design should be given a clear identity in its own right in the curriculum. However, multidisciplinary approaches should still be encouraged. Technology and design projects may provide contexts and experiences that can be utilised in constructive ways for science and mathematics learning. As examples, the three projects presented in this chapter could provide contexts for students to work conceptually with concepts and principles related to scale, electric current, forces and movement. This subject content could be taught *after* the students have got some experiences with material and technological challenges in the relevant situations without being seen as prerequisites or functional tools for attaining the technological outcome. The practical contexts can this way serve as examples that function as stepping stones to the more general concepts and a more general understanding.

Norton and Richie (2009) have discussed the two approaches *just in case* and *just in time* for how conceptual knowledge can be taught in relation to a practical project. The former implies that the conceptual content is taught before the project, and the latter implies that it is taught when the need occurs. In light of our results and perspectives on technological knowledge, our suggestion would rather be a *just afterwards* approach. This would involve that practical projects in technology and design have their focus on technological knowledge, but that projects students have worked with could thereafter serve as relevant contexts and a source of experiences to explore conceptual knowledge from science and mathematics.

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Chapter 5
Can the Principles of Topic-Specific PCK Be Applied Across Science Topics? Teaching PCK in a Pre-Service Programme

Marissa Rollnick and Elizabeth Mavhunga

5.1 Introduction

Pre-service teacher education has undergone many changes in the past 30 years. Controversies exist about many aspects of the activity, but one of the most contentious issues is the mode of delivery of the content and its methodology. Between the science content and methodology lies the students' pedagogical content knowledge (PCK) which refers to their ability to transform content knowledge for teaching. The term PCK was first introduced by Shulman (1986) though the concept has been in existence far longer (Klafki 1958). PCK is regarded as tacit knowledge gained in practice (Kind 2009) and thus difficult to pass on to others. Most importantly, it is topic specific (Mavhunga and Rollnick 2013) and thus needs to be learnt for every topic taught.

This study was conducted on the back of an earlier intervention (Mavhunga and Rollnick 2013) which showed that it was possible to improve pre-service teachers' topic-specific PCK in chemical equilibrium through a 6-week intervention. A critique of this approach was that it is not possible in a normal pre-service programme to devote 6 weeks' instruction to each topic needing to be taught in a curriculum. This study made use of further data gathered from the intervention to investigate the possibility of transferring the knowledge gained in the intervention to a second topic in physical science.[1]

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[1] Physical science refers to a school subject consisting of chemistry and physics in equal proportions in most cases.

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5.2 Background

Much has been done in the 30 years since Shulman first introduced the idea of pedagogical content knowledge. A look at the literature suggests that despite an enthusiastic uptake of Shulman's ideas, there have been as many models of PCK as there are researchers. In recent reviews (Kind 2009; Abell 2007; Jing-Jing 2014), researchers attest to the multiplicity of representations and terminology in the area and agree that thinking about PCK has yet to unify into a single paradigm. Despite this lack of agreement amongst researchers, PCK remains a useful construct and in Abell's and Kind's view is an invaluable theoretical framework for understanding teachers' knowledge. A summit convened in October 2012 in Colorado produced consensus definitions and a model for PCK and the relationship between knowledge and practice (Gess-Newsome 2015). Much research has also been devoted to capturing and portraying PCK using Content Representations (CoRes) and Pedagogical and Professional-Experience Repertoires or PaP-eRs (e.g. Loughran et al. 2006), and some attempts have been made in science education to assess its quality (Kirschner et al. 2015). Part of the problem in this regard is the need to specify exactly what is being assessed. In our view, the value of PCK for improving the quality of teaching lies in its topic-specific nature.

Different models of PCK are employed in the studies cited above, but none provide a perspective of PCK which is located in a specific topic. Our interest is predominantly in topic-specific PCK. The topic-specific nature of PCK has been attested to by many empirical studies in science education (e.g. Loughran et al. 2004). In a previous study (Mavhunga and Rollnick 2013) we introduced the construct TSPCK. We argued that its value lies in its exclusive focus on a topic, in particular, the capacity to transform concepts within a topic. The study further showed that pre-service teachers, in line with Nilsson and Loughran (2012), can develop this capacity by focusing on the nature of the knowledge components of TSPCK. This allows them to elicit specific knowledge about teaching the content knowledge thereby transforming it and significantly improve their PCK in a topic. Hence we regard TSPCK as the knowledge needed for transformation of content knowledge in a particular topic into teachable form using pedagogical reasoning (Shulman 1987). When the teaching of a specific topic is thought through, certain topic-specific components of PCK are considered. We identify these as (1) learners' prior knowledge, (2) curricular saliency (deciding what is important for teaching and sequencing), (3) what makes topic easy or difficult to understand, (4) representations including powerful examples and analogies and (5) conceptual teaching strategies as shown in Fig. 5.1. The quality of TSPCK is influenced by both the knowledge of the content-specific components as well as their interaction (Mavhunga 2015) amongst each other. This definition distinguishes TSPCK from the broader PCK in that it has a selective focus on content knowledge (CK) and the specific knowledge that transforms it. Thus the principles behind the development TSPCK in a topic are based on pedagogical reasoning (Shulman 1987) of the topic concepts where pedagogical transformation is emphasised and considered to emerge from the

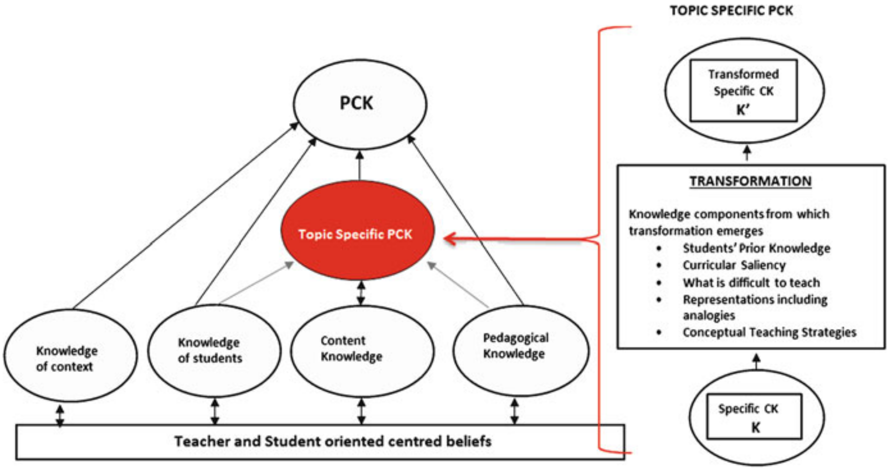
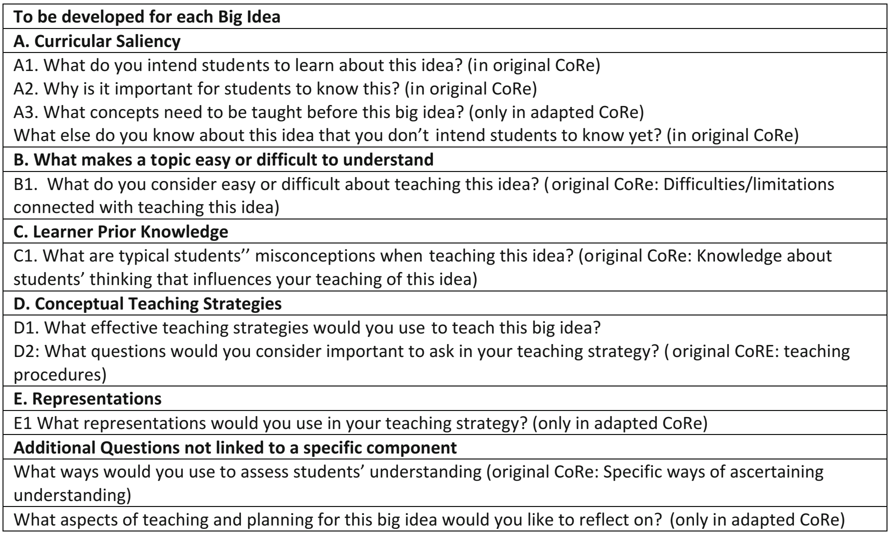


Fig. 5.1 A model of topic-specific PCK (Mavhunga and Rollnick 2013)

knowledge and use of the five TSPCK components interactively. Since the use of these components will depend on the topic being taught, it means that once they are developed for one topic, they would need to be developed separately for different topics. It therefore stands to reason that TSPCK per se is not transferable across topics as pedagogical transformation is needed for each unique topic. However we suggest that the understanding of the 'how' is perhaps transferable. This is the possibility which this study seeks to investigate.

The five categories of TSPCK mentioned above are closely related to the eight prompts used in CoRes (Loughran et al. 2006) to capture the teaching of big ideas on a topic. The first three prompts, viz. 'What do you intend students to learn about this idea?'; 'Why is it important for students to know this?'; and 'What else you might know about this idea (that you don't intend students to know yet)?', are linked to curricular saliency (component (2) above). Their fourth prompt, 'Difficulties/limitations connected with teaching this idea', is linked to what makes a topic easy or difficult to teach (component (3)), while Loughran et al.'s fifth prompt 'Knowledge about students thinking that influences your teaching of this idea' links to the first component of learner prior knowledge in the TSPCK framework. The sixth prompt, 'Other factors that influence your teaching of this idea', is more generic and difficult to link directly to any of the components, but the seventh and eighth prompts, 'Teaching procedures' and 'Ways of ascertaining students' understanding of this idea', are linked to the fifth component on conceptual teaching strategies. The TSPCK component of representations does not have a direct link to any of the CoRe prompts, so it was considered separately in the modified CoRe shown in Fig. 5.2. Thus, as discussed in the methodology below, the idea of a CoRe as a tool to capture TSPCK was attractive to this study.



To be developed for each Big Idea
A. Curricular Saliency
A1. What do you intend students to learn about this idea? (in original CoRe) A2. Why is it important for students to know this? (in original CoRe) A3. What concepts need to be taught before this big idea? (only in adapted CoRe) What else do you know about this idea that you don't intend students to know yet? (in original CoRe)
B. What makes a topic easy or difficult to understand
B1. What do you consider easy or difficult about teaching this idea? (original CoRe: Difficulties/limitations connected with teaching this idea)
C. Learner Prior Knowledge
C1. What are typical students'' misconceptions when teaching this idea? (original CoRe: Knowledge about students' thinking that influences your teaching of this idea)
D. Conceptual Teaching Strategies
D1. What effective teaching strategies would you use to teach this big idea? D2: What questions would you consider important to ask in your teaching strategy? (original CoRE: teaching procedures)
E. Representations
E1 What representations would you use in your teaching strategy? (only in adapted CoRe)
Additional Questions not linked to a specific component
What ways would you use to assess students' understanding (original CoRe: Specific ways of ascertaining understanding)
What aspects of teaching and planning for this big idea would you like to reflect on? (only in adapted CoRe)

Fig. 5.2 Skeleton of adapted CoRe

As mentioned above, the main aim of this paper is to investigate the possibility of transfer of the principles of TSPCK between two topics in physical science by asking the following questions:

1. What is the quality of TSPCK of student teachers after an intervention aimed at teaching them TSPCK in chemical equilibrium?
2. What is the quality of their TSPCK in a different topic after teaching it during their practicum?
3. To what extent have the student teachers successfully transferred the techniques they have learnt for developing TSPCK to the new topic?

5.3 Research Design and Methodology

The study described in this paper is a mixed methods study in which 16 final year physical science pre-service teachers were exposed to a 6-week intervention aimed at improving their TSPCK on chemical equilibrium. Mixed methods (Teddlie and Tashakkori 2009) were used to allow measurements to be made of data from qualitative sources while enriching the quantitative data with qualitative evidence.

5.3.1 Participants

The 16 secondary school pre-service teachers were in their final year of study towards a 4-year undergraduate teacher qualification with physical science as their major subject. The majority of the pre-service teachers come from the rural areas of

South Africa. Communities in these rural areas are commonly exposed to poor education and likely to have very few science teachers with a degree qualification. The general understanding is that the national department would place these final year students as qualified science teachers back in their communities on graduation. All but one of the pre-service teachers used English as a second language.

5.3.2 Description of the Implementation

The intervention focused on exposing the pre-service teachers to TSPCK with respect to the five components elucidated in the theoretical framework outlined above in the context of chemical equilibrium. Chemical equilibrium was chosen as a topic because the pre-service teachers had previously been exposed to it in a separate content course. It is also considered difficult and abstract with terminology that is specific to the topic, yet it constitutes the foundational understanding needed in other chemistry areas (Van Driel and Graber 2002). The five knowledge components were discussed during the intervention one at a time in the sequence given in Table 5.1 in line with suggestions by Nilsson and Loughran (2012) that paying more careful attention to the 'nature of the components that serve as the foundation for PCK offers a way of assisting student teachers to better understand their ongoing professional learning' (p. 20).

5.3.3 Data Collected

The quality of the pre-service teachers' TSPCK in the earlier study (Mavhunga and Rollnick 2013) was shown to have undergone a significant improvement in both their TSPCK and their content knowledge (Ellis 2007). Towards the end of the intervention,

Table 5.1 Overview of intervention activities

Component	Intervention
Student prior knowledge	Discussions on widely researched conceptions and common misconceptions on particle nature of matter found in the literature. Emphasis was placed on awareness and recommended teaching strategies to confront misconceptions
Curricular saliency	Identification of the big ideas and the corresponding subordinate concepts in a topic, sequencing for scaffolding learning, awareness of the background concepts needed before teaching the topic and knowing what is most important to understand in topic
Why it is difficult to teach	Exploration of gate keeping concepts considered difficult to learn and not necessarily misconceptions
Knowledge of representations	Introduction of the three levels of explanations in chemistry at macroscopic, symbolic and submicroscopic level. Emphasis was placed in using all three representations in explaining a phenomenon
Conceptual teaching strategies	Emphasis on conceptual strategies rather than general pedagogy and logistics

the participants were given a major assignment which required them to provide a completed CoRe together with expanded lesson outlines on chemical equilibrium. The expanded lesson outlines were descriptions, in a planning context, outlining a lesson for each of the suggested big ideas in the CoRe. The format of the CoRe was adapted (see Fig. 5.2) to include the five components of TSPCK explicitly.

Later in the academic year, the pre-service teachers were exposed to two periods of practicum where they were required to teach a range of topics. At the end of the academic year, they were required to complete a take-home assignment as summative assessment for their course (referred to as an examination equivalent). In this assignment they were asked to complete another CoRe task, supported with expanded lesson outlines on a topic other than chemical equilibrium which they had taught during their practicum. The expanded lesson outlines for this task would be of a reflective nature in line with the conception of PaP-eRs (Loughran et al. 2006).

The CoRes together with the expanded lesson outlines produced for the (1) major assignment on chemical equilibrium and (2) end-of-year examination equivalent assignment on various science topics constituted the data for this study.

5.3.4 Data Analysis

In the earlier study (Mavhunga and Rollnick 2013), a rubric based on the five components of the TSPCK theoretical framework (Fig. 5.1) was developed which allowed classification of pre-service teachers' TSPCK as limited, basic, developing or exemplary. For this study the rubric was adapted and used to assess the PCK of the students in the topics as demonstrated in the CoRes used for the two tasks. Table 5.2 shows an extract from the adapted rubric for the first component, understanding of learners' prior knowledge.

Table 5.2 Extract from adapted rubric for scoring CoRes (learner prior knowledge component)

Limited TSPCK	Basic TSPCK	Developing TSPCK	Exemplary TSPCK
Scored 1	Scored 2	Scored 3	Scored 4
No identification/ acknowledgement/ consideration of student prior knowledge or misconceptions	Identifies misconception or prior knowledge on one idea only	Identifies misconception or prior knowledge on two or more big ideas	Identifies misconception or prior knowledge on all big ideas
	Calls for standardised knowledge as definition	Provide standardised knowledge as definition	Provide standardised knowledge as definition
	Repeats standard definition with no expansion		Confronts misconceptions/ confirms accurate understanding with evidence of consideration to curricular saliency or what is difficult or representations

The rubric has four categories (limited with a score of 1, basic with a score of 2, developing to exemplary with a score of 4). The raw scores generated from using the rubric were peer validated by independent raters familiar with the theoretical framework, and an agreement rate of 80 % was obtained. The average scores reflected the quality of the TSPCK of the group captured in the CoRes. The scores were then converted to Rasch scores (Bond and Fox 2001) to provide a linear expression of the ordinal scores determined above and enable determination of the item difficulty order for the five components of TSPCK in each of the two sets of CoRes and calculate reliability.

5.4 Findings

Table 5.3 presents the scores generated from using the rubric described above.

On inspection the table shows that the half of the pre-service teachers (SM to BS) attracted high scores across the five components of TSPCK in both the topic of

Table 5.3 Scores generated from the major assignment and examination assignment[a]

Pre-service teachers (pseudonym)	Topic of exam assignment	Learner prior knowledge	Curricular saliency	What is difficult to understand	Representations	Teaching conceptual strategies
SM	Acids and bases	(3)4	(4)4	(3)4	(3)3	(4)4
PRM	Kinematics	(3)3	(4)2	(3)3	(4)2	(4)3
MC	Electric circuits	(4)4	(4)2	(3)3	(3)4	(4)3
TSM (Faith)	Electric circuits	(3)3	(3)2	(3)4	(3)3	(3)3
PM	Electric field	(3)3	(3)3	(3)3	(2)3	(2)3
LLM (Legotla)	Ideal gas laws	(2)3	(3)4	(3)4	(2)4	(2)4
KM	Waves, sound and light	(3)3	(2)3	(3)3	(3)3	(2)3
BS	Waves, sound and light	(3)3	(2)3	(2)2	(2)3	(2)3
NG	Kinematics	(3)3	(2)2	(2)3	(3)3	(2)2
BM	Kinematics	(4)1	(2)2	(4)1	(2)2	(3)2
KGSE	Metals and non-metals	(2)1	(3)1	(3)1	(2)2	(2)2
MM	Energy	(2)2	(3)2	(3)2	(2)2	(2)3
TM	Electrodynamics	(2)2	(2)2	(2)2	(3)2	(2)2
JDL	Electric circuits	(1)2	(1)1	(3)2	(2)2	(2)2
JS	Electrochemistry	(2)2	(2)2	(1)1	(1)1	(2)1
ZS	Electrochemistry	(2)3	(2)2	(2)2	(3)3	(1)2
Mean per component		(3)3	(3)2	(3)3	(3)3	(2)3
Group mean		A mean of 3 for both the major and the examination assignment				

[a] Scores of the major assignment are in *brackets* and those of the examination assignment *outside brackets*; all students had a common topic of chemical equilibrium for the major assignment

intervention (chemical equilibrium) and the topic chosen for the examination task, while a quarter (NG to MM) attracted high scores only in the topic of intervention, and an equal number (TM to ZS) had low scores in both the topics. The aggregated group mean was calculated at 3 for both the tasks. A score of 3 corresponds to the ‘developing’ category. In this category, the rubric used suggests that pre-service teachers are able to identify common misconceptions in a topic and provide an expanded explanation based on a standard definition. However, their explanations are yet to reflect a conscious effort to provide key information to combat the identified misconception. They are further able to organise the topic into three suitable big ideas and sequence them logically but may still struggle to provide concise explanations that link subordinate concepts to corresponding big ideas. They are also able to identify what is difficult to understand providing reasons linked to common student misconceptions or prior knowledge. Their use of representations largely entails a combination of macroscopic and symbolic levels with the submicroscopic level rarely demonstrated. The conceptual teaching strategies that they provide show evidence of consideration of one of the other components of TSPCK, i.e. awareness of curricular saliency aspects or representations at two levels or awareness of what is difficult to understand.

An average score in the developing category is encouraging given that the pre-service teachers are still in training. They show evidence of being able to teach more than content knowledge per se. They are grounded in it and are able to address its teachability. While this understanding is at a planning or thinking level, it constitutes important teacher knowledge to draw upon in practice (Shulman 1987). Thus, the finding of a ‘developing’ score in the topic of examination is encouraging as it implies that there has been transfer of the ability to use the TSPCK framework in reasoning through the topic of examination and thus developing TSPCK in it as a new topic to the same extent as in the topic of the intervention.

In order to gain more insight into how the pre-service teachers interacted with the TSPCK components in the two different topics, we ran item analysis using the Rasch statistical model. Item analysis provides information about the validity of the items, their relative difficulty as experienced by the pre-service teachers.

5.4.1 Item Analysis

Rasch analysis provides measures on two levels – it provides findings with the respect to the ‘items’ (in this case the five components of TSPCK) and at the level of ‘persons’ (in this case the 16 pre-service teachers participating in the study). Table 5.4 provides a summary of the relevant values obtained. The lack of spread of item scores leads to the low value of item reliability. On the other hand the person reliability is high for both tasks.

Despite the poor spread of the item scores, there is a recognisable pattern in their order. As the Rasch measures for the items are directly related to the relative difficulty of the items, they signal a different hierarchy of difficulty for each of the two

Table 5.4 Results of Rasch item analysis

Item (TSPCK component)	Major assignment Rasch measure	Item (TSPCK component)	Exam equivalent Rasch measure
Curricular saliency	0.58	Representation	0.54
What is difficult to understand	0.29	Conceptual teaching strategies	0.26
Learner prior knowledge	–0.29	Learner prior knowledge	0.00
Representations	–0.29	Curricular saliency	–0.27
Conceptual teaching strategies	–0.29	What is difficult to understand	–0.53
Item reliability	0.00	–	0.00
Person reliability	0.93	–	0.80

tasks. Components of TSPCK with positive Rasch measures imply a higher level of difficulty for pre-service teachers than those with negative values. Thus Table 5.4 presents the difficulty in a descending order for each task, starting with the most difficult to the easiest at the bottom of the table. The observed difference in hierarchy is testimony to the difference in demand between different topics and therefore to the different experiences by pre-service teachers as they engage and reason through the components of TSPCK. For the major assignment, the last three items are of equal difficulty meaning that pre-service teachers experienced the engagement with these components of TSPCK to be at the same degree of difficulty. We attribute the poor item reliability to the poor discrimination between the item scores and attribute the different order in the rank of difficulty in terms of the different demands of the topics as guided by the adapted CoRe and the reflections in the lesson outlines.

The discussion so far has provided insight into the measurement of the quality of TSPCK captured in the adapted CoRes of the different topics in the two assignments. Below we provide a qualitative discussion portraying the responses that served as windows into the developing TSPCK of the pre-service teachers.

5.4.2 Qualitative Analysis of CoRes

The pre-service teachers chose a variety of topics for their exam tasks as illustrated in Table 5.3. These included kinematics, electrochemistry, acids and bases, current electricity, electrodynamics, electric fields and electric field strength. Since the task is an examination equivalent assignment, it would be expected that they would choose a topic that they felt they had taught with confidence, implying a good understanding of the content. However, in some cases, lack of content knowledge was observed, and in these cases poor TSPCK scores were observed.

Below are exemplars of developing TSPCK responses from two pre-service teachers in the two assignments.

In the component of learner prior knowledge, the pre-service teachers were exposed to literature on misconceptions in chemical equilibrium (e.g. Huddle and Pillay 1996; Tyson and Treagust 1999). However in the case of the topic used for the exam equivalent, there was no such exposure, and the pre-service teachers had to glean this knowledge from student responses and correcting written work during their practicum. Given this limitation, the responses were encouraging. Figure 5.3 shows an extract from Faith's CoRe in response to the prompt, 'What are students' typical misconceptions when teaching this idea?' on chemical equilibrium, while Fig. 5.4 shows her CoRe responses to the same prompt on the topic of electricity.

Both Figs. 5.3 and 5.4 contain well-documented misconceptions in the two subject areas, e.g. (Huddle and Pillay 1996; Tyson and Treagust 1999) in the case of chemical equilibrium and Mulhall et al. (2001) in the case of electric circuits. Faith's expanded lesson outline, see extract below, indicates how she picked one of the misconceptions listed in Fig. 5.5 from a previous lesson and used it as a starting point in the next lesson.

The expanded lesson outline indicates how student Faith recognised the need to inform her lesson plan for the next lesson. She began by providing a conceptual strategy that sought to combat the misconception; see extract in Fig. 5.6.

There are also pleasing signs of integration of the other four components when it comes to designing conceptual teaching strategies and attempts to encourage student participation. Figures 5.7 and 5.8 show the comparison between responses regarding chemical equilibrium in the major assignment and the gas laws in the examination assignment taken from the extended lesson outlines for Legotla.

-concentrations equal at equilibrium -every closed system is at equilibrium -equilibrium means reaction completion -equilibrium meaning activation point	-effects of temperature, pressure affecting one side of the equation -catalyst increasing the concentration of the reaction -catalyst fostering rate of reactions

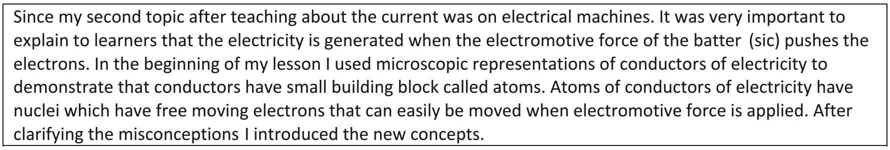
Fig. 5.3 Faith's CoRe responses for learner prior knowledge for the topic of chemical equilibrium

- current flows from an electric source such as a batter to a resistor, but not from a resistor to the battery - all the electrons that make up an electrical current are initially contained in the battery or generator that is the source of the electricity - Wires have a hollow space like a water hose, and electrons move inside the hollow space	- A larger battery will make a motor run faster - Only magnets produce magnetic fields - Machines put out more work than people put in

Fig. 5.4 Faith's CoRe responses for learner prior knowledge for the topic of current electricity

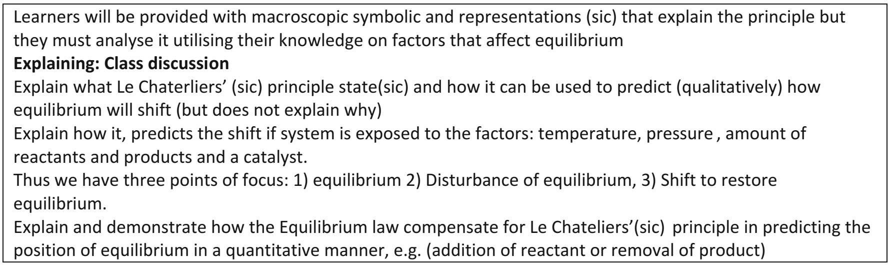
One of the misconceptions I identified from the previous lesson was that "Wires have a hollow space like a water hose, and electrons move inside the hollow space". This kind of misconception if not addressed can cause many misconceptions on how the electric machines functions (sic).

Fig. 5.5 Extract from student Faith's extended lesson outline showing identification of misconceptions



Since my second topic after teaching about the current was on electrical machines. It was very important to explain to learners that the electricity is generated when the electromotive force of the batter (sic) pushes the electrons. In the beginning of my lesson I used microscopic representations of conductors of electricity to demonstrate that conductors have small building block called atoms. Atoms of conductors of electricity have nuclei which have free moving electrons that can easily be moved when electromotive force is applied. After clarifying the misconceptions I introduced the new concepts.

Fig. 5.6 Extract from student Faith's extended lesson outline showing conceptual teaching strategy for clarifying a misconception



Learners will be provided with macroscopic symbolic and representations (sic) that explain the principle but they must analyse it utilising their knowledge on factors that affect equilibrium

Explaining: Class discussion

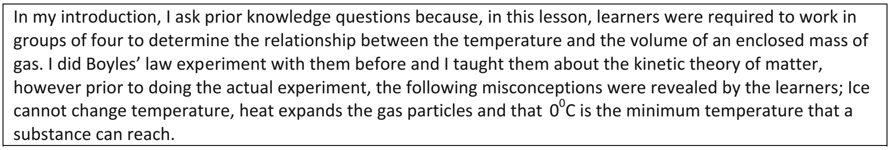
Explain what Le Chaterliers' (sic) principle state(sic) and how it can be used to predict (qualitatively) how equilibrium will shift (but does not explain why)

Explain how it, predicts the shift if system is exposed to the factors: temperature, pressure , amount of reactants and products and a catalyst.

Thus we have three points of focus: 1) equilibrium 2) Disturbance of equilibrium, 3) Shift to restore equilibrium.

Explain and demonstrate how the Equilibrium law compensate for Le Chateliers'(sic) principle in predicting the position of equilibrium in a quantitative manner, e.g. (addition of reactant or removal of product)

Fig. 5.7 Extract from Legotla's extended lesson outline showing conceptual teaching strategies for the topic of chemical equilibrium



In my introduction, I ask prior knowledge questions because, in this lesson, learners were required to work in groups of four to determine the relationship between the temperature and the volume of an enclosed mass of gas. I did Boyles' law experiment with them before and I taught them about the kinetic theory of matter, however prior to doing the actual experiment, the following misconceptions were revealed by the learners; Ice cannot change temperature, heat expands the gas particles and that 0^0C is the minimum temperature that a substance can reach.

Fig. 5.8 Extract from Legotla's extended lesson outline showing conceptual teaching strategies for the gas laws

Both sets of responses show awareness of learner prior knowledge, use of representations and awareness of the need to involve students in their lessons.

5.5 Conclusions

The main question we sought to answer in this study was whether the principles of TSPCK can be applied across science topics when teaching PCK in a pre-service programme. In terms of our theoretical framework, we assumed that because TSPCK is topic specific, the knowledge itself cannot be transferred across topics, but we sought to investigate whether the principles of pedagogical reasoning about the topic are transferable. These principles refer in particular to the transformation emerging from the knowledge and application of the five TSPCK components used in this study, viz. (1) learners' prior knowledge, (2) curriculum saliency (deciding what is important for teaching and sequencing), (3) what makes topic easy or difficult to understand, (4) representations including powerful examples and analogies and (5) conceptual teaching strategies.

In answer to the first research question related to the quality of TSPCK of student teachers, they were found to have a 'developing' level of TSPCK as measured by the rubric which is satisfying considering that they are still in training. The qualitative analysis showed that they were able to recognise well-known misconceptions in the topic of chemical equilibrium.

With regard to the second question about their TSPCK in a different topic, they were also found to be at the 'developing' level. However the qualitative analysis showed that they were less able to recognise misconceptions as easily but did well in choosing suitable representations. This knowledge was gained in practice through their practicum period.

The third question related to the ability of the student teachers to transfer the learnt techniques to the new topic, we found that in general there was good transfer. The analysis indicates a positive transfer of these principles as measured by the captured TSPCK in the topic of the exam which was found to be of comparable quality to that developed through explicit means in chemical equilibrium, the topic of the intervention.

This finding shows promise as it provides a feasible route for the development of PCK in pre-service teacher development programmes. It further suggests that it is worth spending in in-depth class time studying one or two topics in the hope that pre-service teachers will be able to work through other topics to be taught using a similar approach. However given that prerequisite content knowledge is a necessary precursor for PCK (Kind 2014), and content knowledge of the other topics would need to be in place for the successful transfer of the pedagogical transformation competencies and the ensuing development of TSPCK in the topic of transfer.

The study also showed the possible use of the combination of a quantitative TSPCK rubric with qualitative CoRes and the supplementary tasks in a planning context in the major assignment and the traditional reflective tool in the exam assignment. While the Rasch analysis indicates poor item separation and therefore poor item reliability, the high person reliability indices generated from both the scores of assignments qualify the reliability of the rich data captured from the qualitative sources. CoRes and associated tasks thus can be used to capture the quality of TSPCK. Their use has both advantages and disadvantages. On the one hand, they can provide more extensive evidence of PCK, but this evidence can be less focused. CoRes can provide rich evidence for PCK, but they are time-consuming and demanding to complete. The fact that both the data sources for this study were assessment tasks meant that the pre-service teachers were willing to invest the time required for this task. It would certainly not be possible to collect data on a large scale in this manner, so CoRes will remain rich qualitative tools for data collection, while focused instruments will still be necessary for large-scale studies.

Though these findings are very encouraging, the limitations of the small sample under rather specific conditions need to be recognised. This means that the findings cannot be generalised. But they do lay grounds for further investigations of the possibilities opened up but the investigation described.

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Chapter 6
The Efficacy of Visuohaptic Simulations in Teaching Concepts of Thermal Energy, Pressure, and Random Motion

M. Gail Jones, Gina Childers, Brandon Emig, Joel Chevrier, Vanessa Stevens, and Hong Tan

6.1 Introduction

The abstract topics of heat and pressure have been shown to be difficult to teach and learn and are often embedded in naïve conceptions (Harrison et al. 1999; Clough and Driver 1985; Erickson 1979; Erickson and Tiberghien 1985; Tiberghien 1985). Students often mix ideas of heat and temperature and struggle with concepts of heat gain and loss as well as how heat relates to phase changes (Harrison and Treagust 1996; Lee et al. 1993). Other studies have shown that students have difficulty understanding atomic and molecular particles, particle motion, and the relationship of particle motion to heat and pressure (Kesidou and Duit 1993). Like heat, pressure is also a poorly understood topic that students struggle to understand (Shepardson and Moje 1994). Furthermore, students have difficulty conceptualizing the relationship between pressure and thermal motion and how particle motion relates the two (Shepardson and Moje 1994).

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Inherent in understanding applications of particle motion such as diffusion, Brownian motion, phase changes, and molecular self-assembly is the idea of random movement (Garvin-Doxas and Klymkosky 2008). Randomness is a particularly difficult concept to teach and appears to conflict with our innate desire to find order in our world (Batanero et al. 1998; Sun and Wang 2010). Children and adults often believe that there are nearly always drivers or blueprints that control and direct events that have been identified as random such as a coin toss or a lottery (Garvin-Doxas and Klymkosky 2008; Paparistodemou and Noss 2004). Pratt (1998) has termed these as “unreliable intuitions” (p. 2). Even though understanding randomness is difficult for students, it is essential if students are to gain accurate and fundamental concepts of atomic and molecular motion and associated applications in biological and physical systems. In this study we examine the impact of visuohaptic technology as a tool to teach students about thermal energy, pressure, and random motion. Haptic technology creates a sense of touch for the student using forces and vibrations that allow the user to interact with a virtual world through a stylus or joystick. The term visuohaptics is used in this paper to denote instructional tools that utilize vision and haptic perceptual information.

6.2 Theoretical Framework: Touch and Embodied Cognition

Interest in the relationships of perceptual/motor experiences (such as touch) and cognition has grown in recent years as new technologies have emerged. This area of research, known as embodied cognition, rests on a theoretical framework that argues that mental constructs are built from and on sensory motor experiences. This idea that our experiences moving through and manipulating the physical world contribute to our understandings of our environment makes sense. But taken further, the argument maintains that our cognitive architecture rests on these sensory motor experiences. Wilson (2002) suggested that:

> (t)here is a growing commitment to the idea that the mind must be understood in the context of its relationship to a physical body that interacts with the world. It is argued that we have evolved from creatures whose neural resources were devoted primarily to perceptual and motoric processing, and whose cognitive activity consisted largely of immediate, on-line interaction with the environment. Hence human cognition, rather than being centralized, abstract, and sharply distinct from peripheral input and output modules, may instead have deep roots in sensorimotor processing (p. 625).

According to the theory of embodied cognition, higher-order and meaningful thought is a product of neural circuits that are representative of sensory motor activity and characterize embodied experience (Anderson 2007; Lakoff 2012). Wilson (2002) maintains that mental structures that were originally developed in response to physical action are decoupled from the original use, are co-opted, and are used for thinking and knowing.

6.2.1 Haptics: Embodied Technology for Science Instruction

Haptic technology researchers have long maintained that touch is a primary sensory channel and as such is an effective tool for learning an array of topics. Haptic joysticks and other force feedback tools extend the sensory motor perception beyond the hand into the environment. This extension of hand to tool is viewed as a way of connecting the environment, the sensory motor activity, and the mind. For example, Merleau-Ponty (1962/1945) pointed out that even a simple haptic tool like the cane used by an individual with visual impairment serves as an extension of the hand allowing for the perception of textures and objects at the end of the cane. The person with the cane feels objects not in the hand but instead in the cane as an extension of the body (Anderson 2007). Haptic technologies replicate this hand-tool perceptual relationship with virtual and simulated environments by allowing users to touch and feel objects in virtual worlds.

Although research has verified that interactive simulations can be engaging and may promote the learning of science concepts (e.g., de Jong and Njoo 1992; Finkelstein et al. 2005; Hsu and Thomas 2002; Huppert and Lazarowitz 2002; Stull et al. 2011; Tao and Gunstone 1999; Zacharia 2003, 2005; Zacharia and Anderson 2003), there are limited educational studies available to inform educators about the best uses and most appropriate contexts for haptic simulations. There is an almost intuitive belief that in educational settings being able to touch and manipulate objects results in better understandings of concepts and phenomena. Hands-on science experiences are often described as being powerful ways to engage students in learning. However, when the meaning of hands-on is unpacked, it is not immediately clear which elements of the experience are essential to promote learning. Is it the tactile and embodied information that makes hands-on experiences meaningful (de Koning and Tabbers 2011)? Or, is the process of active investigation paired with hands-on experiences makes touch so effective (Loomis and Lederman 1986; Lederman and Klatzky 1987)?

At a fundamental level we know humans explore the world around them with touch and develop concepts of properties through tactile feedback from infancy (Piaget and Inhelder 1967). Furthermore, individuals use tactile sensations to learn about shape, volume, temperature, hardness, texture, weight, and contour (Lederman and Klatzky 1987). These are all critical properties of materials and are used in exploring and investigating science. But is it necessary to touch materials, or is it enough to use vision when learning about properties of materials? There is evidence that vision dominates our senses as the primary mode of learning (Sathian et al. 1997). But it isn’t clear how, or if, haptic feedback provided in addition to visual perceptual information enhances learning. Klatzky et al. (1991) have argued that perhaps vision alone will suffice if the task can be accomplished with only visual feedback.

Of the few studies that exist that compare visual and haptic feedback, there are mixed results on whether the addition of haptic feedback to simulations makes a difference in learning. Studies by Jones et al. (2006) and Minogue and Jones (2009) reported that groups that received visuohaptic treatments scored significantly higher on post-assessments than visual-only groups for using haptic technology to learn about viruses. The results of the study by Jones et al. (2006) found that the attitudes of students using the software program with a haptic device were significantly higher than students that just solely used the computer software with visual images but no haptic feedback.

The link between embodied cognition (such as haptic experiences) and positive affect has been reported as a fundamental component of learning (Lee and Schwarz 2012). Evidence of this embodied experience and affect can be found in metaphorical language such as interactions that make your "blood boil," or "something smelling fishy," or being "numb" after a frightening experience (Lakoff and Johnson 1999: Lee and Schwarz 2012). Although physical reactions to emotional experiences have been well documented, research on the role of embodied thought as a cognitive tool with associated emotional components has been less well developed.

The study by Minogue and Jones (2009) suggested that "haptic augmentation of computer-based science instruction may lead to a deeper level of processing" (p. 1359). Other researchers have also reported that haptic feedback can improve learning. Schönborn et al. (2011) conducted a study of biomolecular binding and reported that the visual-haptic group was able to produce tighter fits between molecules during a simulation and had higher learning gains. Schönborn et al. stated, "[students] experiencing a coordinated visual and tactile representation of biomolecular binding could have a potentially deep-seated influence on students' construction of knowledge concerning submicroscopic phenomena" (Schönborn et al. 2011, p. 2096).

Not all research has found that haptic investigations make a meaningful difference in learning. Minogue et al. (2006) investigated the use of haptic feedback on middle school students' concepts of cell morphology and reported that the visuohaptic feedback group was not statistically different in learning gains than the visual feedback group. Harris et al. (2009) examined the impact of haptic feedback on postsecondary students' understandings of protein structure and function and found that there were no significant differences in the haptic- and visual-only groups. Wiebe et al. (2009) took a different approach to examining visuohaptic technology and measured both learning gains and eye tracking with a group of middle school students learning about virtual levers. These researchers found the visuohaptic group did not outperform the visual-only group on post-instruction assessments. Furthermore, Wiebe et al. reported that the visuohaptic group had a longer fixation time on the software (calculated by using eye tracker data) than the visual group.

It is not clear from these studies if the additional sensory feedback gained through haptic technology contributes to cognitive overload such that the additional information that might be gained from the tactile modality is overridden by the limitations of memory storage. Sweller's (1994) cognitive load theory suggests that individuals need to reduce cognitive load in order for effective processing and learning to occur. The study noted above by Wiebe et al. (2009), which found visuohaptic feedback resulted in a longer fixation time with eye tracker data, argues for a closer look at these issues of cognitive load.

One interpretation of the mixed results that have been found in previous studies is that the learning context drives the benefits gained from adding haptic feedback. As discussed above, if the learning task can be accomplished with vision alone, then haptic feedback may not enhance the learning gain (Klatzky et al. 1991). In the studies described above, the learning contexts included studies of levers, cell morphology, and protein structure. It is possible that these are topics that can be learned predominately through visual feedback, and as a result tactile feedback does not add significant information for the learner. But what happens when the learning context is not visually based such as learning about pressure and heat and the requisite forces involved? Would haptic feedback make a significant difference in the effectiveness of the learning experience? This study explores this very question in an effort to better understand the efficacy of visuohaptic technology as a tool for learning science. The recent developments of new forms of haptic devices and force feedback gaming applications continue to raise questions about the role of haptics and the potential new uses of haptics in learning.

6.3 Materials and Methods

6.3.1 Research Questions

This study was designed to investigate the following research questions:

Is visuohaptic feedback more effective than visual-only feedback for learning concepts of thermal energy, pressure, and random motion?

Does receiving visuohaptic feedback result in greater retention of concepts of thermal energy, pressure, and random motion, as measured by a delayed post-test than receiving visual-only feedback?

6.3.2 Study Context and Instruction

The study was designed to investigate the role of haptic feedback in learning about thermal energy, pressure, and random motion. The study was conducted in a naturalistic setting that included grade-appropriate science instruction given as part of normal instruction in classrooms. The topic for the lesson was molecular motion and the role of random motion in thermal energy and pressure. The lessons were part of the state's science curriculum for sixth-grade students. Four classes (all taught by the same teacher) participated in the study (participants are described further below). Half of the students were randomly assigned to instruction that included a simulation that provided only visual feedback ($n=35$), and half of the students were assigned to use the simulation both visual and haptic feedback ($n = 43$). Prior to beginning of the study, students were trained on how to use the computer technology, and students were allowed to continue with the training until all were comfortable navigating in the virtual simulation.

The study began with a pre-test given several days prior to instruction. Following the initial lesson about heat and pressure (described below), students in both groups (visual and visuohaptic) completed the simulation (about 50 min). Two days later students were post-tested, and 2 months later students completed a delayed post-test.

The instruction began with a task for students to make macroscopic observations of colored dye diffusing in a cup of water. Students were asked to describe the movement and make predictions about future movement of the dye. The next part of the lesson asked students to reflect on particle motion in hot and cold water and to define temperature. This was followed by instruction that described the relationship of pressure to the number of particles contained in a given space. After this introduction to thermal motion and pressure, students were introduced to the simulation designed to allow the students to explore molecular motion with or without haptic feedback.

Students worked through series of tasks that involved making manipulations with the simulation. The instructional program began by showing students a closed three-dimensional system (a virtual box) filled with moving particles (virtual water vapor molecules). Students who had visual-only feedback could observe particles colliding and moving throughout the box. Students with visuohaptic feedback could see the movement of the particles but could also feel the impact of particle collision with a Novint Falcon® haptic device from Novint Technologies, Inc. A grip bubble on the Falcon is connected to a computer that permits a user to manipulate objects in a computer simulation which in turn provides tactile feedback to the user. The instructional program allowed participants to maneuver and control an object (a pollen grain) that was constantly subjected to the random motion of surrounding particles in a closed system. The program allowed users to manipulate the temperature (from *zero temperature* to *high temperature*) and pressure (*high pressure* to *low pressure*) in the closed system. When operating the haptic device along with the computer simulation, participants were able to "feel" the numerous particles that randomly bombard the object they were guiding in the simulation. The intensity of the force feedback depends upon the temperature and pressure settings in the simulation.

Students were given a laboratory guide that led them through a range of explorations with guiding questions designed to focus their attention on the movement of the particles with each variable. At each stage of the simulation, students were asked to make predictions, alter conditions, make observations, and then record their observations. For example, students were asked to predict what would happen to the movement of particles when they changed the temperature setting to high or low. They were also asked to predict molecular movement at different temperatures and to predict a specific direction of movement for a selected molecule. Next, students were given a macroscale model of a virus capsid (plastic capsid pieces in a plastic container) and were asked to model different thermal energy levels (by shaking the container) and to observe what happened during the capsid self-assembly at different levels of thermal energy. The final component of the instruction asked the student to reflect on what they had experienced with the dye and the water, the simulation, and the virus capsid and respond to questions that asked them to compare and contrast the motion of particles in the simulation with virus capsid particles to the molecules of dye in the water.

6.3.3 *Participants*

Participants were drawn from a public middle school located in a rural-suburban community in the southeastern region of the United States. Participants were volunteers and included 78 students (24 males and 45 females; 73 % Caucasian; 15 % African American; 6 % Hispanic; 3 % Asian; and 3 % other). The mean age of the students was 13.5 years of age (range 13–15).

6.3.4 *Assessments*

Students completed alternate forms of the 30-item multiple choice test that was designed for this study and included a pre- and parallel post-assessment. The items were designed after consulting with the state's science curriculum and national curricular standards. The assessments included questions related to thermal energy, temperature, pressure, and random motion. There were knowledge-level questions (such identifying the term for the measure of the average particle speed of a substance), interpretation questions (reasoning that a cold environment may be needed to do precise experiments at the nanoscale), and prediction questions (what happens to the pressure of a gas when the temperature of a gas increases while the volume remains constant). Participants were also asked three open-ended questions about their interest in the simulation, whether they would recommend the simulation for other students and whether they felt like they understood the lesson. Those in the visuohaptic simulation were asked to describe what they thought they would have missed learning if they had not been able to feel the particles and had only been able to see the particles.

Assessment items were piloted using a think-aloud protocol with two middle school students. Items were revised after the pilot assessment and were validated by a team of four science educators, two physicists, one chemist, a middle school science teacher, and an engineer. Cronbach's alpha was calculated with the study sample to establish reliability with a value of .80 for the pre-assessment, .67 for the post-assessment, and .83 for the delayed post-assessment (low but acceptable reliability for newly developed scales with limited numbers of items, e.g., Nunnally 1988).

The pre- and post-assessments were given 2 days before and after the treatment. The delayed post-assessment was given 2 months after the treatment and included 64 students who had completed all three assessments and the treatment. Students were given unlimited time to complete the assessment. The assessment items were designed to match the concepts taught in the simulation and included thermal motion, pressure, random motion, and novel applications of particle motion such as diffusion, self-assembly, and chemical bonding.

6.3.5 Analyses

Pre- and post-assessment items were scored as correct or incorrect, and a score of 3.33 points was given to each correct item (100 point scale). Means and standard deviations were calculated for the pre- and post-assessment scores. Responses to the affective items were recorded and the frequencies of responses were determined.

T-tests were conducted to compare scores for the two groups (haptic and visuohaptic) and the pre to post changes. A repeated measure analysis of variance was run to examine the interactions between groups (visual and visuohaptic) and assessment scores (pre- and post-assessments). Post-instruction assessment scores were analyzed to determine if there were differences by type of assessment item. Questions were classified into the following categories: pressure, temperature, diffusion, randomness, particle movement, and applications. Independent t-tests determined that there were no differences between the groups' post-test scores by individual items or by item category. Subsequent analyses were conducted with all items.

6.4 Results

6.4.1 Knowledge Results

The results of the analyses are shown in Tables 6.1 and 6.2. Equivalence between the two groups was established by comparison of the pre-tests for the two treatment groups. There were no significant differences in the pre-assessment scores for the visual and visuohaptic groups ($t(67) = .255$, $p < .79$).

The analysis of variance results showed that there were significant differences for assessment scores (pre-, post-, delayed post-assessments) but no significant differences for the students' scores for the visuohaptic and visual-only groups.

Table 6.1 Repeated measures analysis of variance for assessment scores and group

Effect	*MS*	*df*	*F*	*p*
Assessment scores (pre, post, delayed post)	3883.87	2	33.31	0.000
Assessment scores X group (visual and visuohaptic)	935.47	2	3.44	0.068
Error	122.13	124		

Note: There was no significant main effect for group (visual and visuohaptic) $F(1,62) = .044$, p < .835

Table 6.2 Post hoc comparison of assessment scores between the visual and visuohaptic groups

	Visual	Visuohaptic		
Assessment	*Mean* (*SD*)	*Mean* (*SD*)	*t* value	*p* value
Pre-assessment	55.23 (15.97)	55.63 (15.11)	0.105	0.917
Post-assessment	68.09 (16.63)	72.42 (15.31)	1.196	0.235
Delayed post-assessment	70.52 (17.30)	65.23 (19.23)	1.132	0.262

Post hoc paired t-tests showed that both groups experienced significant growth from pre- to post-assessment (visual group $t(67) = 6.00$, $p < .00$; visuohaptic group $t(67) = 7.58$, $p < .00$). When the pre-assessment scores were compared to the delayed post-assessment scores, there were also significant differences (visual group ($t(29) = 5.511$, $p < .000$ and the visuohaptic group ($t(35) = 2.771$, $p < .009$).

Table 6.2 shows the means and post hoc t-tests by treatment group. There were no significant differences for assessments by treatment group (pre-, post-, or delayed post-assessment).

6.4.2 Affective Results

Almost all of the students in both groups recommended that the simulation be used in the future to teach these concepts and reported understanding the simulation. However, there were statistically significant differences in the ratings by participants for the question that asked them how interesting the lesson was to them. The item asked participants to rate how interesting the lesson was on a scale of 1 (not at all interesting) to 5 (very interesting). Both groups found the lesson to be interesting, but the visuohaptic group found the lesson to be significantly more interesting (visuohaptic group $M = 4.8$ ($SD = 0.51$) and the visual group $M = 4.3$ ($SD = 0.36$) $t(62) = 2.91$, $p < 0.004$).

All the students in the visuohaptic group reported that the touch feedback helped them learn about particle motion. When asked, "what did you learn by being able to feel the particles that you would not have learned if you were only able to see the particles," the responses primarily related to understanding how the particles moved (73 %). In addition, 31 % of the visuohaptic participants discussed how the particles felt. For example, responses included "being able to feel the shape, size, movement, and speed" and "the texture and the force in which they collide with each other." Similarly to this last student that reported learning about force, a number of other students discussed the how the haptic technology allowed them to detect force. For example, students noted, "you could feel how they were forcing back against you plus you saw how they moved," "how vigorous and violent [the particles were]," "the feel of the particles and the power," and "the force and speed of the actual particles."

Several students reported that the haptic technology enabled their visualization of the particle movement. Students wrote comments such as “I could visualize the process going on” and “it helps you think in three dimensions.” One student reported that the haptic simulation contributed to a sense of presence in the virtual environment. This student said, “I felt like I was there and could actually feel the particles rather than being told.”

6.5 Discussion

Advocates of an embodied cognition view of learning argue that the goal of instruction is to create learning tasks that facilitate learning through building on prior experiences and the existing mental frameworks that arise from sensory motor learning. The results of this study suggest that the simulation was effective in teaching students about thermal motion, pressure, and random motion regardless of whether the students had access to haptic feedback. One interpretation of these results is that the visualization that comprised the software was sufficiently powerful to allow students to determine how increases and decreases in thermal energy would impact particle motion, how increases and decreases in the number of particles would change the pressure, as well as how pressure and thermal motion were related. As noted previously, it is possible that haptic feedback is most effective when there are no other effective avenues for students to perceive the targeted concept (i.e., vision is not available). An example of a haptic-only context would be the tactile feedback from a hand drill that an oral surgeon uses to determine when the root of a tooth has been fully extracted. The surgeon cannot see the root canal of the tooth and depends on the feedback from the drill inserted into the tooth. In the context of the present study, students with visuohaptic feedback could both see and feel the particle motion. There is some evidence that haptic feedback may be processed in the brain in the visual cortex (Sathian et al. 1997), and one interpretation of the results reported here is that haptic feedback is combined with the visual feedback as a visual image, and as a result the haptic information may not be adding to the conceptual learning.

Although the topic of this study was about forces and molecular motion (that are not easily perceived visually), the animations included visual simulations, and students could manipulate variables and see how the particle movement would change as thermal motion or pressure changed. We hypothesized that visuohaptic students would have a better understanding of random motion and the rapid movement of particles that result from thermal energy, but the results of the pre- and post-assessments did not support our hypothesis. It is possible that although we made every effort to assess haptic effects, the assessments we used (verbally based written forms of assessment) may not have fully measured the encoded information gained from the haptic simulation and may have inadvertently favored visual information.

It is possible that the tactile sensations detected as students changed the temperature and pressure may have distracted students from focusing on molecular motion. For example, one student noted that the simulation allowed her to feel "how (the particles) were forcing back against you plus you saw how they moved," "how vigorous and violent [the particles were], "the feel of the particles and the power," and "the force and speed of the actual particles." The force feedback of the falcon may have shifted the students' attention away from understanding the concepts of particle motion under different conditions to a focus on the falcon stylus. Or, as de Koning and Tabbers (2011) have suggested, the physical action used during the visuohaptic simulation may not have mapped on to the more abstract cognitive representational system.

Students reported that the haptic feedback helped them visualize the particle motion. They also reported that the haptic feedback helped them learn about the concepts, but the assessments did not measure a difference in the pre- and post-learning gains for the two treatment groups. Another interpretation of these results is that the haptic feedback information was ignored as students used the simulation in order to limit cognitive load.

Although one might expect that multimodal simulations would strengthen conceptual understanding, there may be a point where the additional information distracts from rather than enhances student learning. This study does not completely resolve the debate of whether or not haptic feedback enhances learning, but it does address the question (in this context) of whether visuohaptic instruction for nonvisually based phenomena such as forces is more effective. Here we found that both the visuohaptic and the visual simulations resulted in significant gains from pre- to post-instruction. Depending on the context, having the opportunity to manipulate and feel materials may not make a difference in learning.

From an embodied cognitive view, physical responses and movement are both built by, and contribute to, cognitive structures that have roots in evolutionary history. Some researchers have argued that embodied cognition developed as humans responded to evolutionary pressures (Wilson 2002). It is believed that over time the direct link to physical experiences was not required and humans were able to co-opt these mental structures in the formation of abstract concepts. What is not yet clear is that which types of learning tasks (if any) build on this sensory mother architectural mental framework and which do not? Most applications of haptic instructional tools have used haptic feedback to teach about microscopic and atomic scale phenomena such as cell organelles or protein folding (e.g., Jones et al. 2006). These studies have found limited advantages to having haptic feedback. Could it be that an evolutionary-based cognitive system built on tactile perceptual information works best for the types of learning that one might encounter on a human scale (the scale that involves actions in the natural environment)? Perhaps this system contributes little to the development of more abstract concepts at the micro- or nanoscale where processes such as particle motion and thermal energy exert effects.

6.6 Conclusions and Implications

It appears that even though the haptic feedback used in the present study was not more effective than visual-only feedback, it did not result in reduced learning. If the findings of this study are replicated, the results suggest that teachers and curriculum developers can use new and evolving touch technologies with confidence that visuohaptic simulations do not detract from learning. Furthermore, students find visuohaptic technological applications highly interesting, and they report that haptic feedback contributes to their visualization of science processes. The costs of new virtual and haptic technologies have fallen considerably in recent years, and whole schools are beginning to adopt virtual reality technology for school-wide use. Additional studies are needed to determine whether the increased student attitudes toward the learning task continue with extended use of visuohaptic and virtual reality tools. Over time one would expect that enhanced interest in the learning task would translate into learning gains. The studies of embodied cognition and haptic learning technologies are rapidly evolving, and although this study investigated one context of haptic learning, the relationships of embodied cognition, interactive haptic technologies, and science learning have not yet been fully explored.

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Part III
Conceptual Understanding

Chapter 7
Content-Focused Research for Innovation in Teaching/Learning Electromagnetism: Approaches from GIREP Community

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7.1 Introduction

Research undertaken by members of the *Groupe International de Recherche sur l'Enseignment de la Physique* (GIREP) involves a wide range of perspectives, populations and methods. A unifying theme is that research problems arise from the teaching and learning of the physics, including its concepts, principles, epistemology and culture. In this paper, electromagnetism provides a context for illustrating this type of research. The subject was chosen because the interpretative ideas developed by physicists to account for electromagnetic phenomena and the mathematical formalism used to represent these ideas make the subject ideal for exploring issues in learning and teaching. These include the impact of students' prior experiences, their understanding of the nature of the interpretative process and their ability to relate formalism to phenomena. Electromagnetism also offers the opportunity to explore the relationships between macroscopic and microscopic models, as well as

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the ‘field’ concept. Research in the learning and teaching of electromagnetism is far too broad an area to be synthesised here. The examples were chosen to illustrate the breadth and depth of this field of research, to identify current areas of interest and to show how findings with broad implications arise from apparently narrow research questions.

While unified by concern with electromagnetism, the research programmes represented here are diverse in terms of their specific foci and the methodology used. The themes, which are common within GIREP, can be summarised as follows: (1) examining the content that is typically taught in the light of documented or anticipated learning challenges, logical coherence and alignment with the epistemology of the discipline; (2) examining learners’ ideas before, during and after formal instruction with a view to understanding how they tend to interpret their experiences inside and outside the classroom; (3) observing students engaged in various learning interventions to identify specific strategies that promote links between common sense ideas and formal ones; (4) developing instructional materials that address students’ alternative conceptions, promote student interest and illuminate epistemological features of the specific topics to promote a more authentic view of science; and (5) developing approaches to supporting new and experienced teachers. These themes thus range from the fundamental representations of the discipline, through cognitive processes involved in learning, to the interaction between learners and curricular interventions and finally to the demands that are guiding learners through their intellectual development place on teachers and teacher trainers.

Below each of these themes is explored in the context of a single study presented in the symposium. For each case, the general features of the framework for research are outlined, the examples are described (including a brief description of the methods and the main results) and the conclusions are drawn that relate to the broader goals of this paper.

7.2 Examining the Content: Crucial Aspects of the Mathematics-Physics Relationship in Electromagnetism

The symbiosis of mathematics and physics appears throughout physics. The well-known saying of Wigner about the ‘unbelievable effectiveness’ of mathematics in physics is a mere spotlight on the complicated and rich interrelationship between physics and mathematics. The interrelationship not only includes algebraic representations (formula, equations or whole theories) of physical laws, but also graphical or geometrical means. From an educational viewpoint the connection between a graphical mathematisation, an intuitive visual presentation and algebraic formulations by the learner is important. Electromagnetism provides an example to focus a discussion of several critical aspects of the relationship between mathematics and physics from an educational perspective. In particular they point out the way that common mathematical descriptions may present challenges for learners.

7.2.1 General Framework

Several different aspects of the role of mathematics in physics can be identified (Krey 2012; Uhden et al. 2012; Pietrocola 2008):

- *Structural aspect:* mathematics can provide structures that help in recognising analogies or structures in physical contexts or give rise to new discoveries.
- *Modelling aspect:* the results of physical experiments and observations are being ordered and (through idealisation) brought into an abstract symbolic system often provided or at least supported by mathematics.
- *Communicative aspect:* mathematical representations and geometrical, graphical or algebraic ones allow for a precise formulation and communication on a fixed basis.
- *Tools aspect:* mathematical techniques or algorithms serve as a tool, e.g. for evaluating or predicting the results of experiments. This aspect often is overstressed compared to the other three aspects.

The process of *mathematisation* includes all of these four aspects. Whereas the more formal aspects often are in the foreground, the underlying structural and conceptual viewpoints are mostly neglected in teaching. The complexity of the process of mathematisation has been analysed by Uhden et al. (2012). A strong focus lies on the interpretation of mathematical constructs within a physical context. Therefore several questions arise:

- Is the mathematics describing a physical observation appropriate?
- What criteria exist for choosing mathematical representations in a physical context?
- What connection exists between the physical object and the mathematical representation?

These questions surely can be answered in different ways depending on the perspective and subject area. In order to be concrete and give an impression of the span of possible answers, we concentrate on the example of flux of electromagnetic energy which will be discussed from the content and from the educational perspective.

7.2.2 The Physics-Mathematics Relationship in Electromagnetism

When we speak of physical quantities such as field lines, light rays and current or energy transport, the learner intuitively builds an internal image of the processes or objects involved. These interfere with his or her pre-knowledge and guide his or her construction of new knowledge. In electromagnetism, the transport of energy by the electric current gives rise to different ideas: as electromagnetic waves travel with the velocity of light, some students think that the electrons in a wire also travel with this velocity. But upon learning that they instead have a small velocity, the problem arises as to where and how the energy transport takes place: in the wire or in the open? One must then examine what the mathematical description of this physical process says. Can it support teaching the transport of electromagnetic energy?

In physics textbooks one generally finds the representation $S = E \times H$ of the transport of electromagnetic energy in connection with electromagnetic waves, the well-known 'Poynting vector'. This is derived from the continuity equation for energy, giving an expression for *div S*. Here we see that the deduction only gives the divergence of *S*. Nonetheless *S* is ascribed a physical interpretation. With this example we address the questions above.

The first question concerning the uniqueness of the mathematical description is readily settled: since only the divergence of *S* is uniquely determined, several representations about the electromagnetic energy flux are conceivable, as discussed by Backhaus (1993). Therefore a second question arises: which kind of reasoning leads us to the Poynting vector? Which criteria for the interpretation do we have? Several criteria are conceivable:

- Simplicity, beauty or elegance of the mathematical expression.
- 'Reality' of the mathematical term, in the sense that the corresponding physical quantity can be uniquely defined and measured. For example, in this sense the em potential would not be 'real' as it is not uniquely fixed.
- Possibility of an interpretation similar to intuitive images.

The deduction of *S* itself does not give any hints, and it is quite formal and generally valid. The first two points are readily accepted: the Poynting vector is a simple expression only containing the observable em fields. However, a short inspection shows that the third point is not fulfilled: in the case of stationary fields, in which case it is difficult to imagine any energy flux, the Poynting vector does not vanish. Therefore it could be that the Poynting vector only applies to electromagnetic waves, contradicting the assumed general validity. Thus the backward interpretation of the mathematical expression is physically not quite convincing.

Could there be better choices for the mathematical description of energy flux in the sense that they correspond to intuitive images of learners such as, e.g. energy flux with the current in the wire or current consumption? There are some proposals in this sense, given by Lai, by Hines and by Backhaus (Backhaus 1993). We will discuss here in more detail the proposal given by Backhaus which is the most intuitive one (Hartlapp 2012). It will be shown that each of the two representations, the Poynting flux and the Backhaus flux, has its advantages and disadvantages. Always one of the above-mentioned criteria is violated at least to a certain extent. The Backhaus-Flux, e.g. is

$$S_B = \frac{1}{2}(\vec{A} \times \vec{H} - \vec{A} \times \vec{H} + F\vec{D} - F\vec{D}) + F\vec{j}$$

obviously violating the criterion of simplicity, at least for the time-dependent case. In the stationary case it uses the scalar potential, which raises its own question of physical reality. However, it corresponds very well to the intuitive images of the energy transport. Therefore concerning the third question from above, we see that a physical quantity, the energy flux, seemingly clear from the first, is not uniquely represented. The different possible representations carry different interpretations and visualisations. So despite concrete mathematics a correct image cannot be chosen.

7.2.3 Conclusion

Teaching physics has to take into account the physical processes, the interrelationship with its mathematical description and the intuitive images of students. The example presented here shows the nonuniqueness of mathematical representations and the difficulties of their interpretations, including the interference with intuitive images of learners. This finding has a didactical benefit by raising awareness for several possibilities of interpretation, implying that students' own images could well have a rigorous mathematical justification. In the example described, there are no right or false answers but only more or less used images and visualisations. This can be an essential hint in teaching the nature of physics and especially the interrelationship of mathematics and physics.

7.3 Examining Learners' Ideas: Examples of Inappropriate Criteria for Generalisation

The example above illustrated how intuitive notions (such as energy flux) may be inconsistent with the content of formal teaching (such as the standard interpretation of the Poynting vector). Systematic research on learners' ideas before, during and after instruction can reveal typical initial conceptions and how classroom teaching is interpreted in the light of those conceptions. In addition to revealing common ideas about specific concepts, these investigations can also reveal larger patterns and tendencies that need to be taken into account in instruction. These investigations address essential cognitive processes involved in the development of knowledge and thus are at the core of discipline-specific educational research. Hundreds of studies in different topic areas have provided essential guidance to teachers, textbook writers and curriculum developers. Student conceptions in the field of electromagnetism have not been as thoroughly investigated as those in some other topic areas. However, previous studies have suggested that difficulties with electrostatics may inhibit learning of more advanced topics (e.g. Guisasola et al. 2010). As part of an investigation of the role of electrostatics as a conceptual foundation for electrodynamics, this example focuses on student thinking about the relationship between electric potential and the distribution of charges on macroscopic objects.

7.3.1 General Framework

The area of student thinking has been the subject of significant theoretical debate, with arguments made in favour of different models of conceptual change, but no general consensus to date. The project described here follows a long tradition of designing, implementing and assessing instructional interventions in an iterative cycle. Broadly speaking, this work falls within a framework of *educational constructivism* (Driver and Erickson 1983; McDermott 1990; Ogborn 1997). More specifically the study is situated within the body of research that attempts to describe and explain a well-known phenomenon: the occurrence of robust patterns of incorrect responses to questions that require qualitative reasoning (see Brown and Hammer 2008 for a review). However, we take no particular stance on conceptual change. We use the term *conceptual difficulty* to refer to underlying patterns of thought that differ from those accepted in the physics community and that are sufficient to explain common student errors (Heron 2004). Conceptual difficulties are not necessarily 'misconceptions', a notion that attributes theory-like breadth and stability to students' ideas.

7.3.2 Identification of Patterns of Student Thinking

The investigation is being guided by two basic questions:

- After instruction, are students able to draw inferences about the electric potential at points on or near macroscopic objects?
- What conceptual difficulties arise when students attempt to do so?

To begin to construct a detailed picture of student thinking about electric potential, we posed questions that require qualitative reasoning (Hazelton et al. 2013) The two written tasks paraphrased below were given to more than 200 students who were enrolled in introductory physics for science and engineering students. At the time they attempted the tasks, they had completed instruction that included the following points: (1) the potential at a distance r from a point charge Q, $V(r)$, is given by the familiar Coulomb potential, $V(r) = kQ/r$ (where $k = (4\pi e_0)^{-1}$ and $V(r = \infty) = 0$); (2) in the presence of multiple point charges, the potential is obtained by integrating the previous expression over the exact charge distribution (therefore Q cannot be interpreted as the net charge on a macroscopic object); (3) positive charges move spontaneously toward points of lower potential; and (4) a conductor whose charges are at rest is an equipotential (i.e. its charges are arranged such that the potential has the same value at all points on or in the conductor). It is implied, if not always stated explicitly, that the potential is fully defined by the charge distribution without regard to how it came to be.

Task 1: Students were told that a metal sphere is connected to ground ('earth') through an ammeter and that while a charged rod is carried toward the sphere, the ammeter is observed to deflect. They were asked how the potential of the sphere compares to that of ground while the ammeter is deflected. (The ammeter deflection indicates a flow of positive charge toward ground, and since positive charge flows spontaneously in the direction of decreasing potential, the sphere must be at a higher potential than ground.)

Only 15 % of the students answered correctly. About 60 % recognised that the sphere would acquire a net negative charge, but claimed it is therefore at a *lower potential* than ground, as if it were a negatively charged particle. About half of the explanations referred to the net charge on the object: '…electrons are coming into the sphere. Thus it [the potential] is negative because the sphere is negatively charged'.

Task 2: In part (a), students were shown a point charge next to a grounded metal sphere and told the system has been at rest for a long time. The asymmetric charge distribution on the sphere is sketched. Students were asked whether the surface of the sphere is an equipotential. (Because the sphere is a conductor in equilibrium, it is an equipotential.) In part (b) students were told that the metal sphere is replaced by a plastic sphere that has *the same charge distribution* as the metal one; the point charge remains as it was in part (a). They were asked whether the surface of the plastic sphere is an equipotential. (Because the metal sphere was an equipotential and the plastic sphere has the same charge distribution, its surface is also an equipotential.)

Only 30 % of the students answered part (a) correctly, and *of those,* only 40 % answered part (b) correctly. About 70 % of the students cited the material of which the spheres were made or the circumstances that led to the charge distribution on the surface of the metal sphere. Typical explanations were as follows: 'the charge is all on one side, so the sphere isn't an equipotential. Plastic can't [be an equipotential] unless it's uniformly charged'.

The most common errors can be viewed in terms of a failure to recognise that a charge distribution fully determines the electric potential. However, while providing a goal for instruction (to help students recognise the general features of the potential), this interpretation does not provide insight into students' alternative ideas, which can form the basis for a strategy for achieving this goal. Thus it may be more useful to interpret the errors in terms of underlying conceptual difficulties: *generalising a relationship for a point charge to a macroscopic object* (Question 1) or *not generalising a result for a conductor to an insulator* (Question 2). It should be noted that these two tendencies are not surprising. It is also important to note that a degree of caution in assuming that a result that holds true for a conductor also holds true for an insulator is appropriate. Therefore students' ideas should not be viewed as entirely without merit.

7.3.3 Conclusions

The examples provided here serve to illustrate that student work can be examined and underlying reasons for common errors proposed; these reasons, while linked to the specific concepts in question, can also be linked to certain common errors made in other contexts. In particular, interpreting errors resulting from tendencies in generalisation raises the possibility of making sense of larger patterns. With an understanding of the criteria students use to decide which rules, laws, definitions and procedures apply broadly and which do not, we will be in a stronger position to affect learning and teaching in general. At the same time, a finer-grained analysis rooted in the specific physics content also provides a starting point for topic-specific instruction that focuses not on students' failure to absorb the desired lesson, but on their own ideas.

7.4 Observing Students Engaged in Various Learning Interventions: Building Vertical Paths in Exploring Magnetic Phenomena by Developing Formal Thinking

The study described above signals the need for different approaches to teaching physics that involve critical examination of the content itself and that take into account students' 'common sense' ideas. It is an example of research that seeks to shed light upon spontaneous ways of looking at phenomena and on common ways of reasoning, which serve as an anchor for building scientific reasoning in vertical coherent educational paths. This example demonstrates how an innovative instructional approach can provide the means to study how learning evolves over time and how thinking reacts to various stimuli. At the same time, the results of this study provide the foundation for improved instruction.

7.4.1 General Framework

This study represents an integration of *Empirical Research* (Gilbert et al. 1998; von Aufschnaiter and von Aufschnaiter 2003) and *Design Based Research* (DBR) to develop *path proposals* (Constantinou, 2010) that bridge common sense ideas to scientific ones in intervention modules. The framework involves vertical paths, a *learning pathway* for individual learning trajectories (diSessa 2004; Psillos et al. 2010) and step-by-step *concept appropriation modalities* (Michelini and Vercellati 2012). DBR is the method for building the vertical path, starting from modular investigations carried out in *Conceptual Laboratories for Operative Exploration* (CLOE labs) (Michelini and Vercellati 2012, 2013).

7.4.2 Analysis of Spontaneous Ways of Looking at Phenomena

CLOE labs were designed to study pupils' conceptual patterns that are activated by the exploration of simple experiential situations (Challapalli et al. 2014). CLOE labs are characterised by research-based inquiry-learning hands-on and minds-on explorations of phenomena, which are carried out by pupils on a specific problematic situation or area of phenomena, with being a researcher the driver. Two kinds of CLOE labs are performed: (a) large-group (max 10 pupils) discussions based on interactive lecture demonstrations when pupils have in their hands the apparatus and (b) small-group (max 5 pupils) explorations of phenomena. Conceptual and learning processes are monitored by means of audio-video recording, semi-structured or Rogers-like (Rogers 1969) interviews and simple tutorial cards (Michelini and Vercellati 2013). The results were analysed to shed light upon spontaneous ways of looking at the phenomena and on common ways of reasoning. In the example presented here, a CLOE lab was implemented with 201 primary school pupils (11 classes; 10 years old) and 114 lower secondary school students (6 classes; 13 years old). The analysis focused on the following questions:

- RQa1) How does operative exploration help pupils to identify and understand how to produce electromagnetic induction?
- RQa2) How does the exploration and the comparison between phenomena help pupils in the interpretation of artefacts?
- RQa3) How do pupils reuse exploratory elements in the interpretation of artefacts?

Audio-video recordings of general discussions during the explorative phase of the CLOE activity were analysed. Figure 7.1 illustrates the monitoring of the *Time Evolution of the kind of Contributions* (TEC) given by students during the exploration of the electromagnetic induction by means of simple apparatus available on the desk. Each contribution was assigned to one of the following categories, represented by means of different colours in Fig. 7.1: key question (red); promotion of further discussion (yellow); introduction or reference to situations (blue), waiting for further answers (grey); answers to a specific question (green); or argumentative discussion (orange). The colour evolution from green to blue and to orange in the first part of TEC for the 10-year-old pupils shows how their behaviour changes from simple answers to mentioning situations they experienced to discussion of relevant aspect of the phenomena (orange) and how this behaviour becomes in the following a conceptual process for pupils. This trend was less marked among the 13-year-old pupils,

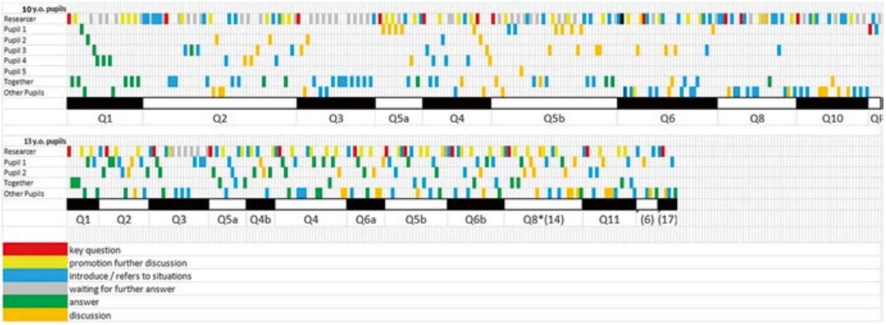

Fig. 7.1 Representation of the time evolution of the kind of contributions (TEC) in a typical large-group discussion of an interactive lecture demonstration by a group of 10-year-old pupils and a group of 13-year-old pupils (the *colours* characterise the different kind of contribution)

for whom the green interventions occur throughout the learning path but especially emerge in the phase of experimental exploration of electromagnetic induction. For 13-year-old pupils, general discussions in interactive lecture demonstration appear to be less productive than small-group experimental work.

The emerging results of this particular experiment show that this experience allows pupils to acquire an interpretive strategy for the electromagnetic induction that accounts for this phenomena in terms of the variables involved and their correlation on an operational level (74 %). In addition, even if the pupils do not acquire structured concepts of magnetic field and flux, they are able to identify the main conceptual cores (68 %) with the main phenomenological characteristics. Indeed, concerning the research questions, the results show that an operative approach helps pupils to focus their attention on the physics-relevant elements in the phenomenon of electromagnetic induction (RQ1) and to bridge the space between a structural and a functional description of the apparatus (RQ2); comparisons and analogies between artefacts, elements and objects explored during the learning path allow pupils to both reuse their previous discoveries in the interpretation of the artefact (63 %) and extend the meaning of the local vision of the physical elements to a more global interpretation of the phenomena (52 %) (RQ3).

7.4.3 Conclusion

Qualitative analysis of the classes of answers to each inquiry question offers a large amount of data on the learning processes. Cross-fertilisation between the empirical research in CLOE labs and design-based research in building vertical paths for electromagnetic phenomena interpretation appears to be a necessary way of working to produce suggestions for instruction. Pupils adopted experimental situations as referents to construct an interpretive strategy for electromagnetic induction that accounts for these phenomena in terms of the variables involved and their correlation on the operational level. In particular, the operative analysis of technological apparatus and the comparison of descriptive and functional analogies allowed pupils to reuse their previous discoveries in the interpretation of the artefact, passing from a local vision related to the specific object analysed to a global vision synthesising the phenomenology that was explored.

7.5 Developing Instructional Materials: A Teaching-Learning Sequence on Electromagnetism at the University Level

The study above showed how detailed analysis of data obtained during a *Teaching-Learning Sequence* (TLS) can illuminate how students respond to the intervention. In this paper, the basis for designing a TLS using an innovative tool is discussed in detail. The TLS is intended for teaching electromagnetism in the first year of university, in particular for teaching the concept of force and its differentiation from the concept of field in magnetism.

7.5.1 General Framework

The innovative didactical tool for designing the TLS (see Table 7.1) shares features with several lines of science education research (Guisasola et al. 2008). (1) The design takes into account students' interests. In the last decades, research in science education shows that attitude- and value-related aspects cannot be considered without making a close connection to cognitive processes. Thus designing activities that relate aspects of Science-Technology-Society-Environment (S-T-S-E) to each other means supporting a presentation of socially contextualised science that encourages students' interest in the scientific topic being taught (1st item in row 1 of Table 7.1). (2) The design takes into account the epistemology of physics. The importance of the epistemological analysis of the curriculum is not only to clarify *what* to teach but also for presenting science as a creative process that proposes theories and concepts as tentative solutions to problems presented by scientists and society (2nd item in row 1 of Table 7.1). (3) The design takes into account the results of research on students' alternative conceptions. Today there is consensus that an intervention in the process of teaching-learning cannot be effective without a careful analysis of students' ideas and ways of reasoning (3rd item in row 1 of Table 7.1).

Working from this epistemological analysis of the scientific content of school curriculum, it is possible to define the teaching-learning aims in a well-founded way. In other words, it is possible to justify choosing these aims on epistemological and cognitive grounds and not idiosyncratically or based on the educational programme's tradition. We use so-called learning indicators to specify what students should learn on the topic in accordance with the school curriculum (2nd row of Table 7.1).

The TLS is a programme of activities (PA) or tasks that involves a dialogical method of teaching designed to promote conceptual learning (second line of the Table 7.1). The programme of activities features a *Guided Problem Solving* (GPS)

Table 7.1 Use of research evidence to design teaching sequence

Interests, attitudes, values and standards	Epistemological analysis of the contents of the school curriculum	Students' ideas and reasoning
S-T-S-E aspects	Relevance of the teaching goals	Difficulties in learning
Learning objectives and teaching goals		
Learning indicators		
Set out specific problems and aims in a programme of activities (PA)		
Interactive learning environment		
Teaching strategies		

approach (3rd row of Table 7.1) . This is an approach to learning and instruction that has the following characteristics: (1) the use of problems as the starting point for learning, (2) small-group collaboration and (3) flexible guidance of teachers. Since problems steer the learning in such curriculum, (4) the number of lectures is limited. The latter is in line with the idea that (5) learning is to be student initiated and that (6) ample time for self-study should be available (Hmelo-Silver 2004).

7.5.2 TLS on Magnetic Field and Force

The sample of the study included a group of 55 students in the first course of the engineering degree at the University of Basque Country. Seven 50-min sessions are devoted to teaching magnetic field and magnetic force. The problems that provide the structure for the TLS are the following: a) Why is the idea of magnetic force necessary? b) Magnetic interactions between magnets and currents – what is the direction of magnetic force? c) How can we represent the magnetic force?

The sequence was evaluated according to the learning achieved by students. The tools of assessment are a pre-test and post-test questionnaire, video recordings of student groups carrying out some classroom activities and the students' written final reports about the classroom discussion. However, in this presentation we comment only the results from the pre- and post-test. The analysis of the answers does not focus on 'correct' or 'incorrect' answers but rather on identifying students' understanding and alternative reasoning. We are aiming at a nuanced understanding of what students understand reasonably well and what is problematic for them with regard to the mentioned major characteristics of magnetic field and force. The students who worked with the new TLS showed an important improvement in the way they posed and reasoned about problem situations on the basis of the theoretical frame they had learned. In some questions, the level of correct reasoning is not very high (about a half of students reason correctly), but in all questions they obtain at least twice as many correct results as at the beginning of the sequence, the differences being in all cases statistically significant. The results show that students have difficulties in establishing difference between the concept of magnetic field and the concept of force (about 20 %). Moreover the difficulties increase when they tackle situations of conflict that require a meaningful application of the concept of magnetic force. In the case of Lorentz force, at the end of the TLS, 65 % of students distinguish between electric and magnetic force, in contrast in the pre-test on which only 9 % of students did. Students have problems distinguishing between the sources of magnetic and electric field when the charges are at rest or moving in relation to the system of reference. A significant percentage of students (25 %–30 %) change in the form of viewing the magnetic interaction from Lorentz force theory to field theory. The majority of students apply the magnetic force concept in different problems correctly. However about a quarter of students have difficulties in determining the direction of the vector force because conceptual difficulties are accompanied by erroneous ways of reasoning. This result confirms that others result from research on students' difficulties calculating the magnetic force (Scaife and Heckler 2010). In two of the items, which aim to analyse the direction of the field vector and of the force vector, 15–20 % students consider that the two vectors have the same direction. It seems that students apply the theory of electric field to magnetism.

7.5.3 Conclusion

The question of whether we can improve the TLS through an interactive process of implementation in successive years has not been answered in this study. In this study we propose activities for the chapter of magnetic force, but the question whether different chapters, such as magnetic field, can be integrated through a sequence whose common thread is the concept of field and force has not been answered here. Further research with larger samples and studies over a longer period of time are needed to answer this question. One challenge for the design and implementation of TLS about the magnetic field theory would be to integrate the programme of activities through the different chapters of magnetism.

7.6 Developing Approaches to Supporting New and Experienced Teachers: PCK in Pedagogical Coaching

The research presented in the previous four studies highlights the demands that teaching physics places on teachers. They must be familiar with the logical structure of the content, its links to mathematics and common student patterns of reasoning. In addition, in order to teach using research-based instructional strategies, they must understand the strategies' goals and framework. All of these can be considered aspects of *pedagogical content knowledge* (PCK). Below an approach to providing teachers with *continuous professional development* (CPD) is described. Although not addressing a specific content area, this paper can be seen as thematically linked to the others in the sense that many aspects of teaching are content specific.

7.6.1 General Framework

Teaching requires many competencies and continuous formation is necessary. Since professional development requires a lot of time and effort, it is crucial that it is effective, motivating and sustainable. In Flanders, school coaching organisations are embedded in the educational system. They are also responsible for coaching in-service teachers. *Pedagogical coaches* are external specialists who can provide CPD in situ, using PCK as a guiding principle (Ball and Cohen 1999; Magnusson et al. 1999).

7.6.2 Language as a Tool to Enhance Students' Results

The use of language in teaching has become more and more important. The study 'Laaggeletterd in de Lage Landen' revealed that in Flanders 1 in 7 adults has a poor use of language and 42 % do not have enough competence in Dutch to participate as an adult in a knowledge-based society. Questions such as 'How can language competences be enhanced in schools?', 'What are specific competences that can be trained for?' and 'What strategy can be used to reach the goals?' need answers. Research reveals that three pillars enhance language competences: activity-oriented learning, the use of relevant context and language support (Hajer and Meestringa 2004, 2009). Based on this, in-service trainings by teacher coaches were organised to help teachers reorganise their lessons to give each pillar more attention. The connection to aspects of PCK ('knowledge of students' understanding of science' and 'knowledge of instructional strategies') is clear: teachers need pedagogical knowledge, content knowledge and knowledge of context to be able to implement the course 'how to use language more in your discipline'.

7.6.3 Coaching Evaluation Quality and Research Competences

The inspectorate pays a lot of attention to the validity and quality of exams; the school decides how to evaluate the learning goals set in the curricula. The goals use Bloom's taxonomy to express levels of understanding. The reports of the inspectorate (Flemish Ministry of Education 2012; Flemish Ministry of Education 2013) reveal the main difficulties for reaching curricular goals, in particular the research competences and their evaluation. Pedagogic coaches can solve the problem by introducing self-evaluation tools for teachers. An Excel spreadsheet shows vertically all the content-related curriculum goals. By systematically comparing the exam questions with these goals, teachers analyse their own exams. This approach targets two PCK dimensions: 'Knowledge of assessment of scientific literacy' and 'Knowledge of science curricula' (Magnusson et al. 1999). It is also possible to analyse the results of specific (problematic) learners in view of their learning and with respect to their levels of understandings. For this, 'Knowledge of students' understanding of science' is crucial again. Alternatively, it is possible to look at the use of these instruments in the reverse way: by applying them and explaining their goals, it is possible to train teachers using PCK.

Research competences are important in all curricula in general education in Flanders. In general it is also a weakness in most teachers' daily practice. In Flanders, the following definition is used for competence: it is the combination of knowing content and having skills and attitudes. How teachers reflect on the evaluation of content is described in the previous paragraph. However, teachers are not confident with learning lines for skills and attitudes nor evaluating them. Rubrics for more than seventy topics concerning skills and attitudes on research competences are developed and brought together in one big file. For each topic, five levels for skills and attitudes are described, going from 'starter' to 'expert', from age 12 to age 18. These rubrics serve as step-stones for a group of science teachers from one school to develop their own evaluation strategy. The coaching process involves the following steps: an intake talk in which goals are formulated by the teacher group, then the group agrees on a specific, chosen set of research competence topics of the table; they review and adapt them line by line; next they agree on whom, when and in which class the rubrics are to be implemented; and finally, after some training, marking becomes easier, and the learners' status can be made visible. The coaching, which takes about 3 years with 2 or 3 interventions a year, results in a team that is competent in managing its own evaluation system and implementing it in all classes at all levels, as confirmed by reports of the inspectorate. This method of coaching connects very well with the PCK element 'Knowledge of the science curricula' since the above-mentioned rubrics are strongly linked to the content. Individual teachers are also invited to elaborate their 'Knowledge of assessment of scientific literacy'. In many cases, reflecting on this assessment leads the teachers to a better insight of 'Knowledge of instructional strategies' for training students.

7.6.4 Conclusion

In Flanders, PCK principles are used only in an implicit way to support teacher coaches of physics teacher groups in their pursuit of CPD. Many actions undertaken by teacher coaches in Flanders cover one or more dimensions of PCK. Two important aspects, evaluation of exams and research competences and the internal collaboration among teachers in one school, show the need for PCK and also make people reflect on their work, stimulating them to enhance their collaboration in all fields of professional development.

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Chapter 8
Talking About Electricity: The Importance of Hearing Gestures As Well As Words

Carol J. Callinan

8.1 Introduction

Constructivism has perhaps been one of the most influential contemporary approaches to understanding how children come to learn science in school classrooms. According to the constructivist perspective, children will have used their previous experiences to have formed some representations of many of the phenomena studied in school science (Driver et al. 1994). In her influential work, Driver proposed that these initial representations take the form of 'alternative frameworks'. Fundamentally, these 'alternative frameworks' provide children with explanatory scope and contain conceptual understanding that frequently contrasts with scientific explanations of the same phenomena; as such, they are subject to change when children begin their formal science education (Driver and Easley 1978; Driver and Bell 1986). Research investigating learning from this perspective has led to the development of a number of explanatory models identifying underlying mechanisms that support such 'conceptual changes' (e.g. Vosniadou and Brewer 1987; diSessa 1988; Karmilloff-Smith 1996; Sharp and Kuerbis 2006, summaries in Vosniadou 2008; Limon and Mason 2002). These models range in their depth and scope with some placing a high emphasis on purely cognitive processes (Rumelhart and Norman 1978; Posner et al. 1982), whilst others attribute a strong role to motivational and affective factors (Pintrich et al. 1993; Dole and Sinatra 1998). In addition, research associated with these individual models of conceptual change focuses on single areas of scientific phenomena. Vosniadou's weak and radical restructuring, for example, draws the majority of its evidence from astronomy teaching (Vosniadou and Brewer 1987).

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Biology concepts are the focus of Carey's (1985) weak and strong restructuring model. And the development of ideas of force studied in physics is the focus of diSessa's fragmentation theory (1988). Models also frequently lack consistency between the ages of participants recruited; notably, diSessa's original contributions came from college students, whereas Vosniadou's research recruited school age children. One criticism that is more fundamental originates from the lack of consensus regarding the level of mental representation studied. In some cases, the aim is to study individual concepts (diSessa 1988), and in others, mental models which result from theory structures are utilised (Vosniadou and Brewer 1987). Taken as a whole, this diversity of subjects studied restricts comparison and evaluation of models across scientific domains and prevents the models being evaluated for their utility in informing teaching across scientific curricula. A fundamental part of the current project was to address these criticisms by closely studying the development of children's ideas about electricity; however, the focus of this chapter is not on the evaluation of the models of change but on the importance that can be attached to different response types that children use when discussing their ideas.

Contemporary literature typically approaches the assessment of conceptual knowledge through largely verbal reports that are accessed through interviews or task-based activities (Osborne and Freyberg 1985; Primary Space Projects 1990/1994). This approach has been highly successful for mapping children's ideas for a range of science topic areas. One criticism has been the bias towards language and linguistic capabilities which may prevent a comprehensive understanding of children's knowledge particularly if children are not able to clearly or fully articulate what they know (Goldin-Meadows 2000). In order to overcome this potential bias, the work presented here investigates the development of scientific ideas and concepts from a multimodal perspective. The multimodal approach to understanding children's learning is developing rapidly. Initial findings from wider research adopting this approach have demonstrated that children utilise a number of different expressive modes; these modes include verbal dialogue, written pieces, drawings and other expressive art forms and non-verbal communication such as gesture, eye gaze and body posture during learning (Kress et al. 2001). Whilst Kress et al.'s research focused on how different modes of activity support children's acquisition of concepts in science, other researchers (e.g. Goldin-Meadows 2000) have investigated the role that non-verbal language such as gesture has in revealing children's existing conceptual knowledge. Crowder and Newman's (1993) study investigated the gesture and speech of thirteen children who were learning the science concepts associated with seasonal change. The results revealed that some gestures were 'redundant', others served to enhance the ideas expressed through speech, and in some cases, gestures served as carriers of scientific meaning that was not present in language. This led Crowder and Newman to conclude that 'as long as ideas outstrip scientific vocabulary, one can expect to see gestures used by elementary science students to carry unstated ideas' (p. 176). Further support for the importance of studying gesture can also be drawn from the work of Roth and Lawless (2002); this study highlighted how gestures can contain important information about children's ideas that are not contained in speech during discussions of knowledge. In a summary paper that drew on a body of research investigating different areas of children's problem-solving ability, Goldin-Meadows et al. (1993) suggested that stability between speech and gesture characterises a stable understanding of a concept; mismatch between the two elements characterises the time in which children are moving between conceptual understandings. It was argued that the 'gesture-speech mismatch signals to the social world that an individual is in a transitional knowledge state' (Goldin-Meadows et al. 1993, p. 279). This was a particularly attractive idea for the work undertaken and presented here as it highlights a window of opportunity through which it may be possible to capture the processes of conceptual change as it actually occurs and also an opportunity to explore how newly forming ideas are represented in gesture.

8.2 Children's Ideas About Electricity

Children's ideas about electricity have been a well-studied concept area (Osborne 1981, 1983; Solomon 1985; Cosgrove and Osborne 1985; Bell 1991; Osborne et al. 1991; Borges and Gilbert 1999; Finkelstein 2005; Glauert 2009). However, at the time that this work was undertaken, there was little evidence of such a study adopting the multimodal research approach. Studies of children's ideas about electricity typically elicited children's ideas and coded their responses thematically in order to capture the underlying frameworks of understanding applied. Many studies then compared within and between the different age groups in order to consider how ideas may have changed over time. The results drawn from this body of work appeared to suggest broadly similar outcomes for different age groups. In addition, studies have explored children's ideas in a range of different countries including the UK, mainland Europe and New Zealand. For example, three typical studies include Shipstone (1985), Osborne et al. (1991) and Borges and Gilbert (1999); these studies are briefly reviewed here as these outcomes were used in this work in order to guide a framework analysis that was undertaken.

According to Shipstone (1985), five models of understanding were evident in the responses of children between 12 and 17 years of age:

- A unipolar model – no current returns to the battery.
- A clashing currents model – current flows to the bulb from both terminals of the battery.
- An attenuation model – current flows around a circuit in only one direction and is used up in the bulb.
- A sharing model – where there is a series circuit, the current is shared between the components.
- A scientific model – where there is an understanding that current travels in one direction through a circuit and is conserved.

In his summary of findings, Shipstone suggested that the younger children were more likely to discuss their ideas of electricity with reference to the unipolar and the clashing currents models but the prevalence of these models dropped as children got older. Notably in this work, it was indicated that 60 % of the 17 year olds involved used a scientific model but this figure fell to less than 10 % of the 12 year olds.

Osborne et al. (1991) explored ideas about electricity and conductivity with children between the ages of 5 and 11 years. Interestingly, the results also revealed some surprising findings regarding the children's drawings of simple circuits. These are summarised as follows:

- A single connection – where children drew in one wire to connect the battery to the bulb
- Two battery connections, one device connection – where children drew in two connections at the battery but failed to acknowledge that the wires needed to connect to separate points on the bulb
- Two battery connections, two device connections – where children used the correct number of connections at both the battery and bulb but these were in the wrong place
- Two correct connections shown – where the children place the wires appropriately
- No response – where the children failed to respond to the drawing tasks

Borges and Gilbert's study (1999) aimed to expand on the models of understanding that had been identified by earlier work by involving older participants including professionals (e.g. electricians). As might have been anticipated, outcomes included presentation of electricity as moving charges and electricity as a field phenomenon. However, the presence of such complex understandings is rarely found in studies with children. Overall, these models highlight the notion that ideas about electricity can be categorised according to specific models that vary in complexity depending on the age and experience of the participants. The three frameworks suggest that early understandings of electricity may reveal the importance of connections between the battery and the bulbs but may not acknowledge that the current within a circuit is conserved or that a return path is important. As ideas progress with age and experience, these become more scientific until concepts such as electrons and moving charges are incorporated.

These important studies underpinned the work undertaken in this project, and during the analysis phase, the researcher explored whether these models were present within the data drawn from the sample, whether additional models were present and whether children used one coherent model throughout the activities or whether they applied different models at different times.

8.3 Rationale

The whole research project specifically investigated the following research questions:

- Does a multimodal analysis of verbal and non-verbal communication facilitate an understanding of children's ideas in science?

- Can such analyses be utilised in order to explore and contribute to an understanding of the dynamics of conceptual change?
- Do outcomes from the work in this thesis have any classroom application?

These research questions did perhaps also propose an overarching question regarding whether or not it was possible to apply a multimodal research lens to the issue of conceptual change in science education. However, this chapter attends to just one of these questions and explores the types of gestures that children used when discussing their ideas about electricity, typical gestures produced during discussions and what importance was attached to understanding these in order to fully appreciate children ideas holistically.

8.4 Method

The research presented here utilised a cross-sectional design by studying the scientific ideas and concepts of three groups of children aged 7, 11 and 14 years in English primary and secondary schools. A total of 93 children took part in the study; the children were distributed as follows across the three age groups: 34 Year 2, 44 Year 6 and 15 Year 9. The participating children were briefed that the researcher was interested in their ideas about electricity; the children were all informed that they would be video recorded, and verbal consent was obtained prior to the activities being undertaken. All of the children participating in the study completed practical science activities in electricity; the study used the same activities and question probes for all three age groups. The practical activities were designed to elicit children's ideas by probing understanding as they completed familiar tasks (e.g. the construction of simple circuits) whilst subsequent tasks were designed to challenge existing ideas (e.g. an analogy of electron movement in a simple circuit using 'smarties'). These activities permitted the analysis of both existing ideas and concepts and the opportunity to observe the outcome when concepts begin to change or are challenged.

The science activities took place in small groups (approximately five children of the same age in each group, for the most part, the groups were of mixed academic ability). The activities were highly contextualised to the concepts studied, were interactive and dialogic in nature and included protocols from participant observation and interview-based methodologies. Each practical science activity lasted approximately one hour. All were audio-video recorded in order to capture events fully and to obtain gesture in transmission.

In order to explore the potential role of each response type, the transcription and the subsequent analysis focused on the modes and areas shown in Fig. 8.1.

Transcripts coded both verbal and non-verbal responses collected during the beginning and the end of each of the sessions; in addition, three group studies (one from each age group of children studied) were fully transcribed for subsequent analysis. The beginning and end of discussions were transcribed fully as these parts

Levels of Comparison
Between Activities
Between Age Groups
Between Participants
Between Individual Groups

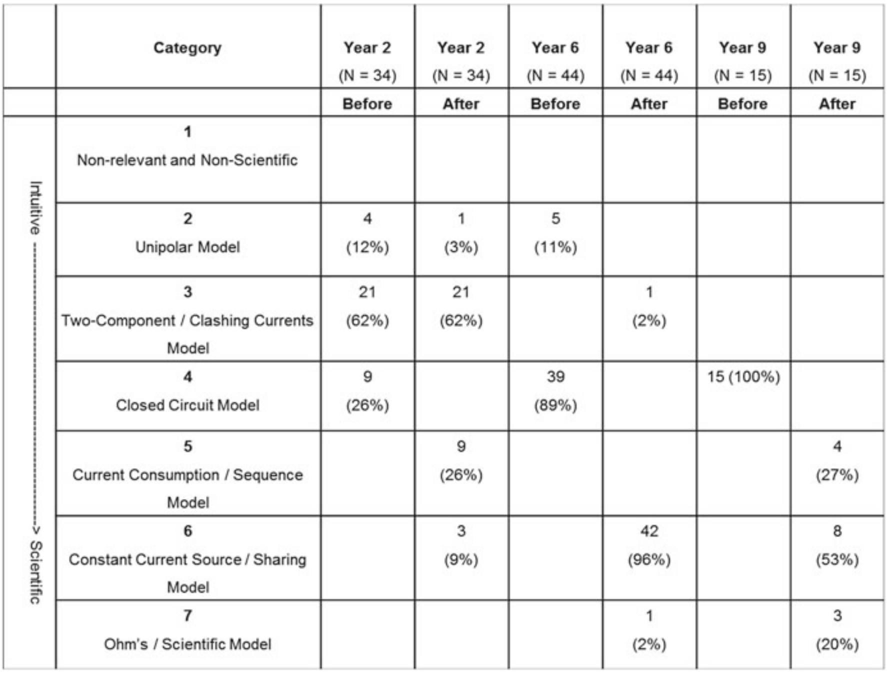
Levels of Analysis
Analysis of Verbal Responses
Analysis of Drawing
Analysis of Written Responses
Analysis of Gesture and Non-verbal Responses
Analysis of Social Interaction
Analysis of the Activity

Fig. 8.1 The different levels of comparison and analysis explored in the study

of the activities included direct probes on the children's ideas about electricity (e.g. what do you think electricity is?); therefore, this data was used to pinpoint which model or models of electricity the children were using, and it was anticipated that the before and after comparison would permit the capture of any changes in ideas or frameworks applied or whether frameworks were used consistently. Analyses of the data included both within and between age group comparisons for children's ideas and concepts related to each of the science topics. Verbal and non-verbal data were interpreted using a content analysis approach (Krippendorff 2012), and previous models about electricity were used as a guide in order to categorise the children's ideas into frameworks. The verbal and non-verbal data was also compared in order to capture matches and mismatches between the two forms of communication. The results to the content analysis were discussed at length with the author's supervisor for the project, and the supervisor also supported the interpretation of the gestures in order to address issues of reliability.

8.5 Results

The results drawn from the study are discussed here in terms of the types of gestures that children used when discussing their ideas about electricity, the typical gestures that children produced and the importance that may be attached to these in terms of revealing aspects of children's ideas that may not be contained in other response types. The overall results regarding the frameworks of understanding that the children used and applied during the activities were largely congruent with the previous research of Shipstone (1985), Osborne et al. (1991) and Borges and Gilbert (1999). For example, the older children demonstrated the more scientific ideas about electricity, whilst the younger children frequently discussed electricity in terms of its purpose (see Fig. 8.2).



	Category	Year 2 (N = 34)	Year 2 (N = 34)	Year 6 (N = 44)	Year 6 (N = 44)	Year 9 (N = 15)	Year 9 (N = 15)
		Before	After	Before	After	Before	After
Intuitive ---> Scientific	1 Non-relevant and Non-Scientific						
	2 Unipolar Model	4 (12%)	1 (3%)	5 (11%)			
	3 Two-Component / Clashing Currents Model	21 (62%)	21 (62%)		1 (2%)		
	4 Closed Circuit Model	9 (26%)		39 (89%)		15 (100%)	
	5 Current Consumption / Sequence Model		9 (26%)				4 (27%)
	6 Constant Current Source / Sharing Model		3 (9%)		42 (96%)		8 (53%)
	7 Ohm's / Scientific Model				1 (2%)		3 (20%)

Fig. 8.2 The models about electricity that the children used at the beginning and the end of the electricity activities

What was particularly interesting were the gestures that the children had during their discussions and the way that these could reveal ideas that were not contained in any other response types (e.g. verbal language, written responses or drawings). These gestures were often fundamental to allowing the researcher to pinpoint which model of electricity the children were applying.

8.5.1 *Types of Gestures That Children Used*

The gestures that the children produced when discussing their ideas about electricity were transcribed and analysed for their content. The analysis revealed that of the different groups, 31 Year 2, 38 Year 6 and 11 Year 9 children used gestures during their discussions. The children used five different categories of gestures; these categories were consistent with the previous work of Callinan and Sharp (2011) which showed that children used both scientific and social gestures (see Fig. 8.3 for full details on the five categories). Callinan and Sharp's paper (2011) had analysed data from a pilot study that had been conducted in order to develop the methodology for the research undertaken here; this work had explored if children used gestures in their discussions of science ideas and what information these gestures had contained in order to ascertain whether this would be useful for revealing a more

Scientific Gestures		
Type of Gesture	**Definition**	**Example Photograph**
Referential	Pointing to objects, pictures or people in order to complete / extend discussions of ideas	
Representational	Acting out the behaviour of objects, people or events in order to show how something works or happened	
Expressive	Using the hands to represent values such as the strength of responses in objects, people or events in order to show how they think they work	
Thinking	Including finger drumming, head holding, face and hair stroking – used when considering how to respond to a question, problem or situation	
Interpersonal Gestures		
Type of Gesture	**Definition**	**Example Photograph**
Social	Eye contact, body movement, touching or nudging others – used to elicit a response from other members of a group	

Fig. 8.3 The five categories of gesture that children use when discussing their science ideas (Callinan and Sharp 2011)

holistic understanding. The analysis here focused on a new sample of children and thus could confirm the presence of the different categories of gesture and the application of these across a larger sample of children in order to support or extend understanding of the ideas and knowledge that the children had.

Scientific gestures contained information about the ideas that children had, whilst social gestures were informative about the social aspects related to learning (e.g. how peer support was elicited when discussing ideas). It is proposed that both are important if we are to understand children's ideas holistically.

Examples of gestures that the children produced included Mike in Year 2 boy who used a referential gesture to add to his discussion of his circuit drawing. As he discussed the content of his drawing, he pointed to where he thought a bulb holder should appear; it was possible to have a clearer understanding of what he thought should be included in the drawing and where by attending to this gesture. The responses of Rachel, a Year 6 child, showed that in her speech, she described electricity using its function (e.g. that it powers things); however, her representational gesture (a circular motion drawn with her hand) demonstrated that she also had an awareness that electricity flowed through the circuit too, and the gesture also showed how she thought that this occurred. Expressive gestures were used by the children in order to show the values such as the strength of responses, for example, how the light from a bulb would appear. In one example, a Year 2 child, Selena, used just such a gesture in order to show how she thought the light would behave once she had completed her circuit; her repeated hand movements were used to reflect the intensity of the light that she expected to see once her circuit was complete.

8.5.2 Typical Gestures Produced

During the electricity tasks, the children across all three age groups used representational gestures in order to draw out paths showing how they thought the electricity moved in a circuit (Fig. 8.4). As shown in Fig. 8.4, the child either used their fingers to trace a path above the circuits and their whole hands or in some cases both hands to draw paths that followed the wires in the circuits that they had built. These gestures, considered representational because it is proposed that these were used to show how the electricity moved in the circuit, were particularly useful in this context for revealing the underlying models about electricity that the children held. For example, some children stopped the gesture once they reached the bulb, whilst other continued the gesture back to battery, and on other occasions, children drew out continuous circuits representing that they believed that the electricity did not stop; it just continued to ‘flow’. It is proposed that these gestures revealed specific

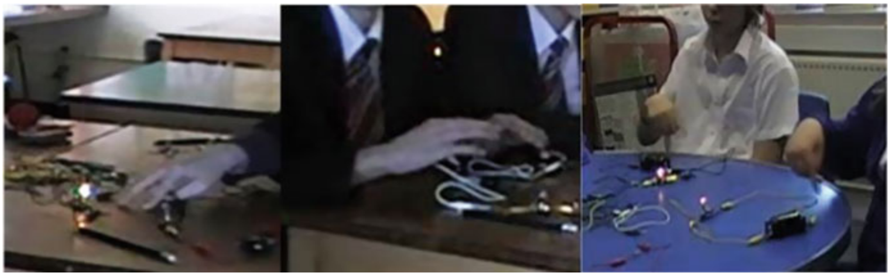


Fig. 8.4 Typical representational gestures that occurred across the three age groups of children during their discussion about circuits. The gestures represented the ways that the children thought the electricity moved through the circuit

and fundamentally different frameworks for understanding electricity. In addition to the representational gestures, children frequently use referential gestures to point to objects during their discussions, often without naming the referent object, and as such, the gestures formed an important aspect of their communication about ideas. Thinking gestures were used by some children in order to indicate that they were considering their responses, and these gestures took many forms and included finger tapping and hair stroking.

Social gestures were also used during some discussions in order to elicit ideas from other members of the groups or to clarify whether there was agreement for the ideas being discussed. These gestures were interesting because on some occasions, these resulted in children stopping their discussions and waiting for other group members to complete or complement what they had said.

8.5.3 Frequency of Gestures for Electricity

The prevalence of the five categories of gesture is show in Table 8.1. The analysis revealed that within the context of the electricity activity, referential and representational gestures were used the most frequently across all of the age groups of the children. However, there was also evidence of expressive, thinking and social gestures occurring within the context of these activities even though these gestures occurred less frequently.

When exploring the differences between the age groups, it appeared that the Year 2 children used the most referential gestures in their discussions; frequently, these included pointing to objects rather than naming them. The same age group also used representational gestures frequently; these tended to be when the children used their hands to act out or represent objects or actions. Such use of representational gestures may have occurred because of the complexity of the language required to explain some aspects of their understanding of electricity. Thus, the gestures served to expand on the ideas available in verbal language. The Year 6 children used representational gestures more frequently than any other age group and any other form of gesture. As with the Year 2 children, these gestures often comprised of the children using their hands to represent objects or actions. This age group also appeared to use social gestures more frequently, and although this may have been a feature specific to this group of children, the social gestures were often used in order to offer support to each other. Finally, the Year 9 children most frequently used referential gestures,

Table 8.1 The number of gestures used by the different age groups of children during their discussions about electricity

Types of gesture	Referential	Representational	Expressive	Thinking	Social	Total
Year 2	38	33	6	8	15	102
Year 6	21	48	18	4	31	122
Year 9	23	15	4	5	15	62

including pointing. As with the Year 2 children, these gestures often referred to objects that the children did not name and appeared to be used to complete verbal discussions. However, it is important to remember that there were some differences in the number of participants in each age group and this may in part explain some of the differences in the number of gestures observed.

8.5.4 What Gestures Add

The results drawn from the analyses undertaken in this work revealed that children used gestures in a number of ways. Interestingly and in contrast to Crowder and Newman's (1993) work, none of the children taking part in the activities used redundant gestures. All gestures appeared to either compliment the content of the verbal and written responses or contain important conceptual information that was not included in the other response types. For example, some children would discuss how electricity moved in a circuit and then accompany this discussion with the representational gestures discussed in the previous section. These gestures were fundamental for revealing the underlying frameworks of understanding about electricity that the children had and helped the researcher to locate the children's ideas within the different models about electricity. In the example shown in Fig. 8.5, the gestures were fundamental for highlighting that once the task changed, (e.g. the number of bulbs included in the circuit) the mental models used to explain how the electricity would travel were also revised. Interestingly, the verbal response produced by Daniel in Year 6 (the child wearing the blue top in Fig. 8.5) remained similar on both occasions; he simply discussed the way that he thought the electricity moved. However, his gesture changed from a single-handed representational gesture that traced a clockwise path around the circuit to a two-handed representational gesture where both hands traced opposing paths beginning at the battery and ending at the bulbs. These gestures revealed the application of two different models about electricity; therefore, this and other examples of this type of response collected during this work helped to illustrate the importance of attending to gesture in order to fully understand the ideas that children had.

Fig. 8.5 Daniel's representational gestures which reveal his underlying ideas about electricity moves in a circuit with one bulb and with two

8.6 Application in Context

It is proposed that the results drawn from the analysis undertaken here have application for teaching and learning, assessment, curriculum development and teacher training. Importantly, in many teaching environments, the significance of gesture is often overlooked, perhaps due to time constraints and other demands when working with larger groups of children, and as shown in this study, important clues and cues to children's ideas can be contained within these. With reference back to the constructivist literature, Ausubel (1978) highlighted the vulnerability of verbal responses when accessed in order to explore the development of children's conceptual ideas. Notably, Ausubel et al. (1978, 102) stated that:

> Since there is often a time lag between the correction of misconceptions and the revision of language usage, it cannot be assumed that conceptual confusion necessarily exists in all instances where words are used inappropriately.

This important discussion highlighted a fundamental critique of the traditional approaches that had been used to measure children's knowledge and indeed can be seen as a criticism of many current teaching and learning and assessment practices. Ausubel further proposed that language alone as a medium may not be enough if researchers and teachers are to understand fully the ideas that children have.

> Prior to being verbalised, new concept meanings also typically exist for a short while on a subverbal level – even in sophisticated older learners. (p. 105)

Such a notion is particularly resonant with the work in this paper which adopted the principles of multimodality, e.g. that knowledge can be held and indeed demonstrated in a range of ways including through gesture. Importantly, language may not always be the best medium to assess conceptual ideas, and gestures can help to locate children's ideas within different models of understanding about electricity such as those identified by Shipstone (1985).

8.7 Conclusions

The work undertaken here supports the notion that a multimodal analysis of children's ideas adds positively to the existing body of literature which aims to provide an understanding of children's ideas for different science concepts. Gestures can contain additional conceptual information that is not contained in any other response type such as verbal or written responses and drawings, and this can help researchers and indeed teachers to appreciate, interpret and understand the ideas that children have for different science concept areas as well as to help locate those ideas within different models of understanding. The analyses undertaken in this project also highlight that the social gestures that children use can be particularly revealing about the impact that peers can have on children's knowledge growth, the way that concepts are negotiated when undertaking collaborative work and the information that children are comfortable with revealing when their ideas are probed in a group context. It is suggested that future research should aim to incorporate such detailed analyses of gesture in order to provide a holistic overview of children's ideas. It is argued that gestures illuminate meaning and reduce ambiguity associated with other response types such as language. Gestures are a useful form of non-verbal communication particularly when language and linguistic skills are underdeveloped.

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Part IV
Reasoning Strategies in Science Learning

Chapter 9

Students' Reasoning in Making Predictions About Novel Situations: The Role of Self-Generated Analogies

Nikolaos Fotou and Ian Abrahams

9.1 Introduction

Analogies and analogical reasoning as tools for instruction have been of interest to scientists, educators and philosophers since Aristotle. Reasoning on the basis of analogies has been suggested to be a key process in human cognition (Vosniadou and Ortony 1989) and is an important factor in learning at all ages (Brown 1989). Indeed, extensive research in this area has consistently found that analogies can play a significant role in students' learning about natural phenomena (e.g. Goswami 1991; Dent and Rosenberg 1990).

Learning about new situations on the basis of comparisons with situations which are already known is central to a constructivist perspective on learning. Within a constructivist approach, the learning process involves such a search for similarities between the unfamiliar and the familiar, between what is new and what is already known (Kim and Choi 2003). This transfer of knowledge from one situation to another enables the individual to reach a better understanding of new information. In this sense, the use of analogies is found to be valuable in the better understanding of new situations by allowing similarities (albeit possibly erroneous ones) to be seen between that new and hence unknown situation someone is presented with and a more familiar situation. More recent research (Jeppsson et al. 2013) has shown that analogies could be productively used in novices' learning as a resource towards

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expertise. However, the introduction of analogies as a more effective way of teaching is not a panacea with Duit et al. (2001) describing such a use of analogies as passing between Scylla and Charybdis. Niebert et al. (2012) analysing studies dealing with the use of analogies as instructional tools showed that they are often not understood as intended, or not used by students in their own explanations, and that this could be because these analogies do not fit with students' experiences and knowledge.

Studies in the area of students' use of analogies have focused more on how analogies provided to the students by teachers and/or researchers can be used effectively inside classroom as a tool for learning new concepts (e.g. Venville and Treagust 1996; Summers et al. 1997). Few studies have examined the spontaneous generation of analogies by students themselves (but see Sandifer 2003) and whether these self-generated analogies can be used by them in an attempt to better understand a situation they have not considered before. As such, while prior research has added instructional value to the use of analogies, details are still missing as to whether there is any connection between the analogies generated and misunderstanding of new situations.

Moreover, as several authors have argued (e.g. Wong 1993; Pittman 1999), self-generated analogies might serve as a diagnostic form of assessment, thus revealing any ideas that might be held by students and which might be inconsistent with the scientific point of view. In other words, self-generated analogies could also be used as a potential approach for the identification of students' prior knowledge and incorrect ideas.

Questions therefore remain as to the source of knowledge students draw upon when generating analogies and the extent to which particular analogies could be an important factor in finding out whether, how and why these analogies could make students misunderstand new situations and come to incorrect conclusions. What has not yet been investigated is the extent to which students' use of analogies could be useful in a better understanding of how and why students made either correct or incorrect prediction in novel situations. In this sense, asking students to generate their own analogies for new situations and phenomena could be a useful tool for the identification of challenges to learning and understanding. These self-generated analogies could reveal what is familiar to the students, and this could help teachers to generate analogies that fit to the formers' experience and knowledge. This would make analogies more functional in the learning process resolving the aforementioned discontinuity of the use of analogies between students and those who generate and provide them to the latter (Niebert et al. 2012).

This paper presents the findings from such a study which was designed in such a way so as to present students with questions about novel situations that it was highly unlikely they would have encountered before. These questions were presented in a pictorial form, and students had to answer about the outcome of a future event. In other words, students were asked to make a prediction about what eventually happen in the situation they were presented with. What was examined was whether students of different age self-generate analogies while they use their prior knowledge in making their predictions, the ideas they expressed in order to explain what led them to make their predictions as well as the compatibility of their predictions with the scientific perspective. Accordingly, this study was guided by the following research question:

(a) What predictions do students of different ages make regarding novel situations?
(b) Do students of different ages draw on analogies when making predictions, and if so, on what analogies do they draw?

9.2 Theoretical Framework

9.2.1 Analogy

In terms of the structure of analogies, we assume in this study that it is similar to that of examples, models or metaphors, albeit there are some differences and several authors have different concepts in mind when the employ these terms (Duit 1991). Others, however, have argued that all of these different terms coexist with analogy, they are close relatives, and moreover they are sometimes used interchangeably (e.g. see Thomas 2006).

Generally speaking, analogies have two main components – the base and the target. The latter is the novel situation which is under consideration, whereas the former refers to the known situation which will form the basis to approach the target (Gentner 1989). These two components share different kinds of similarities which can be used in order to approach the novel situation on the basis of the familiar. Among such similarities, some are related to characteristics and features of the compared entities (surface similarities), while others were associated with relational and structural information (structural similarities) concerning such entities. In this sense, surface similarities refer to mapping attributes or descriptive properties of objects like shape, size and colour, whereas structural similarities concern the matching of processes and functions between the elements that are considered to be similar. An example of mapping surface similarities could be the comparison of a shoe with a tire founded upon the fact that both are made of rubber which is usually black, whereas an example of mapping structural similarities could be the solar system as an analogy for the planetary model of the atomic structure (similarities in orbits between electrons around the nucleus and planets around the Sun).

We consider analogical reasoning to be that process of using analogies to compare structures between two domains and map relations from a familiar (base) situation to a novel (target) situation (Fig. 9.1).

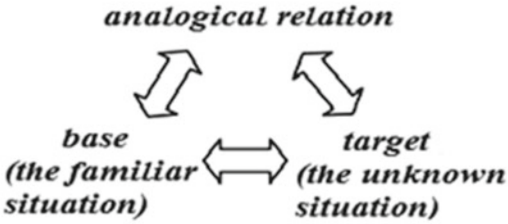


Fig. 9.1 Basic elements involved in analogical reasoning

9.2.2 Spontaneous Analogy

Following Clement (1987), the term ‘spontaneously generated’ analogy is used in this study to mean self-initiated analogy in contrast to those analogies presented by the teacher to the student in order for them to complete or use it to explain and/or understand a phenomenon or a concept. In this sense, a spontaneous analogy is similar to a self-generated analogy which while also generated by the student differs from a spontaneous analogy in that while a self-generated analogy could be prompted, a spontaneous analogy should be self-initiated.

Clement (1988) identified three methods for generating such analogies, and these methods share many features in common with those made by Gentner (1983). These three methods are:

(a) Generation on the basis of a formal principle. In this case a student generates an analogous situation by recognising the target as an example of a formal abstract principle (e.g. conservation of charge or energy) or single equation. The base is then generated as a second example of that principle or equation.
(b) Generation based upon a transformation. In this situation very few elements of the target are modified in order for the analogous situation to be generated. In this method the student makes no mention to a formal abstract principle or equation.
(c) Generation through an association. In this case the student is reminded of an analogous situation which may differ in many aspects from the original situation, but they still perceive many features between that analogous case and the target.

9.3 Research Methodology

9.3.1 Study Sample

The sample of this cross-age study was composed of students from, three schools, each of the three main levels within the Greek education system and with each year group recruited just from one school. Being a small-scale study, the sample was composed of 13, 16 and 12 students from Year 4 (primary education), Year 9 (secondary education, Greek ‘Gymnasium’) and Year 11 (secondary education, Greek ‘Lyceum’) aged 9–10, 15–16 and 16–17 years, respectively. The process for selecting the schools was principally concerned with ensuring what Ball (1984) refers to as ‘naturalistic coverage’ (p. 75) rather than with meeting the statistical sampling requirements associated with traditional quantitative research. Therefore, the schools were selected opportunistically so as to ensure a sample that was, in terms of size, status and socio-economic background, broadly representative of schools across the same geographical region of central Greece.

Given the ethical obligation to protect the anonymity of the participants (Frankfort-Nachmias and Nachmias 1992), a system of codes was used rather than real names. Codes started with S (to indicate student), and it was followed by a number indicating the year of the student followed by another number identifying a unique student within the whole study (Student 1, 2, 3, etc.). So, for example, S4.5 would indicate that this student is in Year 4 and that they are recorded as student number five in this study.

9.3.2 The Research Instrument

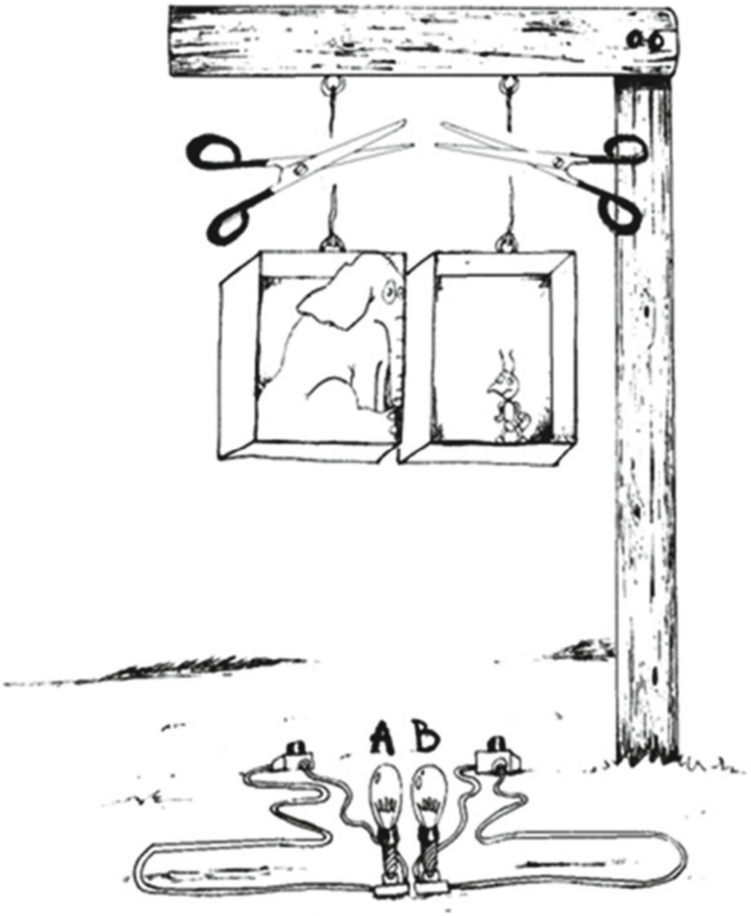
The situations presented to the students about which they were asked to make a prediction were novel in the sense that they had not been asked previously to think and make predictions about them. As such students' predictions, regarding those specific situations, were considered to be new in the sense that it was very unlikely that the students would have had any prior opportunity to have thought about those specific situations before they were presented to them in this study and thus could not have pre-existing answers for these questions.

With images playing an important role both in memory (Marks 1973) and the enhancement of students' recall of information (Purkel and Bornstein 1980), it was decided to present the questions in a pictorial form. As Banikowski and Mehring (1999) argued, the use of pictures allows prior knowledge of a situation held by students to influence their understanding of something new – like the novel situations students were presented with. This approach also had the advantage that pictures have the potential to be very effective in terms of generating engagement (Kaplan and Howes 2004; Miles et al. 2007) a fact that was considered important in work across such a wide age range and also that combining these with the use of written multiple choice questions has the potential to reduce ambiguity (Bock and Milz 1977). Pictures were also used to avoid providing any kind of lead to the students in terms of selecting one particular option from those listed in the accompanying multiple choice question.

Examples of these pictorial questions can be seen below (Figs. 9.2, 9.3 and 9.4). Each novel situation and associated multiple choice question were followed by an open-ended question in which students were asked to explain what led them to make their prediction ('What makes you think that?').

9.3.3 Procedure

The data collection session involved two phases and lasted approximately two hours for every age group. Being a mixed method study, a series of semi-structured group interviews/discussions were carried out in combination with the administration of a paper-and-pencil survey. In the first hour, the questionnaire was administered to the students who were asked to complete it without any guidance being provided. In the questionnaire, students were asked to make predictions about certain novel situations (closed-choice question) and then to provide explanations about those predictions (open-ended question).

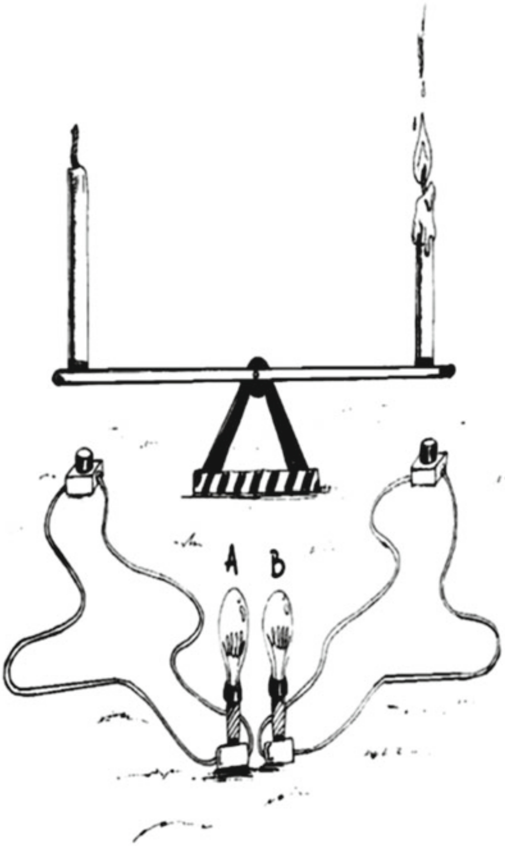


If the ropes shown in the figure are cut at the same time, will the bulbs be switched on at the same time or will one of them be first?

A) Both at the same time *B) Bulb A first* *C) Bulb B first*

Fig. 9.2 Weight and gravity novel as presented to the students

Straight after the students completed the questionnaire, they were divided into two groups of about five participants for each age group, and they were interviewed for one hour. The interviews were conducted directly after the questionnaire was completed in order to prevent them having time to develop second thoughts about the predictions they had made and/or discuss the novel situation with their classmates as doing such might risk losing the spontaneity of their earlier predictions and

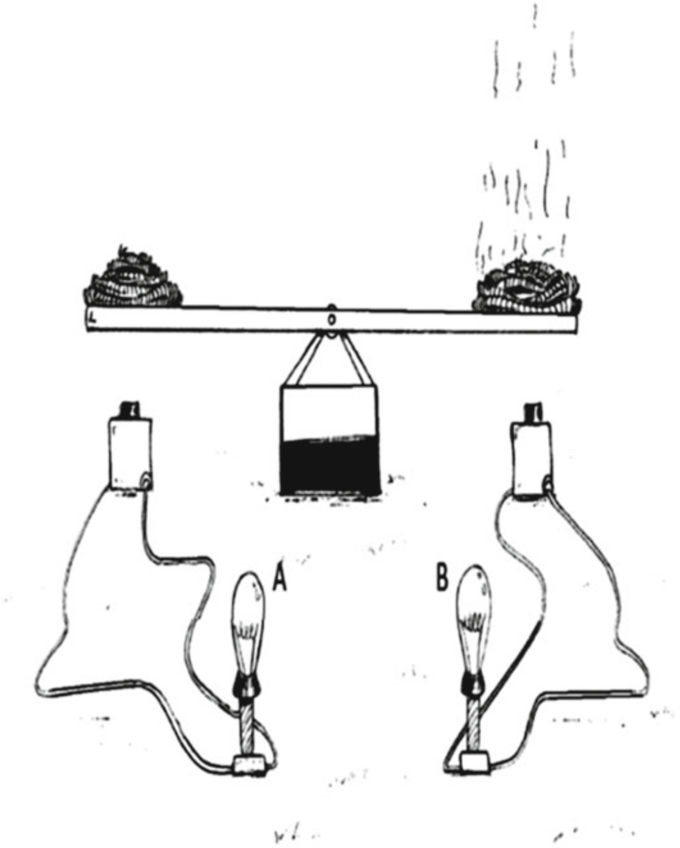


Two identical candles are balanced on a beam. After, we light one of the candles as shown in the figure. Will one of the bulbs be switched on? If yes, which one of the two?

A) Bulb A *B) Bulb B* *C) None of them*

Fig. 9.3 Burning a candle novel situation as presented to the students

the explanations as to their reasons for using them that were to be probed in these interviews. Semi-structured group interviews, considered an effective means of generating a considerable amount of relevant information within short periods of time (Webb and Vulliamy 1996), were used to explore the students' analogical reasoning. The interviews adopted a clinical interview approach (Clement 2000) in which students sat around tables and the researcher asked them about the prediction they made in the novel situations and to explain what led them to make their particular choice in responding to a question on a novel situation in the earlier questionnaire. Instead of simply asking the question 'what makes you think that?' as had been the case with the open-ended question in the questionnaire, there were additional questions, during the group interviews that were used to help scaffold



Two wire sponges which have the same weight are balanced on a beam. After, we light up one of them. Will one of the bulbs be switched on? If yes, which one of the two?

A) Bulb A *B) Bulb B* *C) None of them*

Fig. 9.4 Burning iron wool novel situation as presented to the students

students' explanations of their thinking and prompt reference to analogies in their answers. Although these questions were not standardised, some basic questions such as 'why do you think this will happen?', 'what makes you think that?' or 'why do you think your prediction is the correct one?' were used.

9.3.4 Data Analysis

The data collected through the questionnaire were quantitatively and qualitatively analysed with the students' predictions, made in the first part of questionnaire, being statistically compared across the three different age groups. Written responses in the open-ended questions of the questionnaire were examined to see whether there was evidence for the use of spontaneous or self-generated analogies in the explanations students provided in order to explain what led them to make their prediction.

The group audio-recorded discussions were transcribed and subsequently analysed to ascertain the method of analogy generation used, as well as the basic idea upon which students claimed that they made their prediction.

The identified analogies in students' explanations from the interview transcripts, as well as their written responses in the questionnaire, were analysed in terms of Clement's (1988) framework. It should be noted here that Clement's three methods for generating analogies derived from experts' thinking of novel problems.[1]

Moreover, explanations that involved analogies being generated without any elicitation were classified as 'direct spontaneous explanations' (DSE). Such DSEs were unexpected in the interview transcriptions because it was felt that if students were about to reason spontaneously, on the basis of analogies, when explaining their prior prediction (their choice in the closed-choice question) this way, they would have done so when they were completing the questionnaire, and thus, this type of explanations (DSE) would be identified in students' responses written on the space the questionnaire included to provide an explanation to the open-ended question. Analogies that were generated spontaneously by students when they were asked to elaborate more on their explanation constitute another category and are referred to as 'indirect spontaneous explanations' (ISE). The third and final category, 'prompted indirect explanations' (PIE), is when students were asked to provide an analogous case with the one already presented to them. In contrast to the spontaneously generated analogies, ISEs and PIEs were used essentially to code students' explanations identified in the interview transcripts.

Students' responses in the open-ended question of the questionnaire and responses recorded in the interview settings were combined in order to identify common themes. The predictions made, as well as the analogy generation method and the analogies themselves, were compared among the three different groups. Two science education researchers and one more person (outside the area of science education specialism) analysed the data (questionnaire and interview responses) and coded the responses. Where disagreement about the coding existed, it was resolved through discussion among the coders.

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[1] By using this framework, we make no claim of similarities or comparisons, between students' reasoning and that of experts in Clements' study because students do not have the same categorisation and reasoning ability that scientists have (Chi et al. 1981). In this sense, the framework was only used to classify the way that analogies were generated (the use becomes clearer in students' analogies presented in the results section).

9.4 Results

There were many similarities among students' predictions with the majority of students choosing the same option in the multiple choice question. From the 41 students in this study, 34 made the predictions that might have been expected based on the existing literature on students' ideas about phenomena that were in some ways similar to those presented in the novel situations. Across the six novel situations, only 38 out of the 246 (15 %) of the predictions were correct although students in Years 4 and 9 made fewer scientifically correct predictions compared to students in Year 11.

Many of the students (39 out of the 41 students) looked for analogous cases that would help them in formulating (or selecting) the correct answer in the multiple choice question relating to a novel situation. The analogies students generated were drawn from phenomena that they had, generally speaking, observed in their early childhood. This became apparent as some of the older students made use of the same analogies as those used by the younger students although the frequency with which they drew on those analogies was much lower than that for the two younger student groups. Although it might be argued that in some cases the analogous situations identified (e.g. see the response provided by S9.1 below) could be considered more akin to examples, we argue that these could also be seen as analogies in the sense that the novel situations, in which students attempted to make a prediction and explain what led them to the latter, were analogous to their stored experiential knowledge.

For these predictions, a total of 234 analogy explanations were generated of which 108 were DSE, 103 were ISE and 23 were prompted by the researcher. It emerged that students across the three different age groups used similar, and in many cases identical, analogies in order to make their predictions. Also, even if the analogies generated were not identical, they were similar in terms of the elements that students focused on and changed in order to generate the analogies as described above. The following two responses given for the novel situations two and five as shown in Figs. 9.2 and 9.4 illustrate this point:

> In my opinion bulb A will switch on first because the left box has greater mass than the right and therefore, the one that includes greater mass will fall down first. I think that this is like the example in which we throw from the top of a roof a dumbbell and a feather, the dumbbell always falls faster. This happens because the weight is greater. (S9.1)
>
> I have replied that bulb A switches on. This is because when burning, there is a decrease in the mass of the wire sponge. Isn't this like having two matches on a beam? If we set one of them on fire, it gets burnt losing its weight and thus making the beam lean to the other side. (S4.3)

It can be seen in the first example that the student, as was the case for many others students across the three age groups, changed very few characteristics of the novel situation (the target) generating in this way an analogous situation (the base) that, according to the answer given, helped in making a prediction. They focused on the difference of mass between the animals being placed in the boxes (the elephant and ant), and their analogy was generated by simply exchanging these two animals with two others with which they had more direct personal experiences.[2] From the 41 students in this study, 26 followed a very similar reasoning process in this novel situation. The only difference being that instead of replacing the elephant and the ant with a dumbbell and a feather, respectively, students provided analogous cases of two other objects being dropped from the same height (e.g. a brick and a piece of paper, an olive and an olive leaf), or they even gave examples of two people of different mass (a fat and a thin one as some students wrote) falling from a tree, a roof or into the sea. This way they came to the same conclusion making an erroneous prediction according to which the box with the elephant falls faster (bulb A is switched on first). However, in this situation, the scientific prediction is that both bulbs light at the same time because their acceleration under gravity is constant for both masses (ignoring air resistance). The response given by S4.3 is similar in that the analogy was generated by simply exchanging the less familiar object of iron wool being burnt with lit matches that they were more familiar with.

In agreement with Wellman and Gelman (1998), students in the present study appeared to be paying attention both to surface and structural similarities. However, cases in which students tried to compare only surface similarities failed to generate analogies that would be helpful in facilitating their understanding of the novel situations. For example, in the weight and gravity situation, there were four cases in which younger students (aged 9–10 years) focused on the type of animals and their size. These students made the prediction that the box with the elephant reach the ground first, and during the group discussions, they generated the analogy that an elephant is like a cow (or other big heavy animals) and the ant is similar to a bee in order to think about and deal with this novel situation. Although they were able to identify size and weight within both the base and target objects as being common attributes, their analogy was limited to the mapping of these surface similarities, and albeit they were questioned further, they could not see and they did not refer to any relational similarities concerning the existence (if any) of a relationship between the mass and the speed of their two animals falling to the ground (e.g. that the cow goes faster than the bee). It is not clear therefore whether it was the mapping of these surface similarities that advanced their thinking and reasoning about this situation, and thus it cannot be argued that it was the analogies themselves that led them to their predictions.

On the other hand, within the same novel situation, there were cases in which surface similarities acted as a starting point from which students went on to discover further similarities, like the connection of greater mass with faster motion. This is how they came up with an analogy which helped them to make their predictions. There were also cases in which the focus on structural similarities appeared to play an important role in guiding the generation of analogies. For example, in the situation involving a burning candle (Fig. 9.3), a 10-year-old student wrote:

> Bulb A will be switched. Mass decreases as the candle burns and thus the beam turns to the side of bulb A. It is like having a wet sponge and a dry one trying to balance them on a beam. The only way to make it is to squeeze and twist the wet one. (S4.2)

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[2] Students are certainly familiar with elephants and ants, but we argue here that they might have little personal experience of handling them as they might have with dumbbells and feathers which are objects that also have very different masses as well.

There are no obvious surface similarities between a lit candle and a wet sponge, and it appears that, in this example, all information was functional. However, these similarities contributed to what Mozzer and Justi (2012) refers as 'the initial access stage' (p. 434) of the analogy generation. The generation of analogy was facilitated by this student's experiential knowledge about something flowing from these two objects, and this is how the analogy was generated.

These findings challenge the claim made by Gentner (1989) according to which young students rely merely on object attributes, or surface similarities, when they attempt to reach solutions on the basis of analogies. Rather it appears that in the current study, students across the three age groups focused on both surface and functional similarities.

Having as a starting point the descriptive properties, which are easily accessible (Vosniadou 1989, Haglund et al. 2012), students mapped the explanatory structure that both the base and target shared and then subsequently spontaneously generated the analogies and used these as a basis for making their predictions. As Brown (1989) and Ross (1989) have argued, paying attention to surface similarities can lead to the discovery of similarities in the underlying structure of these objects, or, as Vosniadou (1989) argues, surface similarities of objects can lead to 'deeper, less easily accessible properties in a complex causal/relational network' (p. 418). This is the mechanism that seems to better describe how students in the present study generated the analogies. There are several studies which support this idea (e.g. Vosniadou 1989; Dunbar and Blanchette 2001).

Most of the analogies identified were generated via a transformation. Only very few elements were changed in order for an analogy to be generated. Most of the students selected as base entities situations that had similar features to the entities of the novel situation (the target) they were trying to explain. The generation method of transformation was evenly distributed among the three age groups in the six novel situations and was the most common method for generating analogies among this study sample.

From the total number of 234 analogies identified, 41 were coded as being generated via an association. The analogy generated by S4.2 is a typical example of this generation method. As it can be seen in the example above, this student focused on the element of the liquid that flows while the candle is burning, and this focus led the student to make a prediction that there is a loss of mass as it reminded them of an analogous situation that was different in many ways from the burning a candle situation. While their reasoning is incorrect in the sense that although the candle loses mass, this is not due to the wax drops that flow (these were, in the diagram, retained on the pan balance with the rest of the unburnt candle), but it is due to the carbon particles in the candle reacting with the oxygen in the air to make carbon oxides. Subsequently, this gas (CO_x) is given off, and therefore the remaining candle weighs less than before being lit. Nevertheless, there were students who made the correct prediction in this question by reasoning on analogies and furthermore, in explaining their answers, did use scientifically compatible ideas. This is shown in the questionnaire script response below:

> I chose A bulb to light up. I can see that this is like the case of a piece of paper. After being burnt, the paper will not have the same weight anymore, it becomes lighter. I think that the same happens with the candle, it loses its weight as it gets burnt. (S11.3)

In the above response, this student, as was the case for many others (28 out of the 41 students followed a similar reasoning process), focused on the element of an object being burnt in order to come to the conclusion that burning objects lose their weight or to justify what makes them believe that the latter is a correct idea which indeed appears to be compatible with the scientific view in this novel situation. In other words, there might be some cases in which students' ideas of objects being burnt are not only incorrect, in relation to the experiences they are based upon, and yet, as the above example shows, they can be used to make correct predictions in the case of novel situations. Nevertheless, students who came to a correct prediction in the novel situation 1 (Fig. 9.3) made an incorrect prediction about novel situation 5 (Fig. 9.4) by following a very similar reasoning process and using similar analogies. In both cases, the most common underlying idea identified in students' responses is that there should be a decrease in the mass of objects being burnt. Students' explanations offered about their ideas and what led them to make their prediction explained what led them to think that burning objects lose weight. It appeared that their idea is a reflection upon experiences like firewood being burnt and the remaining ash – which is less bulky than the wood and the coal – being lighter (this analogy was the one most frequently expressed about these two novel situations). While this is correct for the burning candle situation and can lead to a correct prediction, this is not the case for the iron wool. In contrast to the first case in the iron wool situation, the iron wool has chemically combined with oxygen during the burning process, and thus, having oxidised to form an 'ash' of iron oxide, its weight would increase.

One possible explanation concerning what led students to a correct prediction in the first case is that they made their prediction on the basis of their experiential knowledge of burning fuels which, in general, will be materials that, whether they know this or not, contain carbon. On the other hand, there appears to be an absence in students' everyday experiences of objects known to contain iron being burnt. As such, they were led to an incorrect prediction in the iron wool situation because they draw on analogous cases of carbon made materials being burnt. This suggests that there could be some cases in which students have done their observations well, and they can use this experiential knowledge in such a way as to help them to understand new phenomena and information.

9.5 Discussion

The use of the same analogies by students across the three age groups suggests that students were, in many cases, led into making incorrect predictions because of their use of analogies drawn from personal and everyday experiences. However, the results also suggest that spontaneously generated analogies, although frequently leading to erroneous predictions, do have the potential, in some situations, to lead to scientifically compatible predictions. Nevertheless, how this is possible and under which circumstances it occurs are questions still remaining open for investigation. We are continuing with further research upon this issue.

The spontaneously self-generated analogies showed that students were forced to look for similarities between the novel situation (target) and their prior experiential knowledge (base situations that they perceived as being similar), and it was in drawing on these that they made their predictions. This supports constructivists' argument that in order for students to understand a new situation, they should construct personal interpretation of new information by using prior experiences (Driver and Bell 1986).

9.6 Implications

These findings suggest some implications for science teaching in that teachers not only need to be aware of students' prior knowledge (Hewson and Hewson 1983) but also need to better understand how their students use that prior, often experientially grounded everyday knowledge, when presented with novel situations. In this respect a better understanding of the generation and use of self-generated analogies could be a valuable tool in assisting teachers to address existing students' ideas which are not compatible with scientific concepts. Conversely, with self-generated analogies reflecting and explaining where students' erroneous ideas stem from, they could be used in order to help teachers in the identification of the latter.

As Huxley (1894) wrote about science education, 'all truth, in the long run, is only common sense clarified' (p. 282). Therefore, it is important for students to be given the opportunity to connect reasoning in science with their common sense which, as the study showed, is actually how many of them reason in their everyday life.

What should be noted here is that the findings of this study are based on a relatively small localised study from one geographical area in Greece, and, as yet, we make no claims about their generalisability. We are continuing with further research to explore students' predictions and explanations in these novel situations with a larger study sample that will also include individual, as opposed to small group interviews with all students in order to gain deeper insights about their predictions and reasoning in novel situations.

Future research could also focus on students' reasoning in a larger range of novel situations and across different countries in order to see if reasoning spontaneously in novel situation, using analogies, is a common way of understanding new situations.

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Chapter 10
A Framework to Explore the Role of Mathematics During Physics Lessons in Upper-Secondary School

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10.1 Background

In relation to the teaching of physics, weak mathematics skills among students are widely discussed since this is viewed as a hindrance for the learning of physics (cf. Uhden et al. 2012). For example, the TIMSS advance study discusses the decrease in students' mathematics knowledge as an explanation for the decline in Swedish students' results in physics (Angell et al. 2011). Despite this, research focusing directly on the role of mathematics in ordinary physics classrooms is scarce. The purpose of this chapter is to present a framework to further explore the role of mathematics for physics teaching and learning in upper-secondary school.

10.1.1 Reality and Theoretical Models

The intention and strength of science are to describe and predict real phenomena by organising explanations through theories and theoretical models. In the scientific research process, empirical and theoretical work is intertwined leading to construction, confirmation or refinement of theories and theoretical models. This is an interactive process of discussions, experiments and observations made within the science community (Adúriz-Bravo 2012; Giere 1988; Koponen 2007). The relation between a theoretical model and real-world referents and phenomena is in many ways complex, and observations and experiments are by necessity embedded in theory and therefore "theory laden" (Hanson 1958). This complex relation between theoretical models and reality is part of the reason that there are students who find physics

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difficult, uninteresting and irrelevant. Furthermore, it has been widely suggested that learning in science is influenced by students' more general views about the nature of scientific knowledge (Erduran and Dagher 2014; Lederman 2007). Students' knowledge about the relationship between observations, theoretical models and reality could influence also their conceptual learning and their ability to apply their knowledge in real-world situations. Hence, physics teaching would benefit from focusing on meaning making and discussions of relations between theoretical models and the real world.

10.1.2 Mathematics: A Natural Part of Physics

Mathematics is an inherent part of theories, and mathematical manipulations are used by scientists to analyse and make sense of real-world phenomena. Ability to use mathematics to argue for results within the framework of models is central in physics. This importance of mathematics for science is emphasised by Pask (2003) who states that mathematics can be viewed as the *Science of Analogy* since it makes powerful analogies feasible in various applications in science. In addition to this, historical studies show that physics can be a fertile ground for new mathematical ideas and creative mathematical reasoning. The role of mathematics in physics models and reasoning, as well as the relationship between models and observations of reality, could also be understood as part of the nature of science.

Because of the importance of mathematics both in the development and application of physical models and theories, mathematics has an important role in physics teaching and learning. Krey (2014) reports, based on measurements with a quantitative instrument, on the importance of students' conceptions of the role of mathematics in physics studies. He advocates more in-depth studies and further research in the area.

When studying the role of mathematics in the physics classroom, it is important to take into account research both in science education and in mathematics education. Several studies point to that students struggle to transfer their mathematical knowledge to new applied situations (Kuo et al. 2013; Michelsen 2006; Kaiser and Sriraman 2006; Torigoe and Gladding 2011; Uhden et al. 2012). Michelsen (2006) emphasises the value of modelling in situations comprising both mathematics and physics. Mathematical modelling receives an increasing amount of attention within mathematics education research, and efforts are called for to develop theoretical frameworks that can be applied to studies of modelling and problem-solving situations like those in physics teaching (Lesh and Zawojewski 2007). It has also been shown how aspects of socio-mathematical norms could be of importance, e.g. whether students and teachers have a common view of the mathematics in terms of what constitutes a mathematical model or what is appropriate mathematical argumentation (Yackel and Cobb 1996). Nilsen et al. (2013) also address the problem of transfer between mathematics and physics. They separate physics competencies in those requiring mathematics and those not requiring mathematics. In the first case, the students have to be able to transfer between physics and mathematics. This transfer is often problematic due to the algebra, which the students normally master in mathematics classrooms but struggle to perform in other settings. The authors conclude that there is a need for further research on ways to include and apply mathematics in physics teaching.

The terms "technical" and "structural" use of mathematics in physics instruction (Karam 2014; Pietrocola 2008; Uhden et al. 2012) have been introduced to account for different roles of mathematics. "Technical" means that mathematics is viewed as a "calculation tool" with an instrumental use of mathematics. "Structural" means that mathematics is used as a "reasoning instrument" and that there is an emphasis on interpretations or consequences and on using logical reasoning (Karam 2014).

10.1.3 Practices of Physics Instruction

Solving of "standard problems" (often appearing in the end of a chapter in physics textbooks) is traditionally a central part of physics teaching in upper-secondary school. This is emphasised in a Swedish study by Due (2009) where students state that to succeed in physics, it is necessary to put a lot of effort into solving physics problems. Teachers often take for granted that students, who are able to solve standard problems, also have a good understanding of physics concepts and models. However, research show that this is not necessarily the case. Instead, students often solve such problems without really understanding the concepts and theoretical models used. Explanations of this are that students tend to search for a formula that fits the numbers/variables given in the problem (Hobden 1998) and that students have difficulties grasping the universal applicability of models in physics (Hansson 2014). Their use of models is instead often context dependent (Redfors and Ryder 2001). Students have been found to struggle with explanations and the solving of physics problems when they need to use mathematics to relate theoretical models to real-world phenomena, i.e. combining mathematical operations with conceptual reasoning about physical phenomena – realising that equations can express a supreme meaning and be used for both conceptual and formal mathematical reasoning (cf. Karam 2014; Kuo et al. 2013; Michelsen 2006; Torigoe and Gladding 2011; Tuminaro and Redish 2007; Uhden et al. 2012).

In summary, we know from earlier research that the solving of physics standard problems is not a guarantee that students focus on the relationship between theoretical models/concepts and the "real world" as stated above as central for physics. However, less is known about the role of mathematics in other kinds of teaching situations in ordinary physics classrooms. This lack of research is part of a general need of research focusing on "the normal practice of physics instruction" (Duit et al. 2007; Karam 2014).

In line with this, the aim of this chapter is to present an analytical framework to understand how the relations between *Reality, Theoretical models and Mathematics* are communicated in different kinds of situations in upper-secondary physics classrooms (lectures, labwork and problem-solving situations).

10.2 Analytical Framework

To be able to analyse the relations made between *Reality, Theoretical models and Mathematics*, during classroom communication, an analytical framework was developed. In this analytical model, we have separated the three entities from each other. This could from a philosophical point of view be thought to be problematic but makes an analysis possible where different foci can be identified in the classroom communication during different instances of a lesson or in different kinds of instructional situations:

Reality refers to objects or phenomena (or observations of them) in the real world. *Reality* is used in a broad meaning comprising both well-known objects, phenomena and events of which students have experienced from their everyday life and phenomena observed during demonstrations and labwork, sometimes through the use of complex measuring equipment.

Theoretical models refers to a semantic view of theoretical models in physics and concepts related to them (Hansson et al. 2015). The theoretical models could be mathematically or qualitatively formulated.

Mathematics refers to mathematical concepts, theorems, representations, mathematical reasoning and methods.

During communication in the physics classroom, relations are made between these three entities. Relations made are the focus of the framework, not the three entities themselves. In Fig. 10.1 the relations are represented by the sides in the "triangle of analysis". The three sides of the triangle represent bidirectional links made between the three entities.

Link 1 represents relations made between *Reality* and *Theoretical models*. As stated above, it is known from previous research that such relations are important in physics instruction. The focus of the analysis of the communication during a lesson was uses of theoretical models or constituents thereof in relation to observations or predictions of some aspects of *Reality* or when a concept was linked to referents (i.e. objects and events) in *Reality*.

Link 2 represents relations made between *Theoretical models* and *Mathematics*. It could be viewed as problematic, from a philosophical point of view to separate mathematics from the theoretical models in physics since mathematics often is an inherent part. Nevertheless, they have been separated in the analytical model to accentuate the different kinds of roles mathematics can play in the physics classroom. And, as stated above, it has been reported that during problem solving, students get stuck in mathematical manipulations without relating to any physics. This is another reason for separating them during the analysis.

The framework enables the analysis of the classroom communication to pinpoint instances when theoretical models are described in mathematical terms, or when a

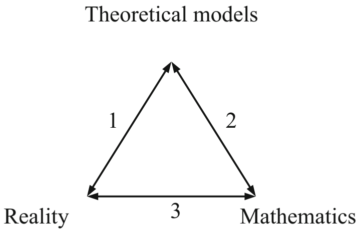

Fig. 10.1 *Reality, Theoretical models and Mathematics* in physics teaching

problem is transferred from a physics problem, to a mathematical problem (e.g. manipulation of formulae, solving equations or constructing graphs). Link 2 can be made in structural or technical ways (Uhden et al. 2012; Karam 2014). Structural means that mathematics is used for reasoning in relation to a theoretical model, while a technical use of mathematics is characterised by manipulations of formulae without meaning making or explicit links to the theoretical model or when searching for the correct formula using a "plug and chug" approach to problem solving. When a link is communicated between *Theoretical models* and *Mathematics* and the role of mathematics is structural, it is denoted "link 2, structural". And likewise "link 2, technical", for instances where the role of mathematics in is technical.

The third type of link (3 in Fig. 10.1) depicts relations made between *Reality* and *Mathematics*. This could happen in physics class when observations are discussed in mathematical terms (without contextualisation of physics concepts). For instance, when referring to experiences, e.g. it hurts more and more in the ears when diving deeper and deeper or during labwork when times or distances are measured for rolling wagons. In these cases different kinds of quantifications of the observations made are done. A quite different example could be when students relate a real-world phenomenon to a mathematical object, e.g. a relation is made between a slope (a real-world phenomenon) and a right-angled triangle (a mathematical object). Hence, links of type 3, between *Reality* and *Mathematics*, are made when teachers/students relate an observation of a real-world observable (referent) to a mathematical representation; the referent can be interconnected to concepts like time or distance.

Analysing the communication through looking for these three different relations made (links 1–3) is not to say that they are independent of each other. When a statement is categorised as link 3 (relations made between Reality and Mathematics), it does not mean that observations are not theory laden per se, only that the theoretical model is not made explicit during the communication. In the same way do links made between theoretical models and mathematics (link 2) not say that there is no Reality, only that it is not explicitly included in the communication. The framework should be viewed as a way to analyse what students and teachers say and do during different parts of a physics lesson. Further details about uses of the framework can be found in Hansson et al. (2015).

10.3 Applications of the Analytical Framework

The use of the analytical framework is exemplified through empirical data from physics teaching of a group in first year of the Swedish national science programme in upper-secondary school. The group of students and the circumstances they were in are described below, before an illustration of the three types of links from the analytical framework is given.

10.3.1 The Studied Classroom and an Outline of the Analysis

The study focused on "the normal practice of physics instruction" (Duit et al. 2007), and observations were made of one teacher and the three physics groups that were taught by her of in total 7 lessons. They were observed during sequences of lessons consisting of lectures, problem solving in small groups and labwork (40–80 min each). The lectures were video recorded using a camera focused on the teacher and the whiteboard, and other cameras focused on the students. During problem-solving sessions and lab sessions, the students worked in small groups of 3–4 students. Selected student groups were video recorded with backup through audio recording devices.

The communication during lectures and student-centred work, i.e. group work during problem solving and labwork, has been analysed. The data is analysed from the ternary perspective where we deductively identified relations between *Reality*, *Theoretical Models* and *Mathematics* as communicated by teachers and students. During the analysis, a multistep process was used: watching a video sequence in its entirety, identifying major events within the sequence, repeated watching the found sections, transcribing the interactions (words and actions) and identifying the links made in the communication. The analysis was done in collaboration to make the interpretations as uniform as possible.

Below we show examples, in form of descriptions of different parts of the learning activities and excerpts from transcripts, of how different links could be identified in the data from classroom communication in the different instructional situations. The examples involve a group of 30 students studying mechanics (dynamics and the energy principle) in their first year on the science programme. The lesson (lecture) is about energy and the conservation of energy, and the teacher led the lesson from the whiteboard.

The problem-solving session started with a short lecture where the teacher solved examples similar to the students' pending tasks in the textbook. She wrote the formulae to manipulate on the whiteboard and informed the students that they also could be found in the textbook. After the lecture, the students sat in small groups and solved problems together. Students often looked at the whiteboard to find the right formula for the problem they were about to solve.

In the labwork, the students were doing experiments with wagons and balls going down boards, varying the slope by lifting one end of the board. The students were to fill out a sheet with the height of the board and the time it took for the item to go down the board and then calculate kinetic and potential energy with the formulae from the first lesson. The selected results used to discuss uses of the framework below are from Hansson et al. (2015), where further descriptions and discussions can be found.

10.3.2 Link 1, Reality and Theoretical Models

As a first example of link 1, i.e. between Reality and Theoretical models, in the analytical framework we look at a description of the lesson:

> In the beginning, one student stated the energy principle and this was picked up by the teacher, who then emphasized its importance. Another student associated energy with wind power, which resulted in other students giving other examples such as wind-, sun- and nuclear energy. The teacher asked where the energy in the wind turbine comes from, and got "the wind" as an answer from the students. The teacher, however, did not explicitly link this to the transformation of energy, e.g. which transformation of energy is relevant for a wind turbine.

In the above example, we have identified that relations between Reality and Theoretical models (the concept of energy) are in focus for the communication. When looking closer into the relations made, we can however also notice that they do not explicitly involve the model in focus (the energy principle).

Another example of link 1 comes from the problem-solving session in a group with four students:

> When the students read the problem text in the textbook they quickly decoded the situation as described in a real context to identify which concepts or models are relevant.

The purpose of the communication in the context of link 1 was to know where to find formulae or strategies in Theoretical models to solve the problems.

A third example of link 1 is at the end of a labwork situation:

> The teacher sums up and there is a discussion about energy in other forms such as friction and rotation when the ball is moving along the board.

The side of the triangle in Fig. 10.1 represents a continuous scale between the two entities of the link; thus, the analytical framework allows varying degrees of emphasis towards either of the two vortices in the link. Reality is emphasised stronger than Theoretical models in the first and last examples, whereas Reality is just briefly touched upon by the link the students made in the second example; for a detailed analysis of the uses of link 1, see Hansson et al. (2015).

10.3.3 Link 2, Theoretical Models and Mathematics

The second type of link, i.e. between Theoretical models and Mathematics, with technical and structural aspects (Uhden et al. 2012; Karam 2014), is exemplified in the lesson in the following description:

> After the introduction the teacher started discussing the conservation of energy, potential and kinetic energy without any links to Reality. She made an illustration of a zero level with a 5 kg-weight, which is more a classroom illustration than a real world phenomenon. She did not say anything about why different zero levels could be useful. She then stated that the potential energy could be calculated using $W = mgh$, without motivating the formula further. The first routine task was then introduced where she came back to the 5 kg weight. The task was an exercise in how to handle the formula. This was emphasized by the teacher writing $5 \cdot 9.82 \cdot 0 = 0$, even though a student had already said that the answer should be 0 because of the zero level.

In this situation, the teacher's communicated relation between Theoretical models and Mathematics has a strong emphasis on a technical use of mathematics with main attention to the formulae. The student at the end used the Theoretical model with a structural perspective linked to Mathematics to come to the conclusion. A detailed analysis and discussions of the uses of link 2 are given in Hansson et al. (2015).

10.3.4 Link 3, Reality and Mathematics

The third type of link, i.e. between Reality and Mathematics, was the most uncommon in the study. The following examples illustrate the link:

> The teacher began the labwork session by asking the students if they remember the formulae for potential and kinetic energy. In her introduction of the experiment, she guided the students thoroughly in every detail such as inclination of the boards.

In this example the teacher left no room for the students to discover why the slopes cannot be too steep, e.g. it is more difficult to measure the time:

> The teacher ended the labwork session with a discussion about measuring errors causing misleading results when doing the calculations.

In both examples the communication is within a Reality context linked to Mathematics in the calculations the students were going to do. Discussions and a detailed time-based analysis of the uses of link 3 are given in Hansson et al. (2015).

10.3.5 Identifying Shifts in the Communication Pattern

The framework is useful as an aid to find shifts of attention in communication. It is illustrated first by an example from the problem-solving session in a group with four students. The main part of the time was spent on manipulation of formulae inspired from decoding the texts guided by the correct answers given in the book. It could be said that the emphasis of the discussions during problem solving very quickly moved from relations between Reality and Theoretical models (when reading the problem text in the textbook to identify which concepts/models are relevant as described in Sect. 10.3.2) to focusing on relations between Theoretical models and Mathematics, with a strong emphasis on a technical use of mathematics (link 2, technical). However, this pattern where the work of the group was focused on technical use of mathematics was broken at some instances. This happened when students connected to reality when discussing the reasonableness in the answers obtained and when the problem text was not easily decoded into formulae. An example of the latter was a problem with an extended rubber band. The relation between the situation described in the problem text (Reality) and models/concept was not clear to the students. They discussed possible real-world situations and the relevance of the different concepts for describing the situation:

John: The ground marks the zero-level, an extended rubber band …Are you supposed to attach it to the ground?

Mary: Doesn't it depend on if you extend it like that or like that [horizontally or vertically]

Jill: You cannot know

John: An extended, that has to mean that you pull upwards

Mary: Then it has pot … kinetic energy

Jill: Can't you just put it between pillars or something [holds the index fingers in the air]

Mary: But if you then let go it will be transformed to kinetic energy so it should be potential energy when it is still

[Talk about how the rubber band lays still and that there is no potential energy when it is not extended]

/…/

Mary: It cannot be kinetic energy? [Asks the teacher]

Teacher: It is called potential energy in the rubber band.

In this situation, relations between real-world situations and theoretical models and concepts (whether the rubber band has potential energy only if extended vertically) were made (and questioned) during the discussion.

In Table 10.1 the broader context of the examples of link 3 discussed above is presented. It gives an overview of the time spent on this type of activities in the group. The main part of the session was spent on measuring and filling out the sheet with the lab instructions and then a short calculation using the formulae.

The dual focus in the framework enables a partition of the three types of links, which can reveal different types of communication in classrooms otherwise possibly overseen. When shifting attention in the analysis, the particular aspects of the communication become visible.

10.4 Discussion

The analytical framework described in this chapter could be used to shed light on the role of mathematics in the practice of an ordinary physics classroom. Examples of how this framework could be used when analysing classroom communication in different instructional settings (lectures, problem solving and labwork) have been given.

Table 10.1 A time-based analysis of links between *Reality (R), Theoretical Models (TM) and Mathematics (M)* during a labwork session

Time (min)	Activity	Link 1, R-TM	Link 2, TM-M	Link 3, M-R
0–3	Teacher introduces lab activity, describes the material	–	–	Measuring conditions described in a few sentences
3–6	Teacher introduces lab activity	–	Teacher describes formulae	–
6–8	Students are placed in groups for labwork	–	–	–
8–10	3 students rig a slide for the experiment	Discuss the construction of the material	–	Measures the slide, 20 s
10–14	Students read the problem sheet and fill out the measured values	Discuss the height	Discuss the formulae	Discuss where the height of the slide is, 20 s, for correct measure
14–16	The waggon is dropped along the slide	–	–	Students collect data measuring time
16–23	Students fill out the sheet	–	Calculating, teacher helps finding error (12–14)	–
23–38	Students drop the waggon from different heights	–	Students fill out the sheet and calculate between measurements	Students collect data measuring time and heights
38–39	Students rig a new experiment, ball in a slide	Discuss the construction of the material, 20 s	–	–
39–58	Students drop the ball from different heights	–	Students fill out the sheet and calculate between measurements	Students collect data measuring time and heights
58–61	Students fill out sheet	–	Students calculate and fill out sheet	–
61–63	Teacher comes to the group, problem to interpret the results	Discuss the meaning of the calculated values, energy loss, e.g. friction and rotation	Discuss the meaning of the calculated values in the formulae	–
63–65	Students write conclusions on the sheets	–	Discuss the meaning of results, the formulae	Discuss measuring conditions
65–76	Students solve problems in the textbook when ready with the experiment	–	Calculations using formulae, check correct answers in the book	–
76–79	Teacher concludes at the whiteboard	Friction and rotation	Interpretations of the results, formulae	Discuss measuring errors

cf. Hansson et al. (2015)

Previous research has discussed the importance of physics teaching focusing on meaning making and discussion on the relations between the theoretical models and the real world (cf. Adúriz-Bravo 2012; Koponen 2007). An analysis with the starting point in the framework helps to shed light on the amount of links made by students and teacher between Theoretical models and Reality (as well as the other links). The framework is an answer to a need in the research field of physics education to identify what kinds of situations that prompt different uses of the links pinpointed by the framework. In this way, through identifying situations where different kinds of relations are made, the use of the framework could give starting points for discussions of the quality of the classroom communication in these situations.

With the analytical framework described here also the distribution in time of communicated links between Reality, Theoretical models and Mathematics can be found and analysed, depicting what the essence of the discussions in the classroom is. Apart from examining relations made between Reality and Theoretical models, this is also suited for addressing questions about the use of mathematics in physics instruction and whether the classroom communication "get stuck" in a technical uses of mathematics, which is another problem reported on Karam (2014) and Uhden et al. (2012).

With the described framework, it is possible to analyse different instructional situations (e.g. lectures, problem solving and labwork), hence widening the scope of the research field to uses of mathematics in different instructional situations, e.g. moving beyond problem-solving situations where a technical use of mathematics has been shown to be frequent (e.g. Due 2009; Torigoe and Gladding 2011). Examples of this have been reported in Hansson et al. (2015). In this way this analytical framework could be a tool to increase our understanding of how, in the classroom communication, relations are made (between *Reality*, *Theoretical models* and *Mathematics*) and thereby form a broader picture of the role of mathematics in the physics classroom.

When analysing lectures with this analytical framework, it is also possible to identify situations that prompt the communication to change – for example, where there is a change of focus from a link 2 (technical use of mathematics) to link 1. Examples of how such situations can be identified are discussed above – such as in qualitatively posed problems, when applications of already introduced theoretical models are used, when students relate to experiences in the real world when discussing how to understand a situation or whether an answer could be reasonable or when the text in a problem formulation is not easily decoded into formulae. Such results give an indication of possible ways to change the predominant communication. This line of research could in the future lead to advices for physics teachers on how to instigate communication in the physics classroom involving all three kinds of relations, a structural use of mathematics and shape the communication towards encompassing the meaning of concepts and theoretical models, how such models are constructed and how they can be used to discuss and understand different kinds of real-world situations.

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Chapter 11
From Algorithmic Science Teaching to "Know" to Research-Based Transformative Inter-Transdisciplinary Learning to "Think": Problem Solving in the STES/STEM and Sustainability Contexts

Uri Zoller

Abbreviations

HOCS	Higher-order cognitive skills
LOCS	Lower-order cognitive skills
PS	Problem solving
STEM	Science, technology, engineering, and mathematics
STES	Science, technology, environment, and society
STESEP	Science, technology, environment, society, economy, and policy
STSSEE	Science, technology, STES, STEM, and environmental education

11.1 Introduction: Theoretical Background, Problem, Rationale, and Conceptualization

There is an ever-increasing gap between the reality of the twenty-first society, which is based on science, technology, globally interacting infrastructures, economies, and advanced, sophisticated technology-based computers, network systems and the response of the diverse, multi-sectorial national educational systems to this reality. Consequently, the advancement of students in the secondary and tertiary levels is based on their scoring on disciplinary, algorithmic knowledge-centered examinations

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and/or "standardized" tests. Their *learning*, however, is assessed and perceived, almost exclusively, on their "grade achievement" in these tests/examinations.

The case study here presented is focused on higher education, aiming at assessing college science students' *problem* (not exercise) *solving* capability in the context of "traditional" chemistry teaching (Beall 1995; Zoller 1993; Lyle and Robinson 2001; Nakhleh and Mitchell 1993). Thus, an action research study was conducted in an attempt to respond to the following leading questions:(1) Does contemporary/traditional university/college chemistry teaching contribute to the development of science students' PS capability and to what extent? (2) What are the science students' views concerning higher-order cognitive skills (HOCS)-type questions? and (3) What can be learned from students' responses to HOCS-requiring *problems* that can be used for promoting their both generic and disciplinary PS capability? This study offers a research-based framework for the development, implementation, and assessment of HOCS-requiring problems in STSSEE courses within the promotion of "HOCS learning" in science education, particularly students' PS capability.

Given the current striving for sustainability (CSR 2014; Zoller 2012; Seghezzo 2009; Benglsson and Ostman 2012) and the corresponding paradigm shift in science, technology, research and development (R&D), environment perception, economy, and policies, the in-accord corresponding paradigm shift, at all levels of science; technology; science, technology, environment, and society (STES); science, technology, engineering, and mathematics (STEM); and environmental education (STSSEE) is unavoidable. This means a shift from the currently dominating lower-order cognitive skills (LOCSs) algorithmic teaching-to-know to higher-order cognitive skills (HOCSs)-promoting learning-to-think (Zoller 2012; Zoller et al. 2014).

The essence of these paradigm shifts is presented in Table 11.1.

A meaningful science/STES/STEM and environmental education, which will be responsive to and having the chance of playing a leading role in the above processes, requires a revolutionized change in the guiding philosophy, rationale, and models of our thinking, behavior, and action, meaning "HOCS literacy" in the transdisciplinary STSSEE interface contexts (Zoller 1993, 2012). This requires a corresponding research-based paradigm shift from traditional teaching to "know" to learning to "think" in the STES/STEM contexts of science education. In accord, the development of competent "decision-makers" and "problem solvers" is necessary for (a) facilitating sensible and reasonable decisions by capable problem solvers in complex realities; (b) making society function productively at all levels, with minimal social friction; (c) enhancing the survival prospects of individuals and communities; and (d) ensuring *sustainability* (Zoller 2013; Vals et al. 2014) in the STES, economy, and policy (STESEP) interphase contexts (Zoller 2012; Zoller et al. 2014).

Improving teaching and learning of science constitute a major driving force for the design and implementation of innovations in science education worldwide (AAAS 1993; NRC 2003; Treagust et al. 1996; Zoller 2000; Zoller and Levy Nahum 2012). An important component of the continuing ongoing reforms in science education is the development of the students' problem-solving (PS) capability, at the expense of the traditional perpetuation of algorithmic-based LOCS (Zoller 1993). This means a paradigm shift from the contemporary prevalent algorithmic teaching

Table 11.1 Paradigm shifts in science, technology, STES, STEM, and environmental education

From	To
Technological, economical, and social growth at all cost	Sustainable development in the global context
Corrective responses	Preventive actions
Reductionism, i.e., dealing with in vitro, isolated, highly controlled, decontextualized components	Uncontrolled, in vivo, complex systems
Disciplinarity	Problem-solving orientation, with decision-making based on systemic, inter-, cross-, and transdisciplinary approaches
Technological feasibility	Economic and social feasibility
Algorithmic, LOCS-oriented teaching	HOCS learning in the STES interface context
Reductionist thinking	System and lateral thinking
Dealing with topics in isolation or closed systems	Dealing with complex, open systems
Disciplinary teaching (physics, chemistry, biology, etc.)	Interdisciplinary teaching
Knowing and recognizing orientation in teaching (e.g., applying algorithms for solving exercises)	Conceptual learning for problem solving and transfer
Teacher-centered, authoritative, frontal instruction	Student-centered, real-world, HOCS-oriented learning

Zoller (2012)

to "HOCS learning" to be facilitated via HOCS-promoting *assessment* methodologies, leading to the improvement of students' PS capabilities (Zoller 1993, 2000, 2002). Such a shift requires teaching and learning which take PS well above the level of algorithmic manipulation into the realm of critical-evaluative, system thinking and creativity, which thus combat the common feature of traditional school and university science education, in which problems have just one unique correct solution (Wood 2006; Zoller et al. 2000; Zoller and Levy Nahum 2012; Torres et al. 2013).

Instructional strategies which incorporate cognitive activities that involve both knowledge and skills components are effective in assisting students to develop their PS skills (Taconis et al. 2001; Lyle and Robinson 2001). Such successful research-evidenced PS skills-promoting instructional studies ranged from a complete discontinued lecture in favor of PS sessions on the expense of the voluminous material covered to the teaching of PS skills without sacrificing course content (Fujii 1997; Jones-Wilson 2005). The related issue is the assurance of the appropriate contextually bound LOCS/HOCS balance/"dosage" which ultimately will lead to students' PS/HOCS development. This requires an in-accord change in both teachers' and students' views concerning teaching and learning and has a long-range implication (Lederman et al. 2006).

Substantial effort to improve students' PS capability has mainly focused on science teaching and learning at the secondary level (Gabel and Bunce 1994; Stamovlasis et al. 2005). Similar efforts at the higher-education level are sparse (Jones-Wilson 2005; Cardellini 2006; Tsaparlis and Zoller 2003; Wyckoff 2001).

11.2 Problem Solving (PS) in the LOCS to HOCS Paradigm Shift Context

HOCS are conceptualized as a superordinate, multicomponent framework of interrelated generic complex cognitive skills, all of them beyond the Bloom's LOCS levels of knowledge, understanding, and application. The core HOCS in the context of science education are question asking, critical and system thinking, decision-making, and problem solving, that, if acquired, have the potential to lead to the HOCS capabilities of evaluative thinking, moral thinking, creative thinking, and transfer (Fig. 11.1) (Zoller 1993, 2000, 2012).

LOCS, HOCS, and mixed levels of cognitive skills have been studied, mainly in the context of science teachers' education (e.g., Zohar 2004; Zohar and Dori 2003). Although traditional science teaching contributes to the development of disciplinary, exercise-solving capability of students, it has little to offer to their PS capabilities in the real-world and STESEP contexts. Typically, traditional high school and college/university science teaching emphasizes rules, formal definitions, equations, facts, formulas, and algorithms, in terms of "knowing," "remembering," "defining," "identifying," "understanding," and "applying." All of these empower students to respond successfully to algorithmic LOCS-requiring exam problems (Tsaparlis and Zoller 2003). A related question of major concern is whether such teaching and assessment contribute to students' HOCS development, PS included, particularly in the sustainability STESEP context.

Problem solving can be conceptualized as "what you do when you do not know what to do" (Wheatley 1984) or as "any goal-directed sequence of cognitive operations" (Anderson 1980). Psychologists and educational researchers agree that it involves cognitive, operative, and affective variables. In the traditional algorithmic LOCS science teaching, PS has been perceived as a process by which the learner

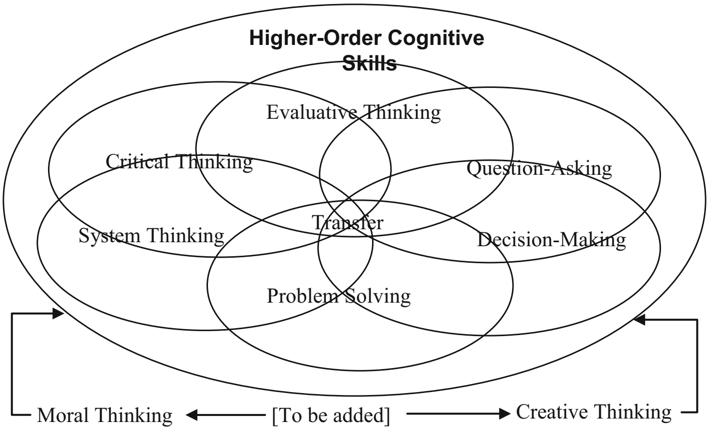

Fig. 11.1 The guiding conceptual model of HOCS in the context of science education (Zoller 2012)

discovers a combination of previous learned algorithmic rules that he/she can apply to achieve *one correct solution* (Holroyed 1985). In other words, PS is a process of applying previously taught and learned algorithms to arrive at a solution of an *exercise*. However, with respect to students' ability to resolve HOCS-requiring problems, "a problem exists when persons perceive a gap between where they want to be, but don't know how to cross the gap" (Hayes 1981).

Several "composite-type" models of, and/or associated with, PS processes, in relation to cognitive functions, have been put forward (Newell and Simon 1972; Shin et al. 2003; Tsaparlis 1998; Stamovlasis and Tsaparlis 2003, 2005). Researchers agree that (a) the context of the problem solving constitutes a critical determining factor in the process (Raine and Symons 2005; Tsaparlis 2005) and (b) by the application of appropriate relevant teaching and assessment strategies, the improvement of students' PS capability is attainable (Danili and Reid 2004; Perels et al. 2005; Sawrey 1990; Zoller 2000).

Researchers distinguish between well-structured and ill-structured problems (Shin et al. 2003; Zoller and Tsaparlis 1997) or between conceptual and algorithmic problems (Nakhleh 1993; Stamovlasis et al. 2005). Consequently, questions and/or exam items have been categorized into those problems that require LOCS exercise and those that require HOCS for their solution/resolution respectively (Zoller 2001; Zoller et al. 2002). Accordingly, "exercise" examination items require, mainly, LOCS-level responses on the part of the solver, that is, a simple recall of information or a routine application of known method, theory, or algorithm to familiar situations and contexts. Such items can be solved algorithmically via mechanistic application of taught/recalled/known, but not necessarily understood, procedures already familiar to the learners via previous specific exposure, practice, or both (Johnstone 1993; Zoller 1993; Zoller and Tsaparlis 1997). Exercises are, usually, familiar to the students, and solving them is simply a matter of writing out the "solution" and checking for mistakes (Lyle and Robinson 2001). Problems, on the other hand, require for their solution the application of HOCS.

Problems, being either qualitative or quantitative, are not algorithmically solvable and therefore constitute an intellectually cognitively challenging "conceptual" questions that may require several cycles of interpretation, representation, planning, deciding, acting upon, and evaluation. They are operationally defined quantitative or qualitative conceptual questions, unfamiliar to the student, that require for their solution more than knowledge and application of known algorithms, that is, reasoning, analysis, synthesis, making connections, and critical-evaluative thinking, as well as the application of known theory, knowledge, or procedure to unfamiliar situations (Zoller et al. 2002). When solving a *problem*, the student not only arrives at a resolution but also acquires a new or revised knowledge base (Lyle and Robinson 2001).

Students have greater success in solving exercises, that is, algorithmic questions, rather than in solving *problems* (Bunce 1993; Nakhleh 1993). This needs to be taken into consideration if the development students' PS in the sustainability STESEP context is the objective of a science course.

The dominance of the algorithmic/LOCS-oriented examinations has been persistently dominating due to both (a) resistance to a change on the part of science teachers and (b) their resistance to the problems associated with the *assessment* of the integrated HOCS items in traditional examinations (Zoller et al. 2002). Studies of PS in the context of chemistry teaching investigated the different phases of PS processes used by graduate students and identified both psychological and cultural influences on the PS process (Bowen and Bolder 1991). Reid and Yang (2002) investigated chemistry students' approaches to solve open-ended chemistry problems. They questioned the notion that PS is a generic skill which can be taught detached from the related content knowledge.

Research suggested that HOCS-promoting teaching and assessment strategies have the potential of fostering PS capabilities and, consequently, chemistry learning (Zoller 1993, 2000, 2012). The traditional chemistry teaching to "know" via algorithmic LOCS-oriented testing that follows does not contribute much to the development of students' PS and/or other HOCS. The related research case study (1.3 below) of college biology freshmen science students' responses to HOCS, LOCS, and mixed-type examination questions was targeted at (a) contributing to the development of PS in the context of HOCS promotion in college/university chemistry teaching and (b) fostering the shift from the contemporary dominating algorithmic science, STES/STEM, and chemistry teaching and assessment to a higher level of cognitive learning in PS, STSSEE, and STESEP sustainability thinking contexts (Zoller et al. 2014)

11.3 The Research Questions, Methodology, and Procedures

The case study research was conducted within the settings of a general inorganic and organic chemistry course and consisted of two hours of lectures, one hour of recitation, and three hours of a laboratory session per week, throughout two semesters, taught by two researchers (in two sections) throughout the entire year. The lecturers occasionally "sneaked in" some HOCS-requiring questions in their teaching and assessment (Zoller 2001), but not in an orderly way, nor in conjunction with the administration of the conventional pre- or post-tests, nor in any relation to the problems posed in the midterm and final examinations. The course participants (research population) consisted of 47 science freshmen students (31F, 16M), averaged 23 years old.

11.3.1 Pre-test

Due to academic, logistical, administrative, and time constraints, the pre-test was administered as a take-home examination, targeting at assessing students' PS capability of resolving chemistry-related problems as well as their views concerning this type of exam questions. It was administered during the first month of the first semester so that students were yet not exposed extensively to science courses. Significantly, examinations in the researchers' freshmen chemistry courses have been conducted with "open books," and the students were encouraged to use during examinations any material they want. The time duration of the exams was "flexible" so that most students did not have a problem answering exam questions. Thus, based on a mutual trust, the context and performance on both class and take-home exams were essentially the same. The pre-test examination consisted of four problem-type questions specifically developed and validated for this and related studies from a pool of 8 that were randomly assigned to the students. The problems emphasized system, critical and evaluative thinking, decision-making, and transfer, within chemistry, other science disciplines, and real, interdisciplinary life situations. They were related to general, organic, analytical, and environmental chemistry as well as to sustainability STESEP context. Of this pod, four clusters of different problems were randomly distributed for the students to respond in the pre-test examination. Each problem contained four sub-questions and the cognitive level of each (i.e., HOCS, LOCS, or mixed) was predetermined and served the basis for the grading of the students' responses. Selected illustrative problems are given in Appendix I and the cognitive levels of the sub-questions in Table 11.2.

11.3.2 *Students' HOCS Views Questionnaire*

As part of the pre-test, students were asked to respond to a Likert-type questionnaire on a scale of 1 (definitely not) to 4 (definitely yes), via assessing their *capability* of solving HOCS-type questions and their self-confidence in having the basic knowledge required for doing that. The questionnaire consisted of 4 statements (Table 11.4). The students were asked to respond to the four statements on a 1–4 scale for each of the four HOCS/LOCS-oriented sub-questions included in the pre-test. Altogether, they responded to 16 "statements," which were later analyzed by the researchers.

Since the students have not been requested to categorize the level of the questions or to be familiar with the notions of either LOCS or HOCS, their responses to the questionnaire were their truly related views, independent on whether they were novices or experts. However, it might well be that not all the students were familiar with the terms and/or concepts that were interwoven in the problems posed, more so, perhaps, in the pre-test, since HOCS are primarily generic and more context-

Table 11.2 Cognitive levels of selected problems in the pre- and post-tests

Test	Problem's topic	Sub-question				Maximum possible score	Type of problem
		a	b	c	d		
Pre	1. Rocket fuels	H	H	H	H	16	H
	2. Industrial plant	H	H	H	H	16	H
	3. Solutions	H/L	H/L	H/L	L	11	H/L
Post	1. Industrial fuels and chlorine compounds	H	H	H	H	16	H
	2. Catalase enzyme	H	L	L	H/L	11	H/L
	3. Buffer solution	H/L	L	L	H/L	10	L

specific than content-specific (Zoller 2012; Zoller et al. 2014). The general approach, procedures, critical system thinking, PS, and other HOCS are the “master” rather than the specific knowledge per se.

11.3.3 Post-test

The post-test was administered at the end of the second semester, as part of the chemistry course final examination. It was designed to assess both students’ problem- and exercise-solving capabilities. The final course test consisted of five problems. The students were required to answer one obligatory HOCS-type problem (problem 1 in Appendix I) and to choose two more to respond to from the remaining four problems. The post-test problems were constructed by the two course professors and were validated by the entire research team. The first (obligatory) question was developed in accord with the HOCS paradigm, whereas the others were either of a mixed HOCS/LOCS-type or just LOCS-type questions, similar to those presented in traditional chemistry textbooks and conventional college/university chemistry examinations. Each problem contained four sub-questions/sub-problems (Appendix I). The two course instructors determined the rubric grading of the final exam and the students were graded accordingly. Pre-post-cognitive gains were based on the students’ scores on similar and, therefore, comparable parts/categories of questions in the preexamination and post examination.

11.4 Quantitative Analysis: Cognitive Categorization of Students’ Responses

Five chemistry and science education experts (from Israel and the UK) were involved in the cognitive categorization of the questions presented in both preexamination and post examination. Each sub-question was categorized as “HOCS,” “LOCS,” or “mixed” level and was assigned with the numerical grades accordingly. HOCS-level sub-question was designated as H and assigned with maximum 4 points. Sub-questions that enclosed both HOCS- and LOCS-level responses were designated H/L (mixed) and assigned with maximum 3 points. LOCS-level sub-questions were designated L and assigned with maximum 2 points, while partial answers received only 1 point. Thus, the maximum possible score for each question was the summative points of its four parts. [For example, the “rocket fuels” problem *1.7* is consisted of four sub-questions, all of which require HOCS for their solution. Therefore, on each sub-question the responding student could achieve a maximum score of 4 points, meaning 16 (4×4) points maximum for the entire problem]. The cognitive categorization of *selected* questions/problems from the pre- and post-tests is provided in Table 11.2.

The following hypotheses have been tested:(1) Traditional chemistry teaching “produces” at least a 10 % gain in students’ PS ability, meaning some improvement.

(2) A gain of 15 % at least means a noticeable improvement. (3) At least 20 % gain means a substantial improvement.The experimental results are given in Table 11.3.

A Spearman rho correlation test was applied on the data presented in Table 11.3, in order to detect possible relationships among the 4 items of the students’ views/questionnaire, that is, the interrelations among students’ views regarding their “knowledge” of PS and self-confidence in their responses concerning the problems’ level and the capability of science freshmen students to cope with them. The high statistically significant relationship between (a) students’ belief of their having the basic knowledge for solving HOCS-requiring problems and (b) their self-confidence in their own responses ($\rho = 0.53$, $p < 0.001$) suggests that the more students felt that they have the required knowledge for PS which, in turn, requires high level of thinking skills, the more they felt confident in their capability of solving them. Further, the correlations between the students’ views and their achievements [part (b) of the second research question] revealed a statistically significant positive relationship between their opinion about having the basic knowledge for solving problems and their scores on both the pre- and post-test ($\rho = 0.41$, $p < 0.01$; $\rho = 0.31$, $p < 0.05$), respectively. The higher positive view of “having the basic knowledge,” the higher was their scores on both pre- and post-test. Whether this means that the belief in having the relevant knowledge enhances success in responding to HOCS-requiring problems remains an open question, since “knowledge” rather than *PS* capability/HOCS is here correlated with successful *problem solving*.

The average percentage scores on the HOCS-type questions (Table 11.3) indicate a pre-post gain of 3.7 % only, which leads to conclude that traditional chemistry teaching does not foster students’ HOCS. This is in agreement with the findings of other studies, namely, that undergraduate students who attend traditional lectures do not develop conceptual understanding of the science taught (Kampourakis and Tsaparlis 2003). A possible explanation of the low pre-post difference between the scores on the HOCS abilities is the traditional chemistry teaching to which the students were exposed. Only occasionally they experienced HOCS-type questions throughout the course. Another possible explanation is that a two-semester course is too short to significantly develop students’ HOCS. Apparently, only longitudinal systemic persistence may achieve significant outcomes in the development of students’ HOCS capabilities (Osborne et al. 2004; Reid and Yang 2002). However, the 20.7 % pre-post gain in students’ average percentage scores on the mixed HOCS/LOCS category suggests that (1) traditional science/chemistry instruction produces a measurable gain in their PS ability on the HOCS/LOCS category and (2) persistent HOCS-promoting teaching strategies and related assessment methodologies,

Table 11.3 Students’ average percentages, standard deviations, and pre-post-test gain percentages

	Pre-		Post-		Gain %
Problem type	%	SD	%	SD	Pre-post
HOCS	61.30	10.66	63.70	17.58	3.7 %
Mixed HOCS/LOCS	53.84	14.73	64.97	15.27	20.7 %
Total	60.15	12.99	70.48	13.54	17.1 %

Students’ $N = 47$

Table 11.4 Students' views of HOCS-type problems

Statements	Mean (on a 1 to 4 scale)	SD
In my opinion, solving this problem is within the capability of beginning science major freshmen	2.94	0.71
In my opinion, the solving of the presented problem requires high level of thinking skills	2.84	0.71
I have the basic knowledge required for solving this problem	2.82	0.47
I have full confidence in my response	2.38	0.67

Students' $N = 47$

e.g., HOCS-type examinations, provide a good chance for a consequent development of PS capabilities. The implications of purposely teaching for "thinking" in the sustainability STESEP context are promising.

Research-wise, the HOCS-type pre- and post-test scores ($r = 0.46$, $p < 0.01$) may suggest that traditional chemistry teaching at least preserves the students' capability of responding to HOCS-type problems.

11.5 Students' Opinions Concerning Their Self- Confidence in HOCS-Type Problem Solving

The students' views concerning their capability of resolving HOCS-requiring problems are presented in the Likert-type (Table 11.4) scale of 1 (definitely not) to 4 (definitely yes). Although the students did not do well on the pre-test, an overall average percentage score of 60.15 (Table 11.3), the responses of about two thirds of them skewed to 3 or 4 with an overall mean of 2.94. Thus, the students believed that it is within the capability of science major freshmen to solve HOCS-requiring problems. Significantly, students also believed that the solving of the presented problems requires high level of thinking, essentially HOCS, and that they have the basic knowledge required for solving them (means = 2.84 and 2.82, respectively; Table 11.4).

11.6 Characterizing Students' Responses to HOCS-Type Questions (Problems)

In order to learn from students' responses to HOCS-type questions about their PS capability, the responses of high achievers were compared with those of low achievers, in both the pre- and post-tests. High achievers were defined as those whose grade was above 80 % on HOCS-type problems; the low achievers are those who scored below 65 %. The content analysis revealed that high achievers, in contrast to low achievers, generated thorough, in-depth, and multidimensional responses, which were characterized by (a) containing successful connections between chemistry-related concepts and *real-world authentic issues*; (b) being composed of multiple representations–textually, qualitatively, and quantitatively; (c) presenting systemic reasoning, where applicable; and (d) presenting several *acceptable options* for alternative solutions, in accord with *problems* that in most cases do not have just one "correct" answer.

Selected responses to such HOCS-type questions are presented below, followed by the researchers' interpretations to illustrate the differences between high and low achievers.

11.7 Selected High Achievers' Responses to HOCS-Type Questions

The following response to the first part of the "rocket fuels" problem (Appendix I, problem 1) was given by S1, who scored 83 (the highest score) and 89 on his pre- and post-test, respectively.

> The burning of octane involves oxygen, forming carbon dioxide and water, as presented in this equation: $C_8H_{18} + 2.5O_2 \rightarrow 8CO_2 + 9H_2O$. Comparing this reaction with the other two presented in the question, I found similarities as well as differences. All three are spontaneous oxidation-reduction reactions that produce energy and water molecules. In the first reaction N_2O_4 is the oxidizing component, while the other two include O_2.

In this response, S1 uses several modes of representations to explain his understanding of chemical reactions, i.e., textual representation, as well as equations which include symbols and numbers. In addition, S1 applies analytical thinking in order to compare types and results of three similar reactions.

11.8 Low Achievers' Responses to HOCS-Type Questions

The following response to the "industrial plant" problem (Appendix I, second problem) was given by S5, who scored 61 and 64 on his pre- and post-test, respectively.

> The plants' management will adopt the cheapest proposals. Their only concern is in gaining as much profit as possible. Therefore, they would probably accept the heightening of the plant's chimneys.
>
> I believe that introducing an alternative technology, for fuel combustion, into the plant will be the best way to preserve the environment.

The characterization of the responses to the posed HOCS-type questions indicated that these cognitively challenging problems do stimulate cognition of science/STES/STEM students.

However, it appears that HOCS-level responses to problems are more likely to be solicited from "high achievers," namely, those students who score high on traditional algorithmic type/LOCS-level exams. More importantly, the multifaceted strategies used by the "high achievers" may serve as a "cornerstone" in designing "HOCS-promoting" teaching and learning for PS and "thinking" in the STSSEE and sustainability contexts (Zoller 2012, 2013, 2012; Zoller et al. 2014).

11.9 Summary and Implications

An important challenge for today's higher education is the development and implementation of instructional practices that will foster students' skills of solving complex interdisciplinary, real-world problems. The case study, here reported, provides some initial insights into the way HOCS-type problems, within chemistry and STSSEE teaching and assessment, may be developed, categorized, and graded, implicating that (1) traditional college/university chemistry teaching may contribute to gains in students' mixed HOCS/LOCS capability via the insertion of "real-world" problems for students to resolve and suggesting that (2) problems, which are integrated in homework assignments and examinations within the learning process, have the potential of developing students' problem-solving capability, since problems do elicit HOCS-level responses. The finding that a traditional chemistry course in which some *HOCS-developing* teaching strategies have been incorporated (by the course(s) lecturers) enabled the students to achieve an intermediate level of PS skills is encouraging. This result suggests that purposed integration of HOCS-level *problem* in traditional science and chemistry courses in both secondary and tertiary science education has the potential of HOCS-level development of students' problem solving.

Research-based HOCS-promoting teaching strategies, instructional materials, and assessment methodologies are recommended to be developed and implemented in chemistry, science teaching, and STSSEE for the inter-/transdisciplinary learning to think in the sustainability STESEP contexts. Further research purposed at promoting this paradigm shift beyond just the problem-solving domain should be a main concern among higher-education researchers to make HOCS learning a reality.

Appendix I: Sample Problems from the Pre-test

A.1. Rocket Fuels [HOCS Type]

Different fuels are used for different purposes and applications (coal for power plants, gasoline in cars, etc.). A fuel used in rockets is dimethylhydrazine ($C_2H_8N_2$) according to the following reaction: (1) $C_2H_8N_2 + 2N_2O_4 \rightarrow 3N_2 + 4H_2O + 2CO_2$

Hydrogen gas is also used as a rocket fuel as shown in the following reaction: (2) $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(g)}$.

(a) Do you think that there are similarities between reactions 1 and 2 and the one occurring during the burning of gasoline in a car? Gasoline can be represented by octane, C_8H_{18} (the process of octane burning will be marked reaction no. 3). Explain your answer by comparing the three reactions. (b) Choose one of the three reactions mentioned previously and explain: what do you think are the main considerations in choosing that specific reaction as an energy source? (c) In your opinion which of the three reactions will be less and which will be most harmful to the environment? Explain. (d) Why, in your opinion, N_2O_4 is used in reaction 1 instead of oxygen? Explain.

A.2. Industrial Plant [HOCS Type]

An industrial plant is emitting combustion gases into the atmosphere as well as waste water, containing acids, oils, and fuels into the municipal sewage system. For the sake of coping with related problems and, hence, improving the quality of the environment, inside and outside the plant, the following suggestions were brought before the factory management:

(a) Neutralization of the acidity in the factory waste effluents *before* their disposal into the municipal sewage system
(b) Using kerosene, instead of water, as a solvent for the washing of the factory workers clothes
(c) Heightening of the plant's chimneys, in order to ensure a better dispersion of its emission gases in the atmosphere
(d) An introduction of an alternative technology, for fuel combustion, into the plant, in order to obtain the energy required for production

With respect to each of the above suggestions think and explain briefly:

1. In your opinion, which of the proposals will it be reasonable to assume to be accepted by the management and why?
2. Which of the suggestions, if accepted and implemented, will indeed improve (or worsen) the quality of the environment inside and outside the plant?

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Chapter 12
Scientific Argumentation Model (SAM): A Heuristic for Reading Research Articles by Science Students

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12.1 Introduction

Research articles (RAs) are the typical means scientists use for communicating their findings to the scientific community (Gross et al. 2002). There is no doubt that reading RAs is a major skill that university science students should learn. In secondary science education, RAs are increasingly used as authentic or adapted sources for teaching scientific knowledge, showing students the ways scientists use to communicate their findings and teaching them about the nature of science (Yarden et al. 2001; Norris et al. 2009). One of the reasons for this trend is that authentic RAs are readily accessible for people outside the academic community through open access journals available on the Internet.

Studies have shown that students struggle with reading scientific texts (e.g., Guilford 2001; Yarden et al. 2001; Van Lacum et al. 2012), but not much research has been done on effective pedagogical strategies to teach students to read RAs. For understanding RAs, both knowledge of the research discipline and knowledge of the genre of RAs are essential. Genre knowledge comprises knowledge of conventions and structural and rhetorical features of RAs.

To improve students' reading abilities with regard to RAs, we want to make them familiar with one specific aspect of genre knowledge: the structural features of the genre. Several authors have suggested a relation between reading ability and knowl-

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edge about the structural characteristics of a text (Hill et al. 1982; Samuels et al. 1988; Blanton 1990; Swales 1990; Du Boulay 1999). In other words, by teaching students about the structural features of RAs, we expect them to become better readers. This is in line with Norris and Phillips (2003), who stated that a scientifically literate person should be able to determine the different types of statements in a scientific text (hypothesis, evidence, conclusion, expressed doubt, etc.).

Therefore, we think that it is important to design pedagogical tools that support science students in reading RAs. To achieve this, we will make use of the structural characteristics of RAs in the natural sciences domain. In this paper, we will describe the development and validation of an argumentation model, called the Scientific Argumentation Model (SAM), which focuses on these characteristics and may serve as a heuristic for science students in secondary or higher education when they learn to read RAs and identify the authors' argument.

In the next section, we describe the structure of RAs from the perspectives of genre analysis and argumentation theory. Then in Sect. 12.3, we present a synthesis of these two perspectives. In Sect. 12.4, we present the heuristic SAM. In Sect. 12.5, we describe the first results on the validation of the heuristic.

12.2 Theoretical Perspectives

Genre analysts have intensively studied written genres, especially RAs. The goal of genre analysis is "to describe the communicative purposes of a text by categorizing the various discourse units within the text according to their communicative purposes or rhetorical moves" (Connor et al. 2007, p. 23). A rhetorical move refers to "a section of a text that performs a specific communicative function" (ibid., p. 23). The work in genre analysis has produced rich descriptions of the rhetorical moves that occur in the different sections (Introduction, Method, Results, and Discussion sections) of RAs. However, genre analysts have paid relatively little attention to the relations between rhetorical moves in the different sections of RAs. These relations are of an argumentative nature. As stated by Du Boulay (1999), an argument refers to "authors' claims (including their degree of strength), his or her theoretical orientation, the quality of the evidence produced or demonstrated and how this is linked to theory" (p. 148).

12.2.1 Argumentation in Research Articles

Several argumentation frameworks have been used to describe the argumentative structure of scientific papers. For our model, we built on Kelly and Takao's (2002) epistemic levels of argument and on Toulmin's argumentation model. Toulmin (1958) devised a "logically candid layout of arguments" (p. 95) that may be used in a variety of cases. The Toulmin scheme consists of the following elements: data, warrant, backing, qualifier, rebuttal, and claim. The data are the facts that form the foundation of the claim. A warrant is a proposition that is used to make the step from the data to claim. These can be rules, principles, and so forth. A warrant is often supported by a backing, "without which the warrants themselves would possess neither authority nor currency" (ibid., p. 103). The qualifier is "the reference to the degree of force which our data confer on our claim in virtue of our warrant" (ibid., p. 101). The rebuttal indicates the circumstances under which the warrant is not applicable. Because the Toulmin scheme is very visual and accessible, it is widely used in educational settings, but it has also been criticized for a number of reasons (Sampson and Clark 2008). The first reason is ambiguity in its categories. Toulmin (1958) himself has already pointed at the confusion that may occur between backings and warrants. In RAs, backings often take the form of rather implicit assumptions held by the scientific community and therefore difficult to identify by novice readers. The second reason is that the model cannot easily be applied to complex arguments frequently used in scientific texts, for example, embedded claims in larger arguments (Kelly and Takao 2002). Some authors have elaborated on the original Toulmin framework for scientific arguments. For instance, Thompson (1993) used a two-step version of the Toulmin scheme in the analysis of RAs. Although more successful in dealing with the complex arguments in RAs, these approaches lack the simplicity of the original Toulmin scheme and require epistemological knowledge that cannot be expected from novice readers. For these reasons, we tried to conceive an approach that is applicable for reading RAs and still easy to use by students.

12.2.2 Rhetorical Moves in Research Articles

For the development of our heuristic, we built on several genre analysis studies (Swales 1990; Thompson 1993; Dudley-Evans 1994; Nwogu 1997; Williams 1999; Peacock 2002; Kanoksilapatham 2005). In the following, we show how genre analysts analyzed the four different sections in RAs: Introduction, Method, Results, and Discussion (IMRD). This four-part structure is found across a wide variety of disciplines in the natural sciences.

In the **Introduction section** of RAs, Swales (1990) identified three rhetorical moves. The first move is establishing a territory, in which the significance of the research field is explained. This is done by the so-called steps (or sub-moves): claiming centrality, making topic generalization(s), and/or reviewing items of previous research. The second move is establishing a niche, in which the authors explain the reasons behind their particular research. These reasons can consist of counter-claiming, indicating a gap of knowledge, question raising, or continuing a tradition. Occupying the niche is the third move, in which the authors' research is introduced. This move can consist of specifying the purpose of the study, followed by an announcement of the principal findings and the structure of the article. Nwogu (1997) and Kanoksilapatham (2005) use more or less the same categories, albeit with some alterations (Table 12.1).

Table 12.1 Moves in the Introduction section of research articles

Swales (1990)	Nwogu (1997)	Kanoksilapatham (2005)
Establishing a territory	Presenting background information	Move 1: Announcing the importance of the field
Establishing a niche	Reviewing related research	Move 2: Preparing for the present study
Occupying the niche	Presenting new research	Move 3: Introducing the present study

The **Method section** of RAs describes the procedures and materials the authors used to obtain their results. Procedures are usually only explained and justified if they are new or adapted. Standard procedures derived from previous studies are simply listed with a reference (Penrose and Katz 1998). Nwogu (1997) identified three moves in the Method section of medical RAs: (1) describing data collection procedures, (2) describing experimental procedures, and (3) describing data analysis procedures. Kanoksilapatham (2005) identified four moves in biochemical RAs: (1) describing materials, (2) describing experimental procedures, (3) detailing equipment, and (4) describing statistical procedures. Like Nwogu, Kanoksilapatham does not mention a move that justifies procedures or methodology, possibly because his analysis suggests that in biochemical RAs, this move occurs in the Results section and not in the Method section.

The **Results section** is used by the authors to present their collected data. Data are reduced (e.g., by calculating averages) and processed into tables and graphs (Penrose and Katz 1998). Authors use the so-called pointers to link tables or graphs with textual statements (Penrose and Katz 1998). Authors not only present their data; they also comment on them, for example, by providing explanations or drawing preliminary conclusions. Genre analysts (Thompson 1993; Nwogu 1997; Williams 1999; Kanoksilapatham 2005) identified a number of rhetorical moves in the Results section (Table 12.2). Nwogu (1997) distinguishes moves that indicate consistent (i.e., expected) observations and moves that indicate non-consistent (i.e., unexpected) observations. Kanoksilapatham (2005) distinguishes four moves (Table 12.2). Move 11 is divided into several steps representing similar descriptions of moves by Thompson (1993) and by Williams (1999). Williams (1999) makes a distinction between presentational and comment moves. Presentational moves contain procedural information (statements about how and why the data has been produced) and what the findings were, while comment moves are – among other things – explanations of findings, interpretations of findings, or comparisons with literature. Interestingly, Thompson (1993) and Kanoksilapatham (2005) identify methodological justifications in the Results section.

The **Discussion section** is probably the most variable and complex part of an RA. There is a direct relationship between the Discussion and the Introduction section: "Whereas the introduction introduces the research question and reviews the state of knowledge in the field that motivated the question, the discussion explains how the question has been answered (at least in part) by the new research and shows how the field's knowledge is changed with the addition of this new knowledge" (Penrose and Katz 1998, p. 57). The Discussion states the main knowledge claim

Table 12.2 Moves in the Results section of research articles

Thompson (1993)	Nwogu (1997)	Williams (1999)	Kanoksilapatham (2005)
–	–	Procedural information	Move 8: Stating procedures
Methodological justifications	–	–	Move 9: Justifying procedures or methodology
–	–	Statement of finding	–
–	Move 7: Indicating consistent observation	Substantiation of finding	Move 10: Stating results
–	Move 8: Non-consistent observations	Non-validation of finding	–
Interpretations of experimental data	–	Explanation of finding	Move 11: Stating comments on the results
Agreement with preestablished studies	–	Comparison of finding with literature	–
Comments on discrepancies	–	–	–
–	–	Evaluation of finding regarding hypothesis	Move 11: Stating comments on the results
Calls for further research	–	Implications of finding	–
Evaluations about the experimental data's accuracy	–	–	Move 11: Stating comments on the results
Interpretative perplexities	–	–	–

(also called main conclusion or thesis). When expressing knowledge claims, authors generally use hedges: words like "likely," "probably," or "may", expressing the uncertainty of a claim (Hyland 1998).

Table 12.3 lists the Discussion section's moves mentioned by Dudley-Evans (1994), Nwogu (1997), Peacock (2002), and Kanoksilapatham (2005). Dudley-Evans' (1994) nine moves often occur in recurring move cycles. For example, a statement of result or finding is regularly followed by a reference to previous research. Peacock (2002) made some small alterations to Dudley-Evans' model. Kanoksilapatham's model (2005) is not so much dissimilar, but within one move, several steps are distinguished, which Peacock distinguishes as separate moves. All four studies mention limitations, being remarks about "problems with errors, methods, and validity" (Ioannidis 2007, p. 324). Limitations are also called weaknesses, caveats, or shortcomings. Aspects not explicitly mentioned by genre analysts are

Table 12.3 Moves in the Discussion section of research articles

Dudley-Evans (1994)	Nwogu (1997)	Peacock (2002)	Kanoksilapatham (2005)
Move 1: Information move	–	Move 1: Information move	Move 12: Contextualizing the study
			Move 13: Consolidating results
–	Move 9: Highlighting overall research outcome	–	–
Move 2: Statement of result	Move 10: Explaining specific research outcomes	Move 2: Finding	Move 13: Consolidating results
Move 3: Finding	Move 10: Explaining specific research outcomes	Move 2: Finding	Move 13: Consolidating results
Move 4: (Un)expected outcome	–	Move 3: (Un)expected outcome	Move 13: Consolidating results
Move 5: Reference to previous research	Move 10: Explaining specific research outcomes	Move 4: Reference to previous research	–
Move 6: Explanation	–	Move 5: Explanation	Move 13: Consolidating results
Move 7: Claim	–	Move 6: Claim	Move 13: Consolidating results
Move 8: Limitation	Move 10: Explaining specific research outcomes	Move 7: Limitation	Move 14: Stating limitations of the study
Move 9: Recommendation	Move 11: Stating research conclusions	Move 8: Recommendation	Move 15: Suggesting further research

alternative explanations or alternative interpretations of results. These doubts, as Suppe (1998) calls them, are included in a selective way: "…confining attention only to those specific doubts the discipline recognizes as legitimate counterpossibilities" (Suppe 1998, p. 384). According to Suppe, doubts are often coupled with rejoinders, which impeach these alternatives as much as possible. The explicitation of these doubts and rejoinders plays an important part in the persuasive process. Genre analysts do mention recommendations for further research, but remarks summarizing the potential significance of the findings (e.g., possible changes in clinical practice) are often not included in their descriptions of the Discussion section (Alexandrov 2004).

12.3 Synthesis: The Argumentative Structure of Research Articles

We wanted to use the rhetorical moves described above for the development of a heuristic, centered around argumentation that can be applied by novice readers of RAs. With this purpose in mind, we formulated four criteria to which our heuristic should adhere:

1. The heuristic describes the RA's rhetorical moves that play an important role in the authors' argumentation.
2. The heuristic describes the relations between these rhetorical moves in a visual way.
3. The heuristic is generic; it is applicable to a broad range of RAs from different sciences, in all variations that different journals exhibit.
4. Because novice readers of RAs should be able to work with it, the descriptions of the rhetorical moves are as simple and as unambiguous as possible.

In this section, we describe how we selected, combined, and supplemented the rhetorical moves identified by various genre analysts in the Introduction, Method, Results, and Discussion sections of RAs. Then we present the design of a schematic representation of the argumentative structure of RAs, stretching from the very reason to undertake the research, through data collection and interpretation, to the outcome of the study. It contains those text elements corresponding with rhetorical moves that, taken from the text and reassembled into a scheme, coherently show the line of reasoning in RAs as a whole.

As stated above, Swales (1990) identified three rhetorical moves in the **Introduction section**: establishing a territory, establishing a niche, and occupying the niche. Nwogu (1997) and Kanoksilapatham (2005) described similar moves (Table 12.1). The first move describes the research area and is not a part in the RA's argument. Establishing a niche and occupying the niche are more specific for a study, and the authors use these moves to describe the "gap of knowledge" and the reasons why their research is important. Because the concept of niches is probably difficult to grasp for students, we avoided this term. We called the establishment of a territory and niche the *motive* of the study (why was the study done?) and the occupation of a niche the *objective* of the study (what did the authors want do know?). The objective may be formulated as a research question, a research aim, or a hypothesis that needs to be tested. The motive and objective are related to each other, as the objective emerges from the motive.

Nwogu (1997) and Kanoksilapatham (2005) both show that the **Method section** contains moves that describe experimental procedures and moves that describe data analysis/statistical procedures (or, as we called this move, data processing procedures). Additionally, Nwogu (1997) mentions a move that describes data collection procedures. Kanoksilapatham (2005) also mentions a move that describes the materials and a move that details the equipment. For the sake of simplicity, we share these methodological aspects under experimental procedures. So this leaves us with two moves: (1) description of *experimental procedures* and (2) description of *data* *processing procedures*. The former is directly connected to the objective, because the objective influences the choice of experimental procedures. In turn, the experimental procedures will influence the data processing procedures.

Statement of finding (after Williams 1999) is arguably one of the most essential moves in the **Results section**. These are statements that provide interpretations of the *inscriptions*. Roth, Bowen, and McGinn (1999) describe inscriptions (following Latour 1987) as "representations other than text" (p. 977). Inscriptions can be "readings from simple devices, recordings from automated devices, computer screen output, photographs, micrographs, data tables, graphs, and equations" (p. 978). Statements of findings can lead to a *preliminary conclusion*. This is a generalization/interpretation of a statement of finding (Kanoksilapatham 2005). Preliminary (or sub-) conclusions can be located in the Results or Discussion section. A statement of finding could be "Rats which were given drug X had a lower blood pressure than rats in the control group." A preliminary conclusion could be "Drug X lowers the blood pressure in rats." Of course, the difference between statements of findings and preliminary conclusions will not always be clear-cut. It is possible that authors only present statements of findings in the Results section and save their preliminary conclusions for the Discussion section. Inscriptions, statements of findings, and preliminary conclusions are comparable to Kelly and Takao's (2002) epistemic levels of claims: these levels describe how specific statements (e.g., simple interpretations of data) develop into more generalized statements, moving away from the original observation or measurement, called externalizations (Pinch 1985). The lines of reasoning between these epistemic levels may be described as a chain of interpretative steps.

One of the most important elements in the **Discussion section** is the claim: a generalization arising from the results (Dudley-Evans 1994). In our selection, we included two types of claims, *preliminary conclusions* and the *main conclusion*. The main conclusion is supported by a wide variety of moves that are located in the Results and Discussion sections: statements of findings, preliminary conclusions, and references to previous research. Together, these moves (and inscriptions) form the *supports* of the main conclusion. A main conclusion may include a hedge or qualifier, expressing the (un)certainty of the conclusion. The main conclusion may lead to remarks about the potential significance of the findings and their possible influence on society or practice (Alexandrov 2004) and recommendations for further research. We call these remarks *implications*. We grouped comments about unexpected outcomes and limitations as *counterarguments*, because they shed doubt on the validity or generalizability of the main conclusion. Suppe's (1998) doubts fall into this category. A counterargument may be "weakened" by *refutations* (or rejoinders, as Suppe calls them). For instance, explanations for unexpected results can serve as refutations of counterarguments. We did not incorporate Dudley-Evans' (1994) information move in our selection, because this move (which describes background information about theory, research aim, methodology, or previous research) is a recapitulation of the motive and/or objective.

In summary, we think that the following moves adequately describe the line of reasoning of RAs*: motive, objective, experimental procedures, data processing pro-*

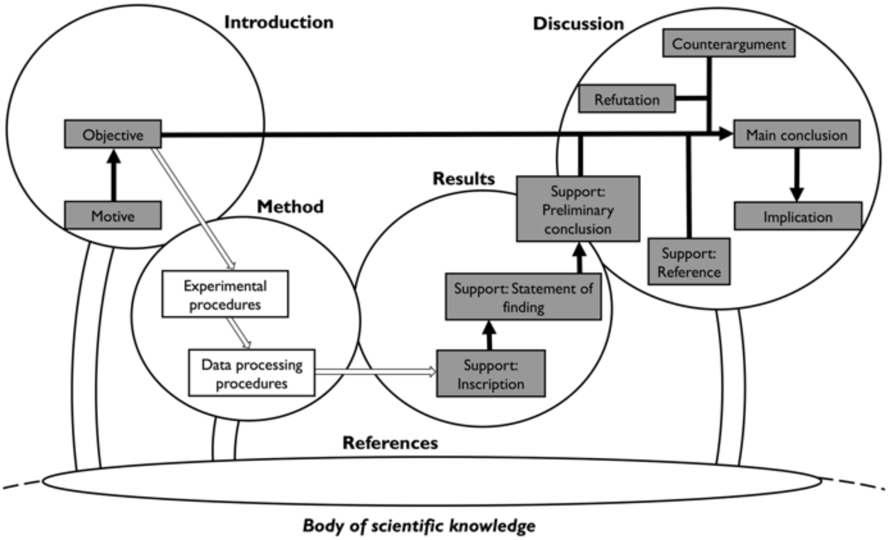

Fig. 12.1 The research article's argumentation scheme. All moves (*boxes*) and their relations (*arrows* and *bars*) are explained in Sect. 12.3. The darker boxes represent the simplified scheme (Sect. 12.4)

cedures, inscriptions, statements of findings, preliminary conclusions, main conclusion, implication, counterarguments, and *refutations*. Due to their extratextual nature, inscriptions are not identified as rhetorical moves by genre analysts. However, because of their importance, we will subsequently group them together with rhetorical moves. Thus, we conceived an argumentation scheme that depicts the abovementioned moves and their relations (Fig. 12.1). The circles represent the four different sections of a typical RA (Introduction, Method, Results, and Discussion sections). In these circles, the connected moves are shown. The central arrow of the scheme is the connection between the objective and the main conclusion.

Below the central arrow, the supports – which form the pillars that justify the main conclusion – are placed: inscriptions, statements of findings, preliminary conclusions, and references to previous research. Supports in these pillars are connected to each other, forming chains. These chains express the increasing abstraction in supports from inscriptions to more general statements (statements of finding and preliminary conclusions), similar to Kelly and Takao's (2002) description of epistemic levels. Counterarguments are placed above the central arrow indicating that their argumentative function is the opposite of that of supports: they weaken the main conclusion. In turn, counterarguments may be weakened or refuted by refutations. Finally, the stems, connecting the circles to the "body of scientific knowledge," symbolize how the references in the Introduction, Method, and Discussion sections connect RAs with the body of scientific knowledge (Amsterdamska and Leydesdorff 1989). References may serve to highlight the relevance of the study,

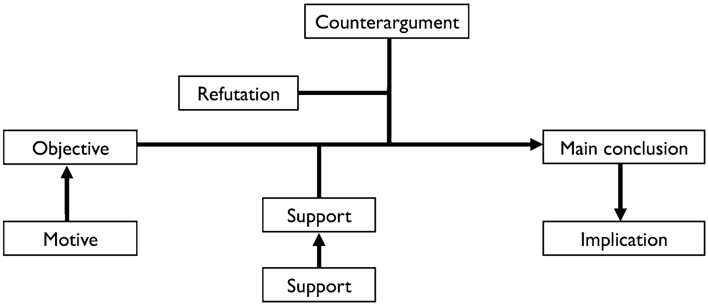

Fig. 12.2 Schematic representation of Scientific Argumentation Model (SAM)

justify the used methods, provide further support for claims, or indicate how the findings can solve a certain problem (Gilbert 1977).

12.4 A Heuristic for Reading Research Articles

With the criteria mentioned at the beginning of Sect. 12.3 in mind, we stripped the schematic representation of the argumentative structure of RAs down to such a level that it contained only those elements that are understandable for non-expert readers: the darker boxes, connected by the black arrows and bars in Fig. 12.1. We omitted the elements from the Method section and their connections, because understanding this section requires a significant amount of prior knowledge due to its technical details. Although this simplified scheme lacks the lowermost connection from the objective to the supports through elements from the Method section, it still features a complete line of reasoning because of the direct link between objective and main conclusion. We kept the chains of supports but decided to simplify the terminology by giving inscriptions, statements of findings, preliminary conclusions, and references all the same name: supports. This makes the terminology more straightforward for students. The resulting heuristic, called SAM (Scientific Argumentation Model), consists of descriptions of seven rhetorical moves (see below) and a simplified version of the RA's argumentative structure (Fig. 12.1, darker boxes, and Fig. 12.2).

The moves of SAM are described to the students as follows:

1. *Motive*: Statement indicating why the research was done (e.g., a gap of knowledge, contradictory findings). The motive leads to the objective.
2. *Objective*: Statement about what the authors wanted to know (may be formulated as a research question, a research aim, or a hypothesis).
3. *Main conclusion*: Statement about the main outcome of the research. The main conclusion is closely connected to the objective. It answers the research question, it says to what extent the research aim was achieved, or it states whether the hypothesis was supported by the evidence. The main conclusion will lead to implications.

4. *Implication*: Statement indicating the consequences of the research. This may be a recommendation, a statement about the applicability of the results (in the scientific community or society), or a suggestion for future research.
5. *Support*: Statement used by the authors to justify their main conclusion. These statements can be based on the authors' own data or can be drawn from literature (references). Supports may be presented in the so-called support chains. For example, Table → Interpretation of the table's data in the Results section (statement of finding) → Further interpretation of the table's data in the Discussion section (preliminary conclusion).
6. *Counterargument*: Statement that weaken the main conclusion. For example, possible methodological flaws, anomalous data, results that contradict previous studies, or alternative explanations. Counterarguments are sometimes presented as limitations.
7. *Refutation*: Statement that weakens or refutes a counterargument.

These descriptions mention the so-called content-based features of the moves (Paltridge 1994), which may help to recognize moves by their function. Further, we added organizational and lexical features of all moves to our descriptions. Organizational features describe the location of the move in RAs. For example, the objective is always found in the Introduction section. Lexical features are words/phrases that may trigger the reader to identify a certain statement as a move. For instance, reporting verbs like "suggest" or "show" may signal a conclusion (Bloch 2010), and "it is still unknown" is a phrase indicating a motive. Thus, our heuristic consists of: a set of seven moves characterizing the argumentative structure of RAs; a description of their content-based, organizational, and lexical features; and the SAM scheme.

12.5 Validation of the Heuristic

To validate the heuristic, we selected ten empirical RAs from the journal *Science* from two different domains: astronomy and biomedical science. By using RAs from one journal, it was guaranteed that all have the same format. We randomly drew five RAs per domain, based on the categorization *Science* uses, from the period between March 2006 and 2011. Within this time frame, each domain contained more than ten reports. This enabled us to take a random sample. Two graduate students, one with a major in astronomy and one with a major in medical biology, read five RAs each and identified the moves. The third author read all five RAs of each domain and identified the moves. Differences in the analysis between the graduate students and the third author were negligible. The results show that there are some noticeable differences between the papers of both domains. The average frequency of motives, main conclusions, implications, and support chains seems somewhat higher in astronomy papers compared to biomedical RAs, although this may depend on the sample of papers (Table 12.4).

Table 12.4 Average frequencies and frequency ranges of moves per research article from different disciplines

	Astronomy RA's ($n=5$)		Biomedical RA's ($n=5$)	
Element	Average frequency	Range	Average frequency	Range
Motive	1.8	1–4	1	1
Objective	1.2	1–2	0.8	0–1
Main conclusion	2	1–4	1.2	1–2
Implication	2	0–5	1.2	1–2
Support	11	8–14	9.4	4–14
Counterargument	6	4–9	1.6	0–3
Refutation	1.4	0–4	1.8	0–3

Most notable is the difference in the number of counterarguments. Furthermore, the number of refutations in astronomy RAs does not match the number of counterarguments. This stems from a particular argumentation pattern within these astronomy RAs, starting with one or two objectives. The authors then present preliminary conclusions, which they subsequently reject as being incorrect using a counterargument, after which they present other data from another observation trying to confirm their model or theory. This is repeated several times before eventually the final main conclusions are drawn. This pattern was not observed in biomedical RAs, where the authors actually refuted all counterarguments. This difference in argumentation may be caused by the nature of research in both disciplines: research in astronomy focuses on validating models and testing theoretical predictions using multiple observations, while biomedical research focuses, for instance, on investigating the effects of a treatment to prevent or cure a disease using a single experiment or a set of closely related experiments measuring several parameters.

12.6 Discussion

In this paper, we described how genre analysis and argumentation theory were used to design a model representing an RA's argumentation structure. This model (the Scientific Argumentation Model or SAM) may serve as a heuristic for novice readers of RAs. In this way, we can extend their genre knowledge with respect to RAs and help them with their enculturation into the scientific community.

Furthermore, SAM is expected to give science students more insight into the persuasive nature of RAs. Students are used to textbooks that tend to neglect the processes by which scientific knowledge is produced (Duncan et al. 2011). As a result, students view academic texts as “autonomous, uncontested and unnegotiated, unencumbered by the values and oppositions that they may freely recognize in their out-of-school lives and textual experiences” (Johns 2002, pp. 239–240). By focusing on the argumentative structure, students may become more conscious of the idea that RAs are persuasive texts.

In Sect. 12.3, we formulated four criteria to which our heuristic should adhere. The first criterion is that the moves that play an important role in the authors' argumentation should be included in the heuristic. By applying ideas from argumentation theory and genre analysis, we made a careful selection of seven moves in such a way that we expect that it will be a valid representation of the RA's line of reasoning.

The second criterion concerns the relations between moves and their visual representation in the SAM scheme (Fig. 12.2). Relations in SAM are pictured by arrows and bars. Arrows represent a sequence – not necessarily a chronology in the research process, but a sequence in the authors' argument as presented in RAs – from motive and objective to conclusion and implications. The vertical bars represent the evidence and contra-evidence for the conclusion. Different than Toulmin (1958), we represented the evidence and the contra-evidence on different sides of the central arrow. It is our expectation that this will visualize for students how the strength of a conclusion is determined by the balance between supports, counterarguments, and their refutations.

The third criterion about the general nature of the heuristic implies that it should be applicable to a wide variety of RAs from different disciplines. Our first analysis demonstrated that the heuristic is indeed applicable to a number of astronomy and biomedical RAs. However, the applicability of the heuristic to reading RAs in various domains should be further investigated.

According to the fourth criterion, novice readers should be able to work with the heuristic. We already used SAM for teaching pre-university and first-year undergraduate students how to read authentic RAs (Koeneman et al. 2013; Van Lacum et al. 2014). These studies show that the heuristic is a promising method for supporting students' reading.

The visual representation of SAM shows some similarities with the Toulmin scheme (Toulmin 1958). However, we believe that our model is more suitable for educational purposes with respect to RAs. For example, Toulmin's scheme does not include explicitly a motive or objective. Our reason for including motive and objective in the model is that they help novice readers with finding other moves. After readers locate the motive and objective – which is relatively easy for them (Van Lacum et al. 2012) – they can deduce what the RA's main conclusion is. Since the main conclusion srelates directly to the objective, it is often worded in a similar way. This points to a major difference between our model and the models we found in literature. The latter are devised and used to analyze RAs from a linguistic or philosophical perspective and were not intended to serve as a pedagogical aid.

We believe that SAM has many potential uses in science education. For example, students may be assigned to individually read an RA and construct a SAM scheme. Then they can compare their schemes in small groups and together analyze the RA's argumentative structure. Since students share the same vocabulary – the model's framework – they can easily discuss their views on the RA's argumentation and reach a deeper understanding of the text. Furthermore, SAM may be used by students to compose reports on their own research projects or lab work. For example, after having done experimental work, students may be asked to organize their results following the pattern of the model. As the SAM scheme lacks the Method section's moves, educators might choose to use the more comprehensive version of the model instead.

It could be argued that a focus on genre knowledge stifles students' creativity and self-expression. However, genre knowledge allows them to explore the possibilities of a genre. According to Cooper (1998), genre knowledge opens up "many possibilities for students and leaving countless decisions for them to make as they develop and shape their arguments" (p. 48).

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Part V
Early Years Science Education

Chapter 13
Identifying and Enhancing the Science Within Early Years Holistic Practice

Terry Russell and Linda McGuigan

13.1 Background, Framework and Purpose

The work reported here builds on ideas generated in the course of previous work on a developmental assessment protocol designed to assess children's overall development, 3–5 years (Russell and McGuigan 2011). Those general developmental data (on 1195 children drawn from 269 settings) helped us to define criteria relevant to emergent science behaviours classified as i) general developmental, ii) enabling of emergent science and iii) science specific (McGuigan and Russell 2012). To extend this line of inquiry towards hypothesising developmental trajectories, we worked collaboratively with teachers and their children (aged 36–84 months) using a design-based research (DBR) methodology (Schoenfeld 2009; Anderson and Shattuck 2012), to identify and illustrate some of the emergent science behaviours and practices that might be developed further within the general approaches of Early Years practitioners.

Research into the teaching of science to younger children has tended to accumulate evidence of its shortcomings. Kallery et al. (2009) and Sylva et al. (2008) raise concerns about the quality of science experience to which young children have access. The longer-term practical aspiration of our work is science curriculum support materials, validated and illustrated by those Early Years practitioners directly involved in their construction and grounded in their current expertise. Our intention was and is to build on existing confidence rather than to inadvertently disempower practitioners by the imposition of top-down views of science practices. Our DBR approach combines science education research and theory with educational design and development intentions to generate evidence-based and ecologically valid recommendations for practice. The research and design questions we sought to

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elucidate concerned how Early Years behaviours of teachers, classroom assistants and children might be conceptualised as moving from generalist to science-specific practice. Specifically:

1. How may the shift from observation and recording towards conceptual development be characterised?
2. How may children's exposure to direct experiences be supported and shaped to become science enquiry skills?
3. How may the expression of ideas be supported in moving through the expression of ideas with evidence towards argumentation and science as discourse?

The initial outcomes of this study included identification of a number of relatively discrete and coherent patterns of activity, observed to be recurring across settings and which seemed to the researchers to resonate with later, more developed, scientific thinking. Such potential relationships with scientific modes of thinking made certain behaviours stand out from the complex flow of activities that characterise Early Years settings. We referred to these recurring facets of behaviour as 'threads' that may be 'woven' together as related aspects of more complex configurations as they are sequenced to describe progression. This emphasis on progression needs to be justified explicitly as resting on assumptions about the importance of a formative approach to teaching and learning whereby teachers accept the need to identify a learner's current understanding and support progressive movement, guided by their pedagogical content knowledge (PCK). Once developmental sequences are mooted, practical targeted interventions will be more apparent. Even tentative descriptions of developmental trajectories support teachers' formative use by helping them to decide zones of proximal development. It is understood (Anderson and Shattuck 2012) that practical and applied project outcomes are more likely from the use of DBR methodology than measurable effect sizes. Because DBR deals with the ecological validity of complex interacting variables, discrete measured outcomes tend to be relatively insignificant in the bigger picture. More weight is attached to the validation by the practitioners involved in the research and construction of curriculum support materials.

13.2 Method

Collaboration involved researchers at the University of Liverpool, Early Years practitioners and the children aged 36–84 months in their care. The ten sample schools are located in Northwest England and North Wales. Though the Early Years curricula of England and Wales differ, the view was that such differences were transcended in the context of the more universal capabilities that were being researched. Table 13.1 summarises the participants in this study.

Professional advisory staff identified the ten participating teachers, all of whom had expressed interest in developing their practice, most describing their science background as 'limited'. All worked with a wider group of co-teachers and support

Table 13.1 Participants in qualitative DBR study

	Teachers directly involved in project	Co-teachers and other support staff in contact with project teachers	Local authority advisers	Children under direct control of project teacher
England	4	16	1	120
Wales	6	12	1	180
Totals	**10**	**28**	**2**	**300**

staff. The project's evidence base drew upon this wider group of staff and children under the management of the 'main project teachers'. Project meetings were scheduled at the beginning, mid-point and towards the end of the 12-month research period. Communications across the geographically disparate group used email, text and telephone, the mainstay being an on-line function, 'VOCAL' (virtual on-line communications at Liverpool), a SharePoint type of facility. Iterative cycles of activity in settings occurred as emerging practices were shared, explored and modified. These iterations form an important part of the refinement and validation of DBR outcomes.

Significant information gathering activity took place during researchers' visits to schools, including video recording, photography and collection of children's products.

Visits provided opportunities for discussions with participating staff and led to a clearer understanding of one another's respective motivations, perspectives and practices. The research followed ESRC (Economic and Social Research Council 2010) ethical guidelines. A core principle of the DBR approach is to assume complementarity between the skills of researchers and practitioners, recognising teachers' existing proficiencies with the age group and seeking to support their professional development where they lack confidence.

Three scheduled face-to-face project meetings held in different schools enabled sharing of experiences and insights into each other's context and resources. Some teachers arranged separate smaller cluster working meetings in each other's settings. Each school was visited at least three times, usually half- or whole-day visits. Photographic and video capture of evidence of emergent science activity informed later reflective review, whilst direct contact provided opportunities to observe and discuss emerging ideas and practices in real time with practitioners and children. Teachers' and children's understandings were both established. Practitioners' contributions to such discussions started from their educationally generalist perspectives; the researchers' contribution was to discern antecedent behaviours that suggested links to later science-specific ways of thinking and to analyse and articulate how such practices might be shaped towards scientific modes of thinking and acting.

Whilst the researchers did not deliberately influence the activities that practitioners undertook, it is acknowledged that the presence of visitors having an explicit interest in science education was likely to have some impact, however, unobtrusive their presence. Similarly, the researchers' prevailing notions of what constitutes science education influenced their perceptions of what was observed in settings. It is not practically possible, nor indeed ethical, to remain socially detached whilst paying close attention to young children's activities. Often, children expected and initiated interaction, clearly delighted to be the subject of adult interest. Interactive exchanges clarified intentions on both sides. Within these terms, it is claimed that observations were not so much objective and dispassionate as reflective and analytical. Opportunities were grasped to clarify with children and the adults managing them, motives, understandings and intentions relevant to the programme's science focus.

13.3 Research Outcomes

Observations and reflections led to the identification of recurring activities classified as 'emergent science behaviours', accepting that borderline behaviours blurred boundaries in the tri-partite classification that had been adopted. Table 13.2 presents some illustrative examples.

'General developmental' threads were defined as important in underpinning developmental processes. 'Attention' is a prime example: it is a fundamental prerequisite of all managed learning, high on practitioners' priority list for new entrants, having perhaps as much to do with socialisation as cognitive development.

'Science-enabling' threads were defined as aspects facilitated by the educational process and which would assist science-relevant activities without having been nurtured with a specific science focus. Examples would be aspects of numeracy and literacy. For example, measurement is essential to making comparisons in many science activities. Language and vocabulary development are a similarly high priority per se as well as being enabling of later science conceptual development through descriptive language, expressing a point of view, etc.

'Science-specific' threads were capabilities likely to be 'self-evidently' recognisable to science educators. Such behaviours would be likely to be in evidence only when deliberately promoted as such by teachers. However, there were some instances of activities nominally associated with other curricular areas that offered a close correspondence to the requirements or expectations of a science curriculum. For example, whilst all sorting, classifying and measuring activity could be regarded as 'science enabling', the use of a particular set of labels such as 'alive', 'was once alive' and 'never alive' tipped the balance into 'science-specific' behaviour. Similarly, some examples of oracy and expressive language, requiring clear presentation of a point of view along with reasons, immediately suggested very close links with the antecedents of argumentation.

13.3.1 Illustration of a 'General Developmental' Thread: Attention

Teachers deploy techniques to engage and extend children's attention. Gagné (1985) saw selective concentration on one thing at a given moment as essential for enabling later learning. A pervasive Early Years strategy is to have children seated around the

Table 13.2 Examples of clustered 'threads' and links with emergent science

Relevance to emergent science	Threads and aggregations of threads	Example behaviours
General developmental	Paying attention, increasing concentration span and persistence	Listening to and engaging with fictional narrative and imaginary starting points
	Naming and labelling concepts and instances	Observation; naming objects and phenomena accurately
	Expressing ideas	Self-generated ideas expressed with some degree of autonomy and confidence; general language and vocabulary development
Science enabling	Concrete operational experiences and manipulations; multimodal opportunities	Many of the 'stations' made available in settings (e.g. sand, water, dough, etc.) are designed to ensure basic experiences and particular language and vocabulary development. Opportunities for change and control of materials and events
	Logical operations	Classifying; ordering; comparing similarities and differences; comparing the magnitude of objects and durations of events
	Exploring the nature of materials and making things	Bricolage; experiencing the relationship between the physical and conceptual demands of making
Science specific	Early explorations and investigations	Children's explorations and more systematic teacher supported enquiries
	Recording outcomes and results	Lists, charts, tables writing, audio, photographs, maps, models, collages, etc.
	Early argumentation	Making claims, drawing conclusions, with justification

adult whilst they listen to a story being read. Engagement and sustained attention are facilitated by various strategies: showing illustrations, inviting anecdotes, using costumes and artefacts representing elements from the story, etc. Also, children quickly learn the words and actions of rhythmic ensemble chants, songs or poems with actions. Any non-attending individual is very noticeable in such group events. Table 13.3 shows some discernible progressive steps in the attention thread.

Many such threads were identified as worthy of detailed examination and discussion. Compression of the qualitative data was essential for reducing information to manageable proportions. The DBR methodology that was intended to generate some practical classroom applications in collaboration with practitioners was realised through the imposition of three broad categories of scientific behaviour. Analyses were structured according to the three areas described above so as to seek cross-sectional evidence of qualitative shifts towards (1) conceptual understanding, (2) formulating enquiries and 3) the antecedents of argumentation.

Each of these agglomerations or weavings of threads will be discussed in turn.

Table 13.3 Progress in the 'attention' thread

➡		➡		➡	
Movements showing no intentionality, apparently at random and quickly distracted. Attention shifts between instances or events	Listens and joins in actions and songs	Can shift own attention when directed	Sustained attention when required	Independently chooses to attend	May be able to pay attention to two things at once, e.g. taking in instructions or conversing on another topic whilst engaged in an activity
		Follows instructions			

13.3.2 Direct Observation and Opportunities to Develop Conceptual Understanding

A cluster of recurring behaviours or 'threads' was grouped to construct a progression that starts with direct observational experiences. Early Years practitioners encourage children to notice and dwell upon the sensory experiences they encounter. This is pervasive and integral to Early Years practices, involving the full range of senses: taste, touch, hearing, and smell as well as observing by using vision. Incidentally, children may be coaxed to record and communicate what they understand they have observed, using representations including spoken or written language, drawings and constructions. This is a hugely important foundational area to children's science education as arguably, observation is where science begins. Subsequently, accurate recording and comparison allow observers to check whether there is agreement as to what it is that has been observed.

Drawings may be strongly influenced by a personal, inner world of feelings and the imagination. On the other hand, they can act as a record of what the child encounters in the real world. We identified the latter as 'observational drawings', because their intention is to re-represent directly encountered objects or events, perhaps as a record of something that might be fleeting. Production of truthful observational drawings is sometimes confounded by considerations other than accurate reproduction. For example, what children believe or expect may distract them from what they observe. Children may also feel more confident drawing things in a conventional manner, the way they think things *should* look, rather than how they *actually* look.

There were differences observed between practitioners in their approaches to observational drawing that reflect a frequent tension in Early Years education: the pursuit of a structured approach, where adults pursue specific learning outcomes, and the alternative, where the paramount consideration is children's imaginative self-expression. In the extreme of the latter style, adults might be loath to suggest any form of 'correction' of children's products for fear of inhibiting them or contaminating their creativity. The methods of different practitioners were reviewed and strategies compared against theoretical possibilities. For example, the encouragement to use a hand lens offered a clear signal to children that the intention was to look at the object in detail, to record with as much accuracy as they could muster. Some practitioners shared magnified images with a group or class, using a microscope connected to the classroom interactive whiteboard (IWB), enabling discussion of interpretations of what could be seen by everyone.

Feedback strategies were of particular interest, because they serve to make observational drawing a self-aware and thus metacognitive activity for children. Equally clear was the fact that suggesting that they should 'look again' for detail, shape, colour or proportions could be managed without oppressing children and result in a more refined product of which children were proud. Ownership of the activity remained with children who also derived pleasure and esteem from the close attention and praise their efforts were evoking. Some teachers required children to think about how they were representing the stimulus material and suggested iterating between object and drawing. This quality of teacher behaviour might be symptomatic of a more general pedagogic strategy that favours formative assessment. Another example of such a strategy is the managed encouragement of peer assessment. Once a supportive climate of respect for one another's expressions and productions is established, children can feel safe both to offer and receive constructive criticism. This will be as a precursor to the self-evaluation procedures that become internalised as self-regulation.

Basic literacy and numeracy skills tend to be foremost amongst Early Years practitioners' concerns, so establishing links between these priorities and the science curriculum is likely to find favour with teachers. It was noted that dialogue with adults whilst children draw might contribute to their mathematics thinking as they judge relative angles, length and size. Representing objects and events also invites the naming and labelling of component parts and thus vocabulary development. Annotations as well as single-word labels were also used frequently to accompany drawings, as children built up 'fact files' or floor books, including the generation of text to record what they had learned.

A strategic variation on drawing objects was to suggest multiple sources, including 3-D models, photographs and other images, each contributing a particular aspect or feature that led to composite drawings. Using this technique, salient qualities were abstracted, and opportunities to discuss structure and function relationships were opened up.

Another way of extending observational drawing towards conceptual development was to invite pairs or small groups of children to assemble large collaborative wall or floor drawings, thus building more complex interrelationships than would be likely through working individually. Elements of such drawings interacted in a visually complementary manner, like visual dialogues or pictorial hypotheses. Some teachers extended this strategy, using 3-D 'observational construction', with the modelling of objects bringing some aspects to greater awareness. As the manipulative and construction skills make more demands on young children than 2-D drawing instruments, the media selected had to be suited to their skills and strength.

In other ways, 3-D work may be more accessible as more relationships (relative size, position, orientation, etc.) are made explicit and the challenge of perspective that is inherent in 2-D drawing is avoided.

Drawn records were valued, some practitioners keeping examples of children's drawings of a particular object over time. When archived, these serve as a source of assessment evidence, offering a compact way of recording children's changing capability to record their conceptual understanding accurately and with detail.

Encouraging children to record their observations in detail, together with providing opportunities and encouragement to discuss, peer review, revisit and add or modify visual information, shifted this activity from the general developmental towards a science-specific mode of operating. During the enquiry, gently probing interactions between practitioners and children were witnessed frequently, a procedure that can be thought of as developing a continuously self-evaluating mode of working. Some practitioners modelled a peer review process, enabling feedback to be exchanged between children themselves. Such strategies hold the promise of young children developing the capability to display perseverance, engagement, reflective thinking and the ability to represent their observations in some detail. Practitioners' sensitive questioning and gentle challenges were seen to play a key role in extending observational and thinking skills.

The developmental trajectory relevant to conceptual development described above resulted from researchers' overviewing the techniques in evidence, sequencing and extending them by drawing on the pool of practitioners' expertise. In turn, these deliberations were shared with practitioners so that familiar holistic practices could be shaped in the direction of consensual science-specific strategies for supporting children's development.

13.3.3 Direct Experiences as Precursors of Formulating Enquiries

Another developmental trajectory was suggested that starts with the direct experiences that are a key element in Early Years provision. Commonly, specific direct experiences were planned for children, even when the stated policy was to follow children's interests in a more laissez faire manner. Particular equipment or materials were characteristically made available – e.g. a water trough, sand tray, role-play area with costumes and so forth. The initial recurring 'thread', commonly identified across settings, was the provision of materials designed to promote physical exploration. The science education focus adopted was how it might be possible to maximise the value of, and extend, these direct experiences, with a view to laying the foundations of later, more structured approaches to science enquiry. The availability of particular resources self-evidently increases the probability of occurrence of behaviours related to those materials: stirring, mixing, pouring, measuring time and estimating volume in the 'mud kitchen' and building structures, joining pipes, moving water and sand in the 'building area', etc. Additional, spontaneous or seasonal activities, such as bubble blowing, walking in the local environment, etc., were also organised. Typical unplanned events included examining the ice forming on the water in a trough or autumn leaves falling in the play area. Such happenings engage youngsters' attention, provoke curiosity and promote the physical handling and manipulation of materials. They support personal and social development through the exchanges they stimulate; they facilitate vocabulary development as children comment on and exchange views about what they are experiencing and generally extend knowledge and understanding of the world. Our interest was in how they might be transformed in the direction of science enquiries.

The researchers were interested in gaining insights into children's views of the experiential activities provided for them. One striking outcome was how relatively little children had to say in the course of informal interviews about the experiences with which they had engaged. It is accepted that, particularly in the younger age range (36–60 months), children's vocabulary and ability to describe activities in other than brief phrases must be expected to be limited. However, care was taken to make children feel comfortable, to have the concrete materials to which they might wish to refer present and to work with small groups of the more outgoing volunteers. Even so, verbal responses tended to be restricted. For example, in the context of explaining the procedure for using a bubble frame and soapy water for blowing bubbles, comparing their sizes and how long they lasted, 'You blow' tended to be a typical communication of the experience. It is tempting to assume that children have more understanding than they were able to articulate, but this may or may not be the case.

The limited form of response also has to be evaluated in the context of the multitude of stimuli that Early Years settings offer children. Many events are ephemeral, and children have to work out which activities adults regard as important by responding to cues. If it is deemed desirable for children to reflect on their experiences, this expectation must be brought to their awareness. The providing adults must be clear about what they aspire for children to derive from such provision. Sometimes, expectations are planned and self-evident because they are in-built, as, for example, the use of a water trough with jugs, funnels and different shaped vessels. Then, the value may be planned and rehearsed and adults are prepared with their responses and cues. At other times, as when an event arises unexpectedly, the situation requires adults to think on their feet. The common factor must be for the adults to be asking themselves, 'What potential value for the children's science development can we envisage in this scenario?' and 'How do we frame our interactions to optimise positive outcomes?' Such questioning interactions provoke children to ponder their role and how they might vary what they are doing. The cause and effect relationships in their experiences might then become more overt and explicit.

With adult guidance for older children, direct experiences often lend themselves to the introduction of quantification. For example, in blowing bubbles, children might be asked 'How big a bubble can we blow?', 'How long do bubbles last?' or 'How far do bubbles travel through the air?' Such questions model an enquiry approach and induce curiosity in children. Some activities invite enquiries that can be directly investigated at a simple level, provoked by practitioners' questions such as 'How long does the ice take to melt?' and 'Where will it melt most quickly?' In educators' desire to move children in the direction of scientific enquiry, questions such as these tend to be about *variation* in the procedure that might give rise to *variation* in outcomes. As such, viewed from a science education perspective, the questions are about a preliminary phase in what later could become a matter of drawing attention to the dependent variable in an investigation.

The apparent gap between the experiences provided in settings and children's capabilities in articulating the details and sequences within such episodes stimulated dialogue between researchers and teachers. Specifically, discussions reflected on how learning progression might be articulated between the provision of direct experiences and the beginnings of structured enquiries, with eventual quantification. Interviews with children identified the likely necessity of prior metacognitive reflection on their experiences as a prerequisite to embarking on investigable questions or their own enquiries. Because of the uncertainty about the extent of children's understanding of those experiences witnessed in the limitations of their oral reports, alternative representational modes that would be less language dependent were considered with teachers. Also, as in so many other aspects of the management of young children, the researchers' predilection was to encourage teachers' deconstruction of events in detail and then to reconstruct them, as if in slow motion, considering each small step in detail. Attention turned to means of facilitating children's external representations using other than language-based modalities – for example, by making picture strip-sequenced drawings or by assembling sequenced photographs of themselves and their peers engaged in each of the steps in any selected activity that was to be the subject of enquiry. Video recording could also be used and reviewed to bring to awareness events as detailed sequences in the correct order. It seemed to the researchers that the apparently simple question, 'How do you blow a bubble?', needs to be posed and understood explicitly before variations such as 'How do we blow the biggest possible bubble?' can make sense to children, as even a simple form of enquiry.

This 'slow motion' deconstruction can be thought of as a step between first-order descriptions and a consideration of possible causal relationships. This approach suggests the need to inculcate a reflective attitude of mind in children as habitual, with implications for the minute-by-minute pedagogy employed by adults managing young learners. The suggestion is that a climate of rational explication, comment and dialogue is likely to be conducive to the establishment of an ethos in which children ask themselves the reason why things happen in the sequence observed. Establishing the desirable ethos has implications for the adults managing such groups as well as for children, since adults will be the ones who initiate this attitude by modelling during science-related activities. The same mindset applies to the management of all aspects of children's Early Years experiences, including socialisation processes. In the context of working on teachers' own science knowledge, Hoban and Nielsen's (2012) research into 'Slow motion' technique is interesting and relevant (see http://slowmation.com).

Another way of making the shift from their direct experiences to the more structured beginnings of science enquiries was by inviting children to anticipate the future or to rehearse what they imagined was going to happen in any particular scenario. This invitation to predict 'What do you think will happen next?' is used regularly in group storytelling sessions, adults using the strategy to maintain children's engagement and curiosity. From a science education perspective, it can be seen as an antecedent to predicting and hypothesising. In other contexts, children made their predictions in the form of annotated drawings showing what they expected would happen, e.g. to ice or to seeds, over a period of time. In some instances, this led to simple variable handling investigations using fair testing, such as when ice or planted seeds were placed in different locations and the different outcomes compared.

Reviewing the ubiquitous practice of providing direct experiences in settings and hypothesising how science enquiries might emerge from them, it became clear to the researchers that adult management is the essential element. It is unsafe to assume that direct experiential activities speak for themselves to children. Managed opportunities to transform their experiences by redescribing them in drawings, role-play or using information technology can help to explicate the steps towards a more enquiry-orientated approach. Encouraging children to express their beliefs and reasoning to explain why things happen as they do can be part of establishing a stronger science orientation. Inviting children to anticipate future events in different scenarios was seen as valuable experience and a helpful antecedent to predicting and hypothesising in a science education perspective. Requiring reasons for expressed ideas was discussed as a potentially habitual part of practice, applying to adults as much as to children, and a step towards evidence-based reasoning and empirical enquiry.

13.3.4 The Expression of Ideas as an Antecedent to Argumentation

The third cluster of behaviours to be discussed was grouped around a progression that starts with children expressing their ideas. The expression and exchange of ideas supported with justifications are viewed as central to science and science learning (Duschl et al. 2011), a standpoint that attributes equal status to this capability, alongside enquiry and practical investigations. It emphasises communication between individuals and groups through 'discourse practices'. Many young children starting their education are very reluctant to express their thoughts, and Early Years practitioners seek to encourage them to do so as soon as possible. In later schooling, this formal way of debating is described as a process of 'argumentation', a process of expressing propositions backed by evidence and responding to counterarguments (Osborne et al. 2013). Argumentation has a central position in the definition of discourse practices, along with group critique and peer review.

In the early phase of the project, many examples of children's struggles to express their own ideas orally were noted; the challenges posed for young children cannot be underestimated. The affective dimension of such discourse was recognised by practitioners, who saw the need to encourage children to be 'brave' as they described their ideas and 'kind' as they listened to others' offerings. Taking into account what 'Theory of Mind' (Baron-Cohen 1991) tells us about early development, these children need also to learn that both they and their peers all have their own ideas, each being different, but all worthy of being expressed and considered.

A step on from the straightforward expression of ideas is to encourage children to support their thinking with a reason. Some teachers were particularly assiduous in not accepting children's responses that were often of the kind, 'Because, I think so' or 'Because, it just is'. Assertions of this kind were encountered widely across settings. Some practitioners encouraged children to give reasons by posing questions such as 'Why do you think so?', 'Does anyone else agree with that reason?' and 'Does anyone have a different reason?' Interactions tended to be facilitated when centred on concrete objects. For example, children's discussions of the parts of the plant on which they thought different vegetables were found would need to be supported by handling real vegetables.

As a step-up to considering whether or not they could agree in detail with the particular quality of an idea expressed, one strategy was for children initially to discuss their ideas in small groups and to classify each one as 'true' or 'false'. A further category of 'don't know' was added to handle those ideas that children could not classify. Later still, for children who could cope with the subtlety, the category of 'insufficient evidence' or 'can't tell' were added, a nuance that much older students and many adults do not use and possibly find elusive.

In one school setting, children's discussions of the design and making of an outdoor musical instrument were supported by the presence of the design drawing and the actual construction. It seemed to be significant in facilitating the exchange of ideas that concrete objects provided a shared reference for the discussion and helped to provide an unambiguous understanding of the points being made. Pointing at or adjusting parts of the construction made the contribution to the discussion plainly evident to all participants. A design assertion (proposition) would be challenged and counter argued on the basis of justificatory data (Toulmin 2003). Aspeitia (2012) argues that images can play a role in propositions that act as premises or conclusions. The experience of this research confirmed that argumentation need not imply or depend upon propositions framed only in the language mode: interactions around the pros and cons of the design features of outdoor musical instruments could be deconstructed as argumentation sequences. Young children showed unexpected capabilities in challenging viewpoints and justifying ideas by producing reasons in the face of such challenges. Teachers felt that assessed learning outcomes with the age group targeted in this research had taken children's discussions to a much higher level than previously met. Science educators' aspirations in this context would be that children's justifications of the kind encountered would, in time, be expressed as 'evidence' and come to be understood as verifiable or otherwise.

Teachers reported that, as a result of their project involvement, they had acquired both an enhanced awareness of the relevance of the expression of children's own ideas to science learning and a repertoire of different ways of encouraging children's communication. Basic principles included establishing a safe ethos in which all expressions of ideas are valued; encouraging children to express ideas in different modes, including speech, drawing, gesture, etc.; expecting ideas to be accompanied by a reason and increasingly, a justification; providing opportunities for children to reflect on their own ideas and to make, for example, 'agree/disagree', 'true/false' decisions; and introducing peer assessment to equip children with the skills to give and receive feedback. Managing interactions around real objects to reduce ambiguity and enhance checking of claims against the evidence was recognised as a significant scaffolding technique.

Ideas supported with justifications are central to science. Our project established that younger children could be helped and encouraged to take steps along the route to the formal exchange of claims supported by evidence and towards 'argumentation' practices. Such interactions are seen in Early Years settings, but the framing of science as discourse tends to be a rarity with the younger age group. The use of multimodal techniques to support propositions, rather than relying on verbalisations alone as the means of putting forward an idea or 'claim', was confirmed as being invaluable.

13.4 Conclusions

Teaching and learning sequences do not lie ready formed, waiting in obscurity to reveal themselves. They must be constructed by human minds, pieced together by drawing on evidence from within a complex set of interacting variables. Plotting a developmental journey is akin to scanning a rock face to discern likely finger and toeholds: it is a challenge that requires expertise and there may well be more than one route. Once scaled, the ascent is validated and others may follow more readily. Practitioners' skills and experience, resources within settings and children's capabilities individually and across the focal age range all vary. This kind of research demands evidence-based acts of judgement in order for learning trajectories to be posited on the basis of theoretical advances. In DBR methodology, this is acknowledged to be an iterative process in which design refinements are to be expected. The utilities for teachers' practices and children's progress are the final tests. It is within this framework of thinking that we suggest how development may proceed in the three domains of science activity described. The grounded, design-based research approach led to increasing specification of 'threads', recurring aspects of behaviour that, when informed by dialogue with teachers and subjected to theoretical reflection, may be aggregated and sequenced to describe more complex developmental patterns. The hypothetical trajectories do this by providing frameworks of progression that help to locate children's position and next steps that can be described as 'zones of proximal development'.

Practical project outcomes will lead to curriculum support materials informed by this research and validated and illustrated by the practitioners involved in their construction. This 'bottom-up' strategy of Continuing Professional Development builds on the pre-existing professionalism of practitioners in contrast to deficit intervention models.

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Chapter 14
'Creative Little Scientists' Project: Mapping and Comparative Assessment of Early Years Science Education Policy and Practice

Fani Stylianidou, Esme Glauert, Dimitris Rossis, and Sari Havu-Nuutinen

14.1 Introduction

Creative Little Scientists was a 30-month (2011–2014) EU-funded comparative study working across nine participating countries: Belgium, Finland, France, Germany, Greece, Malta, Portugal, Romania and the UK. The *Creative Little Scientists* project sought to build a picture of policy and practice in science and mathematics education for children aged 3–8 and their potential to foster creativity and inquiry learning and teaching.

The project aimed to add to previous EU reports in science and mathematics education in its focus on the nature of science and mathematics education in the *early years* and in seeking to characterise and investigate opportunities for *creativity in learning and teaching within the specific contexts of science and mathematic*s. A significant strand of the project was also the development of guidelines for policy and teacher education building on findings from the different phases of the study and ongoing collaboration and dialogue with participants and other stakeholders. The study aimed to mainstream good practices by proposing changes in teacher education and classrooms encompassing curriculum, pedagogy and assessment.

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14.2 Background, Objectives and Framework

14.2.1 Core Drivers for Creative Little Scientists

The project was informed by at least four key drivers that set the context for an increased research focus on science and mathematics education and creativity in early years education:

- *The role of an economic imperative within education*, demanding capable scientists and creative thinkers in an increasingly knowledge-based globalised economy (European Commission 2011) and requiring capabilities such as reasoning skills, innovative thinking and positive attitudes.
- *The role played by science, mathematics and creativity in the development of children and of citizens*, demanding early understanding and interaction with phenomena in nature and technology, which empower students (and therefore future adults) to take part in societal discussions and decision-making processes (Gago et al. 2004; Harlen 2008).
- *The role of early years education in building on children's early experiences and in promoting positive skills and dispositions* (Sylva 2009), informed by increased awareness of the child as an active and competent meaning maker, who can take ownership of their own learning and take part in decision making in matters that affect their lives in the present (Goswami 2015).
- *The role of a digital or technological imperative within education*, enabling but also demanding the development of children's capabilities in science, mathematics and creativity (Wang et al. 2010).

14.2.2 Objectives for Creative Little Scientists

In the light of the above, the *Creative Little Scientists* project set the following objectives:

- *To define a clear and detailed Conceptual Framework* comprising the issues at stake and the parameters needed to be addressed in all stages of the research.
- *To map and comparatively assess existing approaches* to science and mathematics education in preschool and first years of primary school (up to the pupil age of 8) in the nine partner countries, highlighting instances of, or recording the absence of, practices marrying science and mathematics learning, teaching and assessment with creativity.
- *To provide a deeper analysis of the implications of the mapped and compared approaches*, which would reveal the details of current practice and provide insights into whether and how children's creativity is fostered and the emergence of appropriate learning outcomes in science and mathematics is achieved.

- *To propose a set of curriculum design principles as concrete guidelines for European initial teacher training and continuous professional development programmes*, which would foster creativity-based approaches to science and mathematics learning in preschool and the first years of primary education. The proposed principles would be accompanied by *illustrative teacher training materials* aiming to clarify their applicability in complex and varied European educational contexts, thus facilitating implementation, evaluation and further development across Europe.
- *To exploit the results of the research at the European level as well as at national and institutional level*, making them easily available to educational policymakers and other stakeholders, through the synthesis of all research outputs and their transformation into a 'Final Report on Creativity and Science and Mathematics Education for Young Children' (Creative Little Scientists 2014a) and also a 'Set of Recommendations to Policy Makers and Stakeholders' (Creative Little Scientists 2014b).

14.2.3 Conceptual Framework for Creative Little Scientists

The first of these objectives was achieved through extensive reviews of policy-related and research-based literature at the beginning of the project covering areas as diverse as science and mathematics education with a focus on preschool and first years of primary school, creativity in education, creativity as a lifelong skill, teaching and teacher training approaches as well as cognitive psychology and comparative education. The resulting Conceptual Framework (Creative Little Scientists 2012) provided a strong theoretical framework for the study. Two particular features of the Conceptual Framework played key roles in fostering coherence and consistency in approach across the project and in themselves have the potential to contribute to future work in the field, the *definition of creativity* in early science and mathematics employed across the project, and the *synergies* identified between inquiry-based and creative approaches to learning and teaching.

The definition of creativity in early science and mathematics developed from the Conceptual Framework and subsequently refined through discussion with stakeholders is: *Generating ideas and strategies as an individual or community, reasoning critically between these and producing plausible explanations and strategies consistent with the available evidence.* This needs to be understood alongside the 'little c creativity' definition (Craft 2001) – *'Purposive, imaginative activity generating outcomes that are original and valuable in relation to the learner'* – insofar as this effort towards originality and value through imaginative activity drives creativity in other domains including early science and mathematics.

The Conceptual Framework for *Creative Little Scientists* also explored synergies and differences between inquiry-based (IBSE) and creative approaches (CA) to science and mathematics. Although definitions of IBSE vary, there is considerable agreement internationally, reflected in both policy and research, about the value of inquiry-based approaches to science education (Minner et al. 2010). CA, on the other hand, do not refer to a recognised set of approaches to education and learning, but nonetheless, such approaches have gained considerable attention in research and policy contexts in recent years (Chappell et al. 2008). Both sets of approaches are pedagogically associated with a range of child-centred philosophies from European and North American thinkers, which situate the child as an active and curious thinker and meaning maker and highlight the role of experiential learning. Common synergies are:

- *Play and exploration*, recognising that playful experimentation/exploration is inherent in all young children's activity, such exploration is at the core of IBSE and CA in the early years (see, e.g. Goswami 2015; Cremin et al. 2006; Poddiakov 2011).
- *Motivation and affect*, highlighting the role of aesthetic engagement in promoting children's affective and emotional responses to science and mathematics activities (see, e.g. Craft et al. 2012b; Koballa and Glynn 2008).
- *Dialogue and collaboration*, accepting that dialogic engagement is inherent in everyday creativity in the classroom, plays a crucial role in learning in science and mathematics and is a critical feature of IBSE and CA, enabling children to externalise, share and develop their thinking (see, e.g. John-Steiner 2000; Mercer and Littleton 2007).
- *Problem solving and agency*, recognising that through scaffolding the learning environment, children can be provided with shared, meaningful, physical experiences and opportunities to develop their creativity as well as their own questions and ideas about scientifically relevant concepts (see, e.g. Cindy et al. 2007; Craft et al. 2012a).
- *Questioning and curiosity*, which is central to IBSE and CA, recognising across the three domains of science, mathematics and creativity that creative teachers often employ open-ended questions and promote speculation by modelling their own curiosity (see, e.g. Chappell et al. 2008).
- *Reflection and reasoning*, emphasising the importance of metacognitive processes, reflective awareness and deliberate control of cognitive activities, which may be still developing in young children but which are incorporated into early years practice, scientific and mathematical learning and IBSE (see, e.g. Kuhn 1989; Bancroft et al. 2008).
- *Teacher scaffolding and involvement*, emphasising the importance of teachers mediating the learning to meet the children's needs, rather than feel pressured to meet a given curriculum (see, e.g. Rittle-Johnson and Koedinger 2005; Bonawitz et al. 2011).
- *Assessment for learning*, emphasising the importance of formative assessment in identifying and building on the skills, attitudes, knowledge and understandings children bring to school, supporting and encouraging children's active engagement in learning and fostering their awareness of their own thinking and progress (see, e.g. Harrison and Howard 2011; Feldhusen and Ban 1995).

14.3 Research Approach and Design

14.3.1 Research Questions and Approach for Creative Little Scientists

The project's Conceptual Framework also developed the methodological framing of the study and identified the following research foci:

RQ1. How are the teaching, learning and assessment of science and mathematics in the early years in the partner countries *conceptualised* by teachers and in policy? What role if any does creativity play in these?

RQ2. What *approaches* are used in the teaching, learning and assessment of science and mathematics in the early years in the partner countries? What role if any does creativity play in these?

RQ3. In what ways do these approaches seek to *foster young children's learning and motivation in science and mathematics*? How do teachers perceive their role in doing so?

RQ4. How can findings emerging from analysis in relation to questions 1–3 inform the development of practice in the classroom and in teacher education (Initial Teacher Education and Continuing Professional Development)?

These questions were examined in relation to three broad strands (*aims, purposes and priorities*; *teaching, learning and assessment*; and *contextual factors*) broken down into more narrowly defined dimensions drawing on the framework of curriculum components 'the vulnerable spider web' (van den Akker 2007), comprising key aspects of learning in schools: rationale or vision; aims and objectives; learning activities; pedagogy (or teacher role); assessment; materials and resources; location; grouping; time; and content. These were complemented by dimensions focusing on teachers' backgrounds, attitudes and education.

Within these dimensions, a List of Factors was identified, drawing on the Conceptual Framework and encompassing key features and processes that had been found to be associated with creativity in early science and mathematics (see Appendix 1). The curriculum dimensions and associated List of Factors provided an essential common framework across the different phases of research for capturing an in-depth empirical picture of conceptualisations, practices and outcomes related to opportunities for creativity in early science and mathematics across partner countries.

To meet the project's objectives and research questions, mixed methods were employed, combining quantitative approaches used in the surveys of policy and of teachers' views, alongside qualitative approaches employed in the case studies of classroom practice and iterative processes associated with curriculum design research. It was recognised that policy and practice needed to be interpreted within partners' particular national contexts, especially when making comparative judgements. As a result, all phases of research were reported in separate National Reports.

These were then synthesised to form overall *Creative Little Scientists* project reports, available on the project's website (www.creative-little-scientists.eu).

14.3.2 Comparative Assessment of Conceptualisations by Teachers and in Policy

This paper is concerned with presenting findings from the first stage of the research, focused on the comparative assessment of how early years science and mathematics is conceptualised by teachers and in policy in the nine partner countries, highlighting instances of, or recording the absence of, practices marrying science and mathematics learning, teaching and assessment with creativity. It thus addresses parts of RQ1 and RQ4 above. The research used the methodology of comparative education employing the same methods of data collection and analysis in making comparisons, drawing on data collected via two routes:

1. *A desk survey of policy* to examine how teaching, learning and assessment of science and mathematics in the early years are conceptualised in 134 national policy documents, including curricula, reports and assessments of school practice.
2. A *teacher survey*, which gathered data through a teacher questionnaire addressed to a sample of 815 teachers from 605 schools (238 preschools and 367 primary schools) across all partner countries, aimed towards gaining insights into practicing teachers' conceptualisations of science, mathematics and creativity in early years education.

The planning of the two pieces of research commenced at the same time to achieve maximum coherence between the studies. In addition, as research instrument, they both used a similar 4-point Likert scale questionnaire based on the curriculum components of Van den Akker (2007) and on the creativity and inquiry approaches identified in the List of Factors. In the case of the *policy survey*, the questionnaire aimed to assess the extent to which these approaches were emphasised in policy documents and how far the role of creativity was emphasised. In the case of the *teacher survey*, it aimed to assess the extent to and frequency with which teachers use these approaches in their classrooms. Aligning the two surveys facilitated subsequent comparison of their results.

14.3.3 Phases of Data Analysis

In the *first phase*, partners carried out separate analyses of their country's policy and teacher data to produce National Reports discussing the findings and situating them within their country's educational context.

Data gathered across partner countries for each survey were then amalgamated, grouping questionnaire items according to the dimensions and approaches identified by the List of Factors and analysed as a whole, using descriptive statistics. For example, frequency tables presented teachers' responses to questionnaire items as percentages, means and standard deviations. Preschool and primary school data were considered separately. This produced an overview of the current situation across the nine partner countries. Comparisons were made between findings at the partner country level, as follows:

(a) For the comparative analysis of *policy conceptualisations*, National Reports were drawn upon to identify similarities and differences in approaches amongst national polices. Comparisons of ratings for each questionnaire item indicated similarities and differences, and justifications for the ratings and related commentary provided by the partners gave further insights into such similarities and differences.
(b) For the comparative analysis of *teachers' conceptualisations*, statistical comparisons were performed using SPSS and Microsoft Excel software to identify similarities and differences between teachers' responses across partner countries, in relation to the dimensions and approaches identified by the List of Factors; information provided in the National Reports was used to interpret these similarities and differences.

In the *second phase*, the *policy survey* findings were compared with the relevant findings from the *teacher survey* with a view to revealing any similarities and differences between policy and teachers' conceptualisations of teaching, learning and assessment in early years science and mathematics education and the role of creativity in these. Again, this comparison took place according to the pre-identified factors and dimensions, at two levels:

(a) At a partner country level, using data from the national policy and teacher surveys;
(b) At a European level, drawing on the overall findings from the policy and teacher surveys.

At the partner country level, comparative tables were created for each item in the survey, presenting the data from both surveys by country and school phase (preschool and primary school). These permitted a quick identification of the core similarities and differences in policies and practices within and between countries. Where these similarities and differences appeared more significant, radar charts were created to show policy and teacher ratings (means) for the respective item, by school phase across countries. These charts allowed both a visual and a more in-depth comparison of national findings.

The synthesis of comparisons, focused on the List of Factors and dimensions targeted in the project, brought out issues and tensions in science and mathematics early years education, most relevant to the role of inquiry-based approaches and the potential for creativity.

14.3.4 Methodological Issues and Challenges

From the outset language was a key challenge, common in comparative policy studies across countries. Terms, such as 'inquiry' or 'creativity', did not translate easily between countries. It was also important to recognise that even if terms appear comparable, they may differ in the meaning attributed. Therefore, making comparisons by measuring the use, or absence, of particular terms is problematic. Furthermore, educational policy or practice in a country may embody much of what is signified by a word without using this word explicitly. This is highly relevant for examining the term 'creativity', where its role may not be reflected by explicit use of the term. It was therefore important to give attention to *implicit* as well as *explicit* references to creativity drawing on definitions from the Conceptual Framework.

In relation to the *policy survey*, another issue was to identify what was meant by national policies. It was important first to clarify the different jurisdictions across the partnership. Then given the wide range of policy documentation and varied degrees of regulation, partners needed to make judgements about the documents that best captured curriculum, assessment and pedagogy in early science and mathematics. This could include generic or phase-specific policies alongside subject-specific documentation. Policy in a number of countries was in transition, and it was necessary to review previous or future policy documents that would be in operation during fieldwork. Coding and rating the documents according to the survey tool based on the List of Factors was also not straightforward, particularly in relation to rating the emphasis on creativity. Here the Conceptual Framework and dialogue between partners provided vital support. Partners were asked to provide policy references and comments to support their ratings.

In relation to the *teacher survey*, motivating teachers to participate proved to be difficult in some partner countries. Partners indicated a number of factors that might have contributed to this, including the timing of the survey in the school term, attitudes to research participation, pressures on teachers in particular policy contexts and the extent of partners' networks and previous contacts with schools.

14.4 Conceptualisations of the Teaching, Learning and Assessment of Science by Teachers and in Policy: The Role of Creativity

This section provides an overview of key themes emerging from the comparison of research findings from the policy and teacher surveys at the European level, presented under the main strands and curriculum dimensions of the project. Specific results on which this overview is based are included, only on an exemplary basis, given limitations of space.

14.4.1 Aims, Purpose and Priorities

14.4.1.1 Rationale for Early Years Science and Mathematics

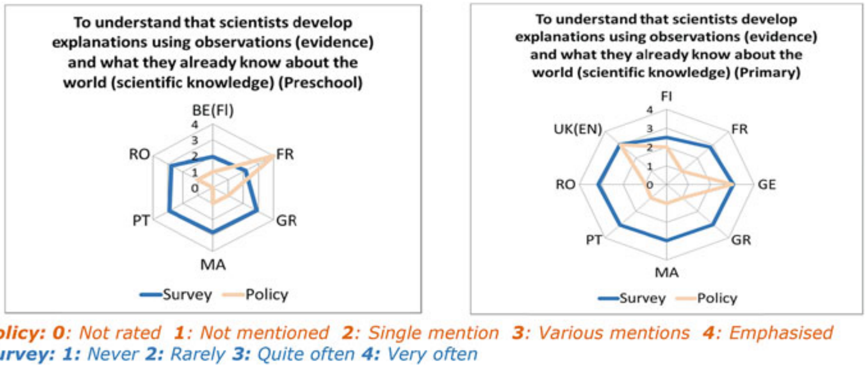
Two common emphases were evident in the rationale for early years science education in partner policies: the need to *develop socially and environmentally aware citizens* and the importance of *fostering skills and dispositions to support future learning*. In both instances, links to creativity were identified implicitly in the need to promote skills of inquiry and positive attitudes to science, in particular curiosity and critical evaluation. In only a small minority of countries was the need *to provide a foundational education for future scientists* or *to develop more innovative thinkers* prioritised in policy.

The results of the *teacher survey* showed that teachers across all partner countries largely agreed with the two main emphases in the policy rationale provided for early years science education. In addition, the view of science learning as an economic imperative was reflected in very few *policy* documents, and this view was mirrored in the *teacher survey*.

14.4.1.2 Curriculum Aims and Content

Science was represented in different ways within the curriculum: in some countries within a broad area of learning such as 'Knowledge of the World' or 'Study of the Environment', in others as a single subject. The aims, objectives and content of the *science curriculum* in partner countries emphasised the development of *process skills associated with scientific inquiry* and of *knowledge and understanding of science ideas* (the latter particularly in primary school). More limited attention was afforded to *social* and *affective* dimensions of learning, and few countries highlighted *understandings related to the nature of science*. A role for creativity was most strongly indicated again *implicitly* in the focus on questioning and investigating and the importance given to curiosity. In most countries, a very limited role for creativity was identified in relation to the *development* of science ideas.

In comparison, *teachers* reported pursuing most often *affective* and *social* dimensions of learning. More limited attention was afforded to cognitive outcomes especially by preschool teachers. In relation to aims related to inquiry-based science learning, teachers fostered quite or very frequently the development of children's capabilities to carry out scientific inquiry, such as to ask questions, gather and communicate findings, but to a lesser degree, children's abilities to plan and conduct simple investigations. Learning aims related to understandings *about* scientific inquiry were the least frequently pursued by teachers, though still quite high compared to the limited emphasis put on understandings related to the nature of science in policy (Fig. 4.1).


To understand that scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge) (Preschool)

To understand that scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge) (Primary)

Fig. 4.1 Learning aims related to understandings about the nature of science: results from policy review and teachers' responses (means) per partner country

14.4.2 Approaches to Teaching, Learning and Assessment

14.4.2.1 Learning Activities

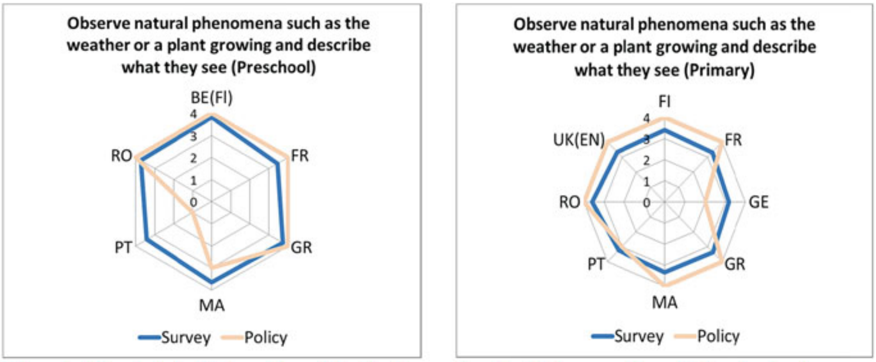
In general, decisions about learning activities were made by teachers in the light of the rationale, learning objectives and curriculum content specified for areas of learning in the partner countries, although some form of policy guidance about appropriate activities was provided in all nine participating countries.

Partners' commentaries in their National Reports for the *teacher survey* pointed to a common emphasis on hands-on approaches and activities *linked to children's everyday lives*. The learning activities reported as used most commonly by teachers were predominantly linked to *eliciting children's curiosity* in natural phenomena and allowing them opportunities *to gather evidence* and *ask questions*. The National Reports from the policy survey, in common with the *teacher survey* results, indicated an emphasis on hands-on approaches and activities linked to children's everyday lives. Observation and communication featured strongly in learning activities recommended for both phases in almost all partner countries (see Fig. 4.2). Questioning was also commonly mentioned in some countries, more particularly by teachers in relation to preschool.

In the majority of countries, conducting investigations or projects and using simple equipment were also included in the guidance provided. There was more variation in relation to planning investigations and using data to construct reasonable explanations. These activities featured more strongly in early primary school policy.

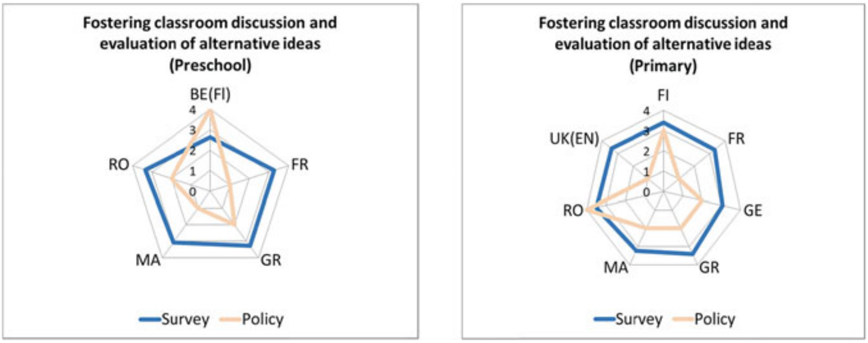
14.4.2.2 Pedagogy

As mentioned above, there was a common emphasis in *policy* across partner countries on hands-on approaches and activities linked to children's everyday lives. In preschool in particular, providing a broad range of experience and making links



Policy: 0: *Not rated* **1**: *Not mentioned* **2**: *Single mention* **3**: *Various mentions* **4**: *Emphasised*
Survey: 1: *Never* **2**: *Rarely* **3**: *Quite often* **4**: *Very often*

Fig. 4.2 Promoting observation in learning activities: results from policy review and teachers’ responses (means) per partner country



Policy: 0: *Not rated* **1**: *Not mentioned* **2**: *Single mention* **3**: *Various mentions* **4**: *Emphasised*
Survey: 1: *Never* **2**: *Rarely* **3**: *Quite often* **4**: *Very often*

Fig. 4.3 Fostering classroom discussion and evaluation of alternative ideas: results from policy review and teachers responses (means) per partner country

across the curriculum were widely recommended. There was a considerable focus on *play* and *fostering autonomous learning. Encouraging problem solving* and *children trying out their own ideas* in investigations were advocated in the majority of countries. Approaches given the least attention included the *use of drama*, *stories*, *history*, *field trips and everyday experiences* as contexts for learning. Moreover, in the aspects of inquiry discussed, most limited reference was given to *connecting explanations to scientific knowledge* and *reflection on inquiry processes and learning*. It is notable that in most countries, limited references were made to the role of *imagination* or the *discussion of alternative ideas* in *policy* (see Fig. 4.3) – also linked with creative approaches to learning and teaching. Some differences were evident between phases of early years education. In preschool, *play* was strongly emphasised and greater attention was given to *questioning* and *fostering* *autonomous learning*. In primary school, greater importance was afforded to *investigation* and *problem solving*.

The results from the *teacher survey* suggested a consensus amongst teachers that the teaching of science should *build on children's prior experiences* and help *relate science to everyday life*. Teachers consistently and uniformly across the partner countries reported appreciation for all pedagogical contexts and approaches that promote *dialogue and collaboration* in science amongst children, but did not recognise the potential of these approaches for developing creativity. Furthermore, *using drama or history* to teach science and *fostering children's autonomy* in learning were not practices very commonly used by teachers across the partner countries, nor were they considered very 'creativity enabling' by them. It should therefore be noted that although uniformly teachers strongly endorsed *affective* learning outcomes in their teaching of science, the way they perceived the contexts and approaches identified in the research literature as enhancing motivation and affect in children, such as using drama or field trips, varied. The *physical exploration of materials* was frequently promoted by the large majority of all teachers and considered as a creative practice. Finally, all *problem-solving* science contexts and approaches were thought of as amongst the most 'creativity enabling' by a large number of teachers, who also reported using them quite or very frequently.

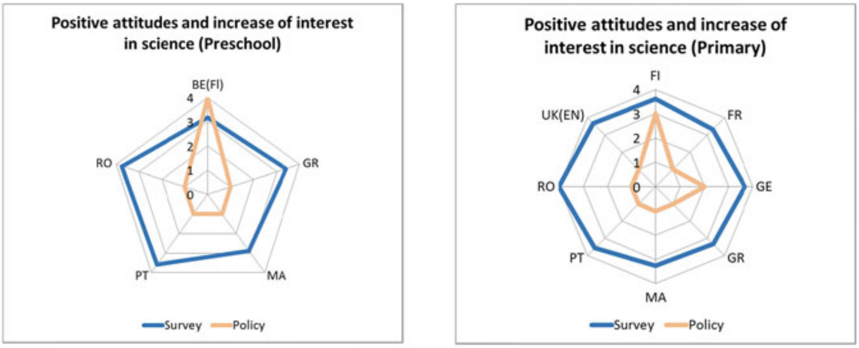
14.4.2.3 Assessment

Policy in relation to assessment showed the widest variation across partner countries. The findings reflected the limited guidance for science assessment and inconsistencies in emphasis across different elements in curriculum policy. There was very limited evidence in policy of a role for creativity either in the *priorities or methods for assessment* advocated across partner countries. Greatest emphasis was given to the assessment of science ideas. *Understandings and competencies in relation to scientific inquiry* were emphasised in assessment policy in a minority of countries, and in only a few instances were attitudes a priority for assessment in science. In general, guidance in relation to assessment methods was limited, with little attention to *multimodal forms of assessment* or the *involvement of children in assessment processes* often associated with creative approaches to learning and teaching.

According to the *teacher survey*, teachers prioritised the *affective* dimensions of learning in science assessment in agreement with their declared rationale, vision, aims and objectives for science education (see Fig. 4.4). In contrast with policy however, they did not consider the assessment of scientific ideas and processes or scientific inquiry in early years science education as important.

14.4.3 Physical and Social Environment

In general, limited advice was given in policy in terms of the physical and social environment for learning. Where advice on materials was provided, it mostly related to the provision of equipment for inquiry and use of digital technologies. There was



Policy: 0: Not rated **1**: Not mentioned **2**: Single mention **3**: Various mentions **4**: Emphasised
Survey: 1: Never **2**: Rarely **3**: Quite often **4**: Very often

Fig. 4.4 Assessment of positive attitudes to science: results from policy review and teachers' responses (means) per partner country

very little emphasis on a budget for teaching or technical support for science. In terms of ways of grouping children for learning, common themes included the recommendation of a variety of approaches to suit particular tasks and learning needs and the benefits of collaborative learning.

According to the *teachers* in the study, preschools and early primary schools were well resourced in computers and relevant library materials for science teaching and in instructional materials, computers and equipment and materials for hands-on exploration in the classroom for mathematics teaching. Support personnel for teaching or for technical issues in both science and mathematics was overall the least available resource in schools, though more available in primary schools than in preschools.

Primary schools were overall better resourced than preschools in computers and technical support personnel. Accordingly, primary teachers overall used computers and ICT resources more frequently than preschool teachers, whereas preschool teachers overall used more frequently relevant library materials and resources for hands-on exploration.

14.5 Discussion

14.5.1 Implications for Policy Development

14.5.1.1 Aims and Content of the Curriculum

The findings suggest that the aims and content of curricula for early years science and mathematics could pay more explicit attention to social and affective dimensions of learning, both also inextricably connected with cognitive dimensions. Greater recognition could also be given to young children's capabilities to engage with processes associated with the evaluation as well as generation of ideas in science and mathematics and with understandings related to the nature of science.

14.5.1.2 Approaches to Learning and Teaching

Policy implications for learning and teaching approaches in early science and mathematics were interlinked with recommendations concerning the aims and content of curricula. Approaches involving play, practical exploration and investigation featured strongly in policy across most partner countries. However, reflecting the need for attention to affective dimensions in the aims and content of curricula, policy guidance and exemplification could pay greater attention to the provision of varied contexts for science learning shown to promote children's motivation, interest and enjoyment in science and mathematics, such as drama, stories, history projects, field trips and children's everyday experiences.

Moreover, in seeking to foster opportunities for inquiry and a role for creativity, greater recognition could be given in policy to the roles of imagination, reflection and consideration of alternative ideas in supporting children's understanding of scientific ideas and procedures. Consideration of alternative ideas is also connected to social factors in learning and opportunities for development of understandings associated with the nature of science. As highlighted above, both these important dimensions of learning deserve greater attention.

14.5.1.3 Assessment

The findings highlight the need for a closer match between the aims and rationale for science education and assessment priorities and approaches. For example, while assessment of science ideas was widely prioritised in policy, more limited attention was given to assessment of inquiry processes and even less to social and affective dimensions of learning, although these dimensions were often highlighted in the rationale and aims set out for early science and mathematics education.

While the importance of formative assessment was increasingly recognised in policy, the results indicate that further guidance would be valuable to support classroom practices in assessment. Areas highlighted in particular include examples of multimodal forms of assessment to give young children opportunities to show the best of what they understand and can do, ways of involving children in peer and self-assessment to support children's reflection on inquiry processes and outcomes and criteria to assess progression in learning, particularly in relation to inquiry and the development of dispositions associated with creativity.

14.5.1.4 Role of Creativity

Findings suggest that a more explicit and detailed focus in policy on the role of creativity in early science and mathematics would be helpful. Where explicit references were made to creativity in policy, they were often in very general terms without provision of guidance about what this might mean in the context of early science and mathematics. The review of policy across partner countries identified implicit connections to creativity in policy for early years science and mathematics, but these need to be drawn out and exemplified to support teachers in translating policy priorities concerning creativity into specific classroom practices. Furthermore, while certain teaching approaches were often signalled as associated with creativity, such as problem solving and the use of digital technologies, there was often limited indication of how such approaches might be used to foster creativity or inquiry in early science and mathematics.

14.5.2 Implications for Teacher Professional Development and Future Research

Findings overall suggest a number of areas for attention in teacher education to support inquiry and creativity in early years science and mathematics education. They include:

- Perspectives on the nature of science and mathematics and the purposes of science and mathematics education in the early years.
- The explicit characteristics and roles of creativity in learning and teaching in early science and mathematics.
- Importance of both cognitive and affective learning outcomes in preschool science and mathematics education.
- The use of drama, stories, history and field trips as motivating contexts for learning.
- Fostering children's autonomy in learning.
- Importance of evaluation of alternative ideas in science and mathematics learning as well as of their generation.
- Assessment strategies and forms of evidence that can be used to support learning and teaching in early science and mathematics and the roles of peer and self-assessment.

Some of these areas also suggest additional implications for future research, since they are related to factors that were not strongly represented in the data such as:

- Opportunities for outdoor learning in the wider school environment.
- The potential of children's use of ICT to enhance inquiry and creativity.
- Role of representation in varied modes in fostering young children's reflection and reasoning.
- Opportunities for exploring the nature of science with young children.

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Appendix 1: Dimensions, Sub-questions, Survey Questions and Factors

	Dimensions	Factors important to nurturing creativity in early years science and mathematics
	Sub questions	
Aims/purpose/priorities	**Rationale or vision**	Science economic imperative
	Why are they learning?	Creativity economic imperative
		Scientific literacy and numeracy for society and individual
		Technological imperative
		Science and mathematics education as context for development of general skills and dispositions for learning
	Aims and objectives	Knowledge/understanding of science content
	Towards which goals are the children learning?	Understanding about scientific inquiry
		Science process skills; IBSE specifically planned
		Capabilities to carry out scientific inquiry or problem-based activities; use of IBSE
		Social factors of science learning; collaboration between children valued
		Affective factors of science learning; efforts to enhance children’s attitudes in science and mathematics
		Creative dispositions; creativity specifically planned

Teaching, learning and assessment	**Learning activities**	*Focus on cognitive dimension incl. nature of science*
	How are children learning?	Questioning
		Designing or planning investigations
		Gathering evidence (observing)
		Gathering evidence (using equipment)
		Making connections
		Focus on social dimension
		Explaining evidence
		Communicating explanations
	Pedagogy	Role of play and exploration; role of play valued
	How is teacher facilitating learning?	Role of motivation and affect; efforts made to enhance children's attitudes in science and mathematics
		Role of dialogue and collaboration; *collaboration between children valued*
		Role of problem solving and agency; use of IBE/PBL, children's agency encouraged
		Fostering questioning and curiosity – children's questions encouraged
		Diverse forms of expression valued
		Fostering reflection and reasoning; children's metacognition encouraged
		Teacher scaffolding, involvement and sensitivity to when to guide/stand back
	Assessment	*Assessment function/purpose*
	How is the teacher assessing how far children's learning has progressed, and how does this information inform planning and develop practice?	Formative
		Summative
		Recipient of assessment results
		Assessment way/process
		Strategy
		Forms of evidence; excellent assessment of process + product, diverse forms of assessment valued
		Locus of assessment judgement – involvement of children in peer/self-assessment

(continued)

(continued)

	Dimensions	Factors important to nurturing creativity in early years science and mathematics
	Sub questions	
Contextual factors (curriculum)	**Materials and resources**	Rich physical environment for exploration; use of physical resources thoughtful; valuing potential of physical materials
	With what are children learning?	Environment fosters creativity in science/mathematics
		Sufficient space
		Outdoor resources; recognition of out-of-school learning
		Informal learning resources
		ICT and digital technologies; confident use of digital technology
		Variety of resources
		Sufficient human resources
		No reliance on textbooks or published schemes
	Location	Outdoors/indoors/both – recognition of out-of-school learning
	Where are they learning?	Formal/non-formal/informal learning settings
		Small group settings
	Grouping	Multigrade teaching
	With whom are they learning?	Ability grouping
		Small group settings
		Number of children in class
	Time	
	When are children learning?	Sufficient time for learning science and mathematics
	Content	Science/mathematics as separate areas of knowledge or in broader grouping
	What are children learning?	Level of detail of curriculum content
		Links with other subject areas/cross-curriculum approach; evidence of science and mathematics integration (planned or incidental)
		Subject-specific requirements vs. broad core curriculum
		Content across key areas of knowledge

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Part VI
Affective and Social Aspects of Science Teaching/Learning

Chapter 15
The Future of European STEM Workforce: What Secondary School Pupils of Europe Think About STEM Industry and Careers

Irina Kudenko and Àgueda Gras-Velázquez

15.1 Introduction

A relative drop in the number of STEM (science, technology, engineering and mathematics) graduates coupled with a shortage of workers with high-vocational and technical skills has increasingly become a matter of political and economic concern in most European countries. Recruitment to the STEM sector and a proportionate decline in a qualified STEM workforce are publicly recognised as EU-wide problems that require urgent and systemic countermeasures (Eurobarometer 2008). In both public and academic discourses, the issue has become firmly linked to young people's disengagement with STEM subjects in school and their decreasing interest in STEM careers (ERT 2009; Sjøberg and Schreiner 2010).

Multiple research studies register a growing decline of pupil's interest in STEM subjects, which is particularly noticeable in secondary school (Rohaan et al. 2010) and which is exacerbated by the parallel development of stark gender differences (Jenkins and Nelson 2005). To explain variations in pupil's engagement with STEM subjects and careers, researchers have identified various social, cultural and economic factors.

For example, the UK scholars investigating educational and career aspirations of school children within the project ASPIRES (2013) developed a concept of *science capital* as the main explanatory tool that helps to understand how pupil aspirations are shaped. *Science capital* relates to the level of interest, knowledge and

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understanding of science matters encapsulated in pupil immediate environment (family and friends). It is important because it directly influences a young person's disposition towards STEM learning and careers: increase in *science capital* makes a pupil more likely to continue learning STEM subjects post-16 and to consider a STEM-related job in the future. Being a powerful heuristic and explanatory concept, it also implies that the key forces that determine and sustain pupil aspirations lay outside the classroom. Consequently, raising *science capital* is a crucial but a very difficult task that requires structural social changes as well as long-term and large-scale social investments.

A different line of enquiry is focused on the quality of teaching STEM at school as well as on the quality and relevance of career advice. For instance, Cleaves (2005) shows how school experience of STEM could make a crucial difference in young people's predisposition to STEM learning and careers. However, the nature of formative processes shaping career aspirations at school is not well understood.

The present study examines secondary pupils' views on different aspects of STEM subjects and careers, including their personal interests, views on school teaching of STEM and their social attitudes, and considers their relative role in fostering young people's inclination towards STEM-related careers.

15.2 Rationale

The data for this paper comes from the pan-European project inGenious (also known as ECB – the European Coordinating Body for STEM education), which involved over 40 partner organisations representing European industry, policy makers and STEM educators. The project, which overarching aim was to foster young people's interest in STEM education and careers, was launched in spring 2011 and finished in autumn 2014. To this purpose, inGenious facilitated existing school-industry partnerships and supported the development and dissemination throughout Europe of innovative STEM educational practices designed by industry partners.

While participation in inGenious was open to all schools in Europe reaching nearly 2000 classrooms by the end of the project, the project also recruited 150–170 teachers in each of the three testing cycles as 'pilot' teachers, who were provided with additional professional development opportunities and learning resources in exchange for their school participation in a more rigorous evaluation process of inGenious practices. Participating pupils and teachers were asked to fill in the questionnaires at the beginning, during and after each pilot cycle. The collected data was used for evaluation purposes, but it also provided valuable insights into the current state of STEM teaching and learning, personal and social views and job aspirations. More importantly, this data enabled us to consider the relative role a personal interest, school teaching, social attitudes, industry and job stereotypes play in shaping pupil's predisposition to STEM-related careers in different parts of Europe.

Drawing on the existing research that investigates formative processes that shape career choices, our research questions were:

- How do pupil participants of inGenious perceive various aspects of STEM education and employment?
- Are there any gender and regional differences in their views and experiences?

In addition, we were also able to make exploratory analysis of some possible links between pupils' views on and experiences of STEM in school and their inclinations towards STEM-related careers.

15.3 Methodology

This study is based on the analysis of 7,601 responses from secondary pupils (11–16-year-olds) of schools participating in the pilot testing of the inGenious practices. The data was collected in 23 European countries and two EU partner countries (Turkey and Israel) at the onset of the two consecutive pilot cycles of the project. 2,756 questionnaires were received in the first pilot year, which was a shorter cycle, and 4,845 in the second pilot year.

Due to the nature of the project and the way schools were recruited to the 'pilot', the study faced a number of methodological limitations. First, the survey was administered in 15 different languages, so that the majority of pupils answered questions in their native language. However, where the number of participating schools in a country was between one and three, e.g. Bulgaria or Macedonia, both pupils and teachers used English questionnaires. To overcome this limitation, the survey instruments were designed to be robust and simple: pupils were presented with a number of themed statements and asked to show how much they agree with each of them on a four-point scale ranging from *strongly disagree* (1) to *strongly agree (4).*

Second, the number of participating schools and pupils in each country varied from one school to 11 schools, and for some countries, the number of participating schools was different in each pilot cycle. Therefore, the analysis has been carried out by grouping the schools into five larger geographical areas in Europe (Table 15.1).

Finally, despite the wide geography and high volume of collected responses, we have no exact knowledge of how representative our sample is. The results show that we achieved a reasonable gender representation in each region (Table 15.2), but due to the nature of the sample, we also anticipated some positive skewness of the data. Given the self-nominating and voluntary mechanism of participation in the project, it was assumed that the inGenious teachers were more enthusiastic and better performing teachers than an average teacher in their respective countries and that this was likely to impact their pupils' views and attitudes to STEM. In addition, some of these teachers could have selected their better performing and more motivated STEM pupils for testing inGenious practices and filling in the questionnaires.

Overall, data collected through inGenious reveals a mixed picture of pupils' interests, attitudes and career preferences in STEM. Our results were found to be slightly more optimistic than the findings reported in other research projects

Table 15.1 Respondents per country and geographical area

Region	Country	Pupils
Eastern Europe		2178
	Bulgaria	65
	Croatia	572
	Czech Republic	609
	Estonia	339
	Hungary	13
	Lithuania	44
	Macedonia	25
	Romania	31
	Slovakia	530
Northern Europe		1556
	Denmark	293
	Finland	486
	Netherlands[a]	453
	Sweden	324
Southern Europe		1466
	Greece	48
	Italy	335
	Portugal	615
	Spain	468
Western Europe		1454
	Austria	221
	Belgium	10
	France	262
	Germany	438
	Ireland	13
	United Kingdom	510
EU partner countries		947
	Israel	442
	Turkey	505
Total		7601

[a] Although geographically the Netherlands is not part of Northern Europe, in terms of their approach to STEM education this country has more in common with ‘Nordic’ countries than with countries in the Western European group. This decision was discussed and received endorsement in a series of consultations with education experts and other project stakeholders from this part of Europe

Table 15.2 Gender representation in each region

Region	Girls to boys ratio (%)
Eastern Europe	51:49
Northern Europe	50:50
Southern Europe	51:49
Western Europe	59:41
EU partner countries	45:55
Total	51:49

(Sjøberg and Schreiner 2010), which supported our initial hunch of a certain positive skewness of the sample. However, should such selection bias exist, it is also expected to be universal, i.e. applicable to all participants in our sample. This means that the nature of the relationship between variables should not be affected, and we were still able to explore the relations and differences between key categories of pupils. A relatively large sample size also helped to offset the selection bias. Indeed, when we compared results from each of the testing cycles, most of our findings showed high year-on-year consistency and largely confirmed trends and gender/regional differences identified in earlier studies (Sjøberg and Schreiner 2010).

15.4 Results

15.4.1 Interest in STEM Topics

We had a number of statements designed to measure the level of pupil's interest and enjoyment of science, technology and maths in and outside the school. The answers were measured on a four-point scale, yet for some of the analyses, those were collapsed to a binary scale (*disagree* vs. *agree*).

On total, more than 70 % of pupils claimed some interest in science and technology (S&T) topics (Fig. 15.1), but there were clear and significant gender and regional differences. Overall, boys were more likely to give a positive answer ($M=3.02$, $SD=0.78$) than girls ($M=2.76$, $SD=0.77$). Running an inferential statistical analysis of the data showed that gender differences in pupil interest in S&T were statistically significant, $t(7744)=14.80$, $p<.001$, yet the effect size was moderate ($d=.43$).

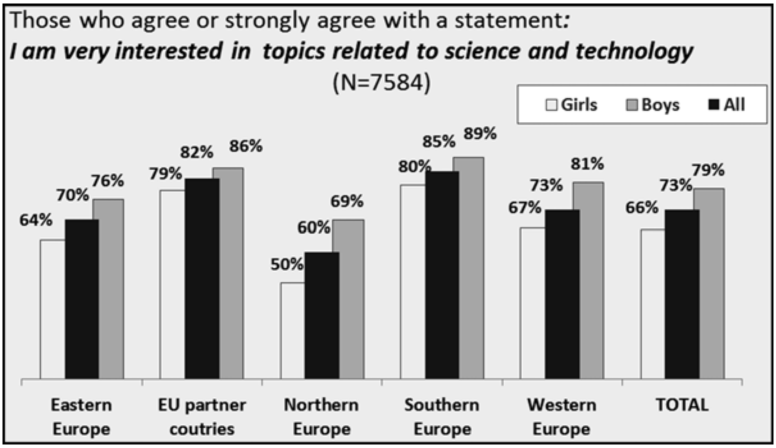

Fig. 15.1 Pupils' interest in science and technology topics

When different regions of Europe were compared, Southern European students came across as the ones with the highest levels of interest in S&T. 85 % of pupils in this region gave a positive answer ($M=3.09$, $SD=0.71$), while Northern European youngsters scored the least ($M=2.66$, $SD=0.82$) with only 60 % of youngsters showing enthusiasm for S&T. To assess the significance of a regional variable to pupil interest in S&T, we applied a one-way ANOVA test, which verified the existence of significant regional differences in how interested in S&T pupils were, $F(4,7741)=83.13$, $p<.001$ It is also noteworthy that the South European cohort had the lowest difference between genders, 9 %, while their peers in Northern Europe showed the greatest gender divide (19 %).

The same North-South divide was visible when pupils reported on their interest in S&T lessons: 66 % in the European North ($M=2.75$, $SD=0.78$) vs. 84 % in the South ($M=3.07$, $SD=0.711$) considered their S&T lessons interesting (Fig. 15.2). The importance of regional dimension for the interest in lessons reported by pupils was proven statistically significant, $F(4,7722)=48.17$, $p<.01$. To evaluate the difference between Northern and Southern cohorts, we administered a separate t-test, which showed that this difference was indeed statistically significant, $t(3001)=12.02$, $p<.001$ with a moderate effect size ($d=.42$).

Testing for gender differences, we received confirmation that gender also plays some role in the way pupils perceive their S&T lessons $t(7725)=9.61$, $p<.001$. However, the effect size for this variable was smaller ($d=.22$).

Interestingly, when we compared boys' and girls' interest in S&T lessons to their general interest in science maters, we observed a gender-related pattern of a different sort. Girls appeared to be more interested in STEM lessons ($M=2.85$, $SD=0.75$) than in S&T matters in general. Boys demonstrated an opposite trend as boys were more likely to report general interest in S&T than interest in S&T lessons ($M=3.01$,

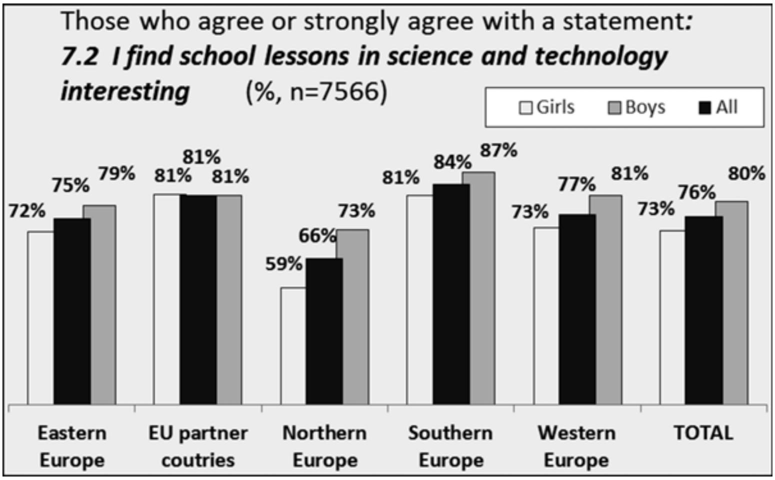

Fig. 15.2 Pupils' interest in science and technology lessons

Table 15.3 Science learning outside the classroom – comparing boys and girls across the regions

	Region	Girls	Boys	*t*-test[a]	Effect size
I learn a lot about science and technology matters outside my school lessons (by reading or watching a programme on the topic, attending science club, etc.)	Eastern Europe	$M=2.39$ $SD=.81$	$M=2.68$ $SD=.89$	8.72	$d=.38$
	Northern Europe	$M=2.23$ $SD=.80$	$M=2.60$ $SD=.84$	8.76	$d=.46$
	Southern Europe	$M=2.49$ $SD=.85$	$M=2.73$ $SD=.85$	5.3	$d=.28$
	Western Europe	$M=2.31$ $SD=.83$	$M=2.50$ $SD=.94$	4.14	$d=.23$
	EU partner countries	$M=.56$ $SD=.87$	$M=2.83$ $SD=.87$	4.79	$d=.32$
	Total	$M=2.67$ $SD=.89$	$M=2.37$ $SD=.83$	14.93	$d=.32$

[a] With $p<.01$ unless stated otherwise

$SD=0.76$). Testing the relation between general interest in S&T and interest in lessons for both genders yielded a moderate level of correlation (boys, $r=.57$, $N=3773$, $p<.001$, and girls, $r=.58$, $N=3992$, $p<.001$).

When pupils were asked about their STEM-related learning outside classroom, only 60 % of boys and 44 % of girls said they were engaging in learning about S&T outside classroom. This level of engagement in STEM is nearly 20 % lower than the level of interest in STEM registered through the two previous questions. The relationship was evidenced as statistically significant for both genders across all regions (Table 15.3), although the effect size ranged from small to medium. Reviewing the results for this question helped to reassess an overtly optimistic picture of pupil interest in STEM, which emerged from measuring pupil interest in STEM topics and STEM school lessons only.

The existence of considerable differences in the level of pupils' exposure to STEM outside the classroom is an important observation, which is in tune with the findings of the longitudinal research project ASPIRES (2013). Investigating the role of various factors in shaping pupil career aspirations, this project pointed to the key influence played by a pupil's immediate environment (like family or friends) and developed the notion of *science capital* to embody such an influence on a young person's level of interest, knowledge and understanding of science (Archer et al. 2012). The research carried within the project inGenious also showed that for many children, and especially for girls, school remains the key point of contact with STEM and consequently the main source of information about and motivation for STEM careers.

15.4.2 Views on STEM in School

Further analysis of pupils' views on their school experience of STEM subjects (Table 15.4) revealed that while pupils are more likely to consider science rather than mathematics as their favourite school subject (55 % vs. 44 %), the reverse is

Table 15.4 Views on STEM subjects in school – comparison between boys and girls

	Pupils who agree/ strongly agree with the statement					
	Girls (%)	Boys (%)	Girls	Boys	*t*-test[a]	Effect size
Lessons in science and technology are among my most favourite subjects at school	48	64	$M=2.48$ $SD=.85$	$M=2.77$ $SD=.86$	14.94	$d=.34$
I like mathematics more than most other subjects at school	40	48	$M=2.31$ $SD=.95$	$M=2.49$ $SD=.86$	8.08	$d=.21$
I think school mathematics will have practical use in my daily life	69	70	$M=2.82$ $SD=.85$	$M=2.84$ $SD=.89$	0.81 **ns**	$d=.02$
School science and technology will help me with everyday practical problems	60	66	$M=2.65$ $SD=.76$	$M=2.75$ $SD=.81$	5.73	$d=.13$

[a] With $p<.01$ unless stated otherwise

true with their views on the practical importance of school knowledge in science and mathematics (63 % vs. 70 %). This dichotomy is particularly visible for girls: only two in five girls name mathematics as their favourite subject, yet more than two thirds of them agree that they mathematics has practical importance in their life. In contrast, almost half of girls enjoy science lessons; however, only 60 % consider the knowledge they receive there as relevant to real life.

15.4.3 Social Views and Personal Relevance

The examination of pupil views on the social significance of STEM (Table 15.5) shows greater regional and gender homogeneity as well as an overall high awareness of the role the STEM sector plays at present (73 %) and will play in the future (84 %). In a similar fashion, when pupils were asked to consider their own future education and career, they attributed high importance to learning STEM (79 %).

Gender gap is reduced as more than ¾ of girls and more than $^4/_5$ of boys agreed that '*doing well in mathematics, science and technology is important for my further education and career*' and fewer than 30 % in each gender category did not think that STEM knowledge would be useful in their future. At the same time, girls showed a slightly lower self-esteem when asked to assess their personal suitability for work in this sector: 39 % of girls vs. 29 % of boys agreed with the negative statement *I do not have personal qualities and skills necessary for a career in industry, science or technology*.

Although the difference between boys' and girls' views on the role of STEM in society and in their own life were smaller than in other areas, gender was found as a statistically significant variable for all of the above statements. However, the effect size was negligible ($d<.1$).

Table 15.5 Social views on STEM and its relevance to personal future (pupils who agree/strongly agree with the statement)

	$N > 7518$	All (%)	Girls (%)	Boys (%)
Social views	Today all people, regardless of their career choices, need to learn science, mathematics and technology	73	74	73
	In the near future, our society will need more engineers, technicians and scientists	84	82	85
	Jobs in industry, science and technology can be very different, and they need people with very different personal qualities and skills	88	88	89
Vision of personal future	Doing well in mathematics, science and technology is important for my further education and career	79	76	83

15.4.4 Attitudes to STEM Jobs

While a very high number of pupils, boys and girls alike, acknowledged the importance of STEM in society and showed awareness of the diversity of STEM-related jobs with a variety of personal qualities and technical skills required, many pupils, and especially girls, did not consider STEM education/career path for themselves. Overall, boys showed more positive attitude to the prospect of having a STEM-related career ($M = 2.78$, $SD = .94$) than girls ($M = 2.43$, $SD = .87$) with this difference confirmed as statistically significant, $t(7492) = 16.26$, $p < .01$.

The comparison of pupil predispositions to STEM jobs and of their willingness to learn about job opportunities revealed stark regional differences (Fig. 15.3). Pupils in the Northern and Western parts of Europe demonstrated the lowest levels of interest in STEM careers (Northern Europe $M = 2.54$, $SD = .79$; Western Europe $M = 2.55$, $SD = .83$), while pupils in the Southern region and in the EU partner countries showed the highest level of enthusiasm (Southern Europe $M = 2.89$, $SD = .72$; EU partners $M = 2.97$, $SD = .82$). Applying ANOVA to evaluate the importance of regional variable confirmed its statistical significance, $F(4,7687) = 69.37$, $p < .01$.

The situation in the North is exacerbated by a vast gender gap. Only 28 % of girls in Northern Europe indicated that they would like a job related to S&T, pushing the mean score for this group to the lowest level, $M = 2.1$, $SD = .84$. In contrast, the number of boys, who answered positively to this question, was almost twice as much (51 %), and the mean score for this group was .47 points higher, $M = 2.57$, $SD = .93$. On the other side of the spectrum were pupils from Turkey and Israel (the EU partner group) with 60 % of girls ($M = 2.7$, $SD = .97$) and 70 % of boys ($M = 2.96$, $SD = .97$) indicating their positive dispositions towards STEM jobs.

When pupils were queried on their attitude to learning about STEM-related jobs, more pupils across the regions, and especially more girls, said they like receiving information about careers (Fig. 15.4). Comparing to their current career aspirations,

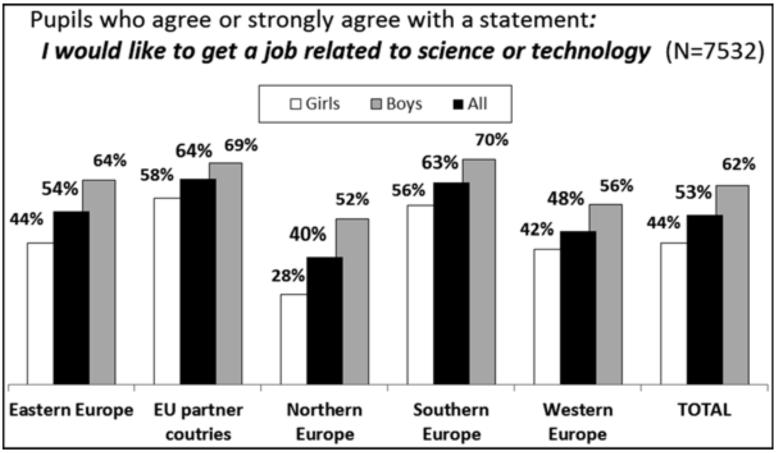

Fig. 15.3 Pupils' interest in getting a job related to science or technology

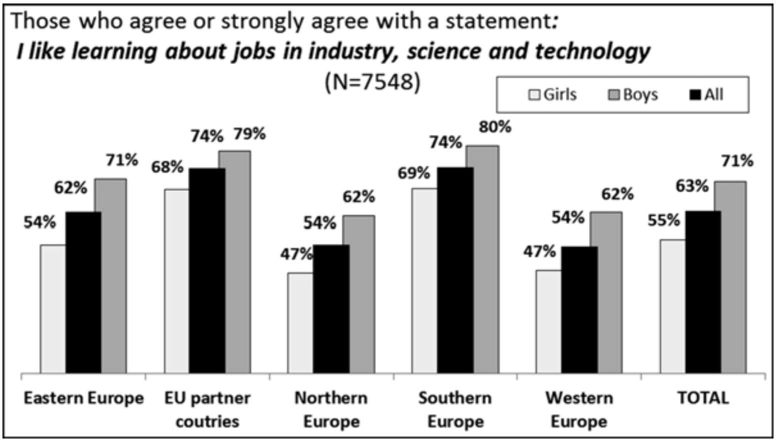

Fig. 15.4 Interest in learning about jobs in industry, science and technology

the mean score on this question was higher for both genders (boys $M=2.86$, $SD=.80$; girls $M=2.58$, $SD=.79$). Once again, the difference between boys and girls was statistically significant, $t(7705)=15.27$, $p<.01$, so was the difference between regions, $F(4,7702)=76.90$, $p<.01$.

Interestingly, in Northern Europe, the percentage of girls who were interested in learning about STEM jobs was almost double on the share of girls who displayed an existing interest in such a career. Comparing to the group mean score for the previous question, the North European girls' average for interest in learning about careers was .3 points higher, $M=2.41$, $SD=.76$, and was closer to the overall girls' mean for this question, $M=2.58$, $SD=.78$.

Overall, the data in Figs. 15.3 and 15.4 hints of a serious problem with the quality of career information and a lack of career advice in some schools across Europe.

15.4.5 What Helps to Foster STEM Career Choices?

In this study we also examined the relationship between variables that describe pupils' attitudes and views and tried to determine factors most helpful in explaining pupils' positive dispositions to STEM careers.

The first connection to explore was the link between career inclinations and a general interest in STEM subjects. Checking for the linear relationship between these variables revealed a moderate level of correlation ($r = .57$, $p < .01$), and performing a linear regression showed that interest in STEM was a significant predictor of pupil career aspirations, $\beta = .6$, t (7674) = 60.89, $p = 0$, explaining 33 % of the observed variance, $R^2 = 33$, $F(1,7678) = 3707.85$, $p < .01$.

To explore the relationship further, we collapsed the four-point scale to a binary one (*disagree* vs. *agree*) for both questions and then looked at their cross-tabulated results (Table 15.6).

Such data representation confirmed the link between interest in S&T and interest in STEM careers, but it also showed that this relation was nonlinear. On the one hand, nine out of ten pupils who agreed with a statement 'I would like to get a job related to science or technology' also said they were interested in S&T topics. On the other hand, in the cohort of pupils with *no interest* in STEM jobs, almost half of the respondents, and this number is 58 % for boys, nevertheless stated their general interest in S&T matters. Overall, the cross-tabulated data indicated that having an interest in STEM topics was not enough for generating an interest in STEM careers and that it was *a necessary but not sufficient condition* for selecting a STEM-related career path.

Looking at the inferential statistics for these groups of pupils gave support to our assertion that interest in S&T is important and statistically significant in explaining differences in pupil predisposition towards STEM careers, t (7676) = 50.14, $p < 0.01$.

Table 15.6 Cross-tabulation of interest in STEM careers and interest in a job related to STEM

			I am very interested in topics related to science and technology	
$N = 7184$			Disagree (%)	Agree (%)
I would like to get a job related to science or technology	Disagree	Girls	53	47
		Boys	42	58
		All	49	51
	Agree	Girls	9	91
		Boys	7	93
		All	8	92

The average career aspiration score of pupils who stated no interest in S&T matters was much lower, $M = 2.47$ SD = .74, than the group average of pupils with an interest in S&T, $M = 3.26$ $SD = .63$.

As mentioned earlier, the data obtained from the analysis of individual questions related to STEM jobs (i.e. 'I'd like to get a job…' and 'I like learning about jobs…') was suggestive of the likely role school experiences and classroom practices play in shaping personal dispositions on STEM careers. To examine this relationship further, we investigated the relationship between the following statements:

- At school I learn about different career choices available in industry, science and technology.
- I would like to get a job related to science and technology.

Testing for correlation showed that the variables were in a positive and statistically significant, yet relatively weak, relation ($r = .27$, $p < .01$). However when we collapsed the scale to a binary one and investigated the cross-tabulated results, the relationship was more evident. Indeed, this showed that adding the element of career learning to school STEM education could lead to a 20 % increase in the number of pupils positively considering a career in STEM (Fig. 15.5).

Comparing group averages and testing for the significance of group differences gave further support to the idea that when pupils are provided with information and advice on STEM careers, their aspirations towards such careers will increase (Table 15.7).

Overall, classroom practices that contextualise information on STEM jobs should be beneficial to all pupils. Yet, for those who generally like S&T, but who have not yet decided what career to choose, such information could be particularly useful in helping to relate theoretical knowledge to their own experience and to sway their career choice towards STEM.

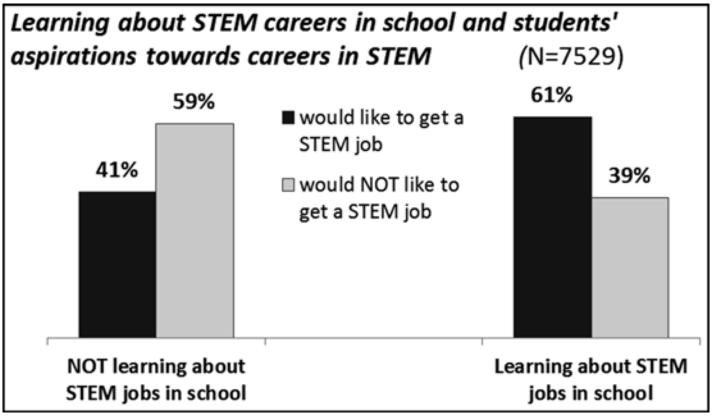

Fig. 15.5 STEM career aspirations of pupils who recall learning about STEM careers in school compared to students who say they do not learn about STEM careers in school

Table 15.7 Comparison of career aspirations of pupils who say they receive career information in school and those who do not recall learning about STEM careers

	‘At school I learn about different career choices available in industry, science and technology’			
	Pupils who strongly disagree/ disagree	Pupils who strongly agree/agree	*t*-test[a]	Effect size
Girls	$M=2.18$ $SD=.88$	$M=2.59$ $SD=.93$	13.70	$d=.46$
Boys	$M=2.52$ $SD=.95$	$M=2.92$ $SD=.89$	12.8	$d=.45$
All pupils	$M=2.34$ $SD=.93$	$M=2.76$ $SD=.93$	19.42	$d=.46$

[a]With $p<.01$ unless stated otherwise

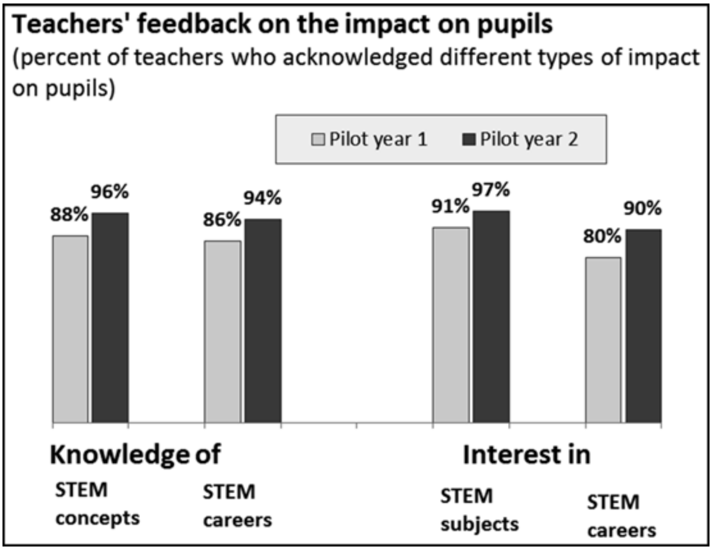

Fig. 15.6 Teachers’ feedback on the impact on pupils

The feedback collected from participating teachers gave additional support to this finding (Fig. 15.6).

In addition, there is some anecdotal evidence that when done properly (e.g. by bringing motivational role models), career information and advice can themselves generate or boost interest in the subject and improve pupils’ attainment and progress.

15.5 Conclusions and Implications

Career choice is a complex phenomenon, where multiple personal, cultural and socio-economic factors interplay (Cleaves 2005) and no single answer could be found to reverse a declining trend. Some of these factors, like family cultural and socio-economic background captured in the notion of ‘science capital’, are very important, but not easily changeable. On the other hand, school experience, the way science is taught in classroom and beyond, could make a difference across social boundaries and is a factor that could be improved more rapidly. Our research shows that just making science lessons interesting or informing pupils about social significance of STEM is not enough to sway young people towards STEM careers. While a majority of pupils see science lessons as ‘fun’ and agree that STEM is very important for society and useful qualifications to have, many, especially girls, do not identify with STEM careers. On the other side, when information about the modern state of STEM jobs and real-life applications is blended in with STEM education in a meaningful way for young people, it can trigger important changes in career choices. The direct contact between pupils and industry fostered by such projects as inGenious goes along these exact lines.

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Chapter 16
Which Answering Strategies Do Low Achievers Use to Solve PISA Science Items?

Florence Le Hebel, Pascale Montpied, and Andrée Tiberghien

16.1 Introduction

The Program for International Student Assessment (PISA http://www.pisa.oecd.org) has been carried out every 3 years since 1997 to assess to what degree 15-year-old students near the end of compulsory education have acquired the knowledge and skills that are essential for full participation in society. In all PISA cycles, the domains of reading and mathematical and scientific literacy are covered not merely in terms of mastery of the school curriculum, but in terms of the knowledge and skills needed in adult life. Scientific literacy is the major domain in PISA 2006 and in the next PISA 2015. There were no new science items in PISA 2009 and 2012. In 2015, for the sake of comparison, part of the PISA science items will be similar to those of PISA 2006. At any rate, the new items will have quite similar formats and types of situations, even if in PISA 2015 the assessment will be done on a computer and no longer with pencil and paper. PISA data can exert a profound impact on science education policies by providing information on the school systems of participating countries. It could also lead to the development of research projects on secondary analysis of PISA results (see overview in Le Hebel et al. 2014).

In France, PISA science 2006 globally indicated average scores (OECD 2007). French results are characterized by a rather high proportion (compared to the OECD average) of students in difficulty at level 1 (meaning that "students have such limited knowledge that they are only able to apply them in a very small number of familiar

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situations") or below level 1 (meaning that "students are not able to use scientific knowledge to understand and do the easiest PISA tasks"). This result leads us to focus our research on the population of low achievers in France who would have weak PISA science scores.

In our previous studies, we concluded that the competencies should be refined to evaluate the scientific literacy competencies, in particular for low-achieving students, because we are not actually able to evaluate exactly what low achievers are capable of doing or not (Le Hebel et al. 2012, 2014). We observed that low achievers could give the right answer without understanding the aim of the question or give a wrong answer although they partially understand the question. Therefore, in this study, we have decided to focus on low achievers' answering strategies while they answer PISA items. Our aim is to determine which strategies they use when they answer and whether it involves understanding the item.

Our study is based on observation of the students when they are constructing their answer to PISA science items and on the analysis of the diversity of the answering strategies they use.

The results should lead to a better interpretation of PISA scores and a reflection about the assessment of low achievers and their expectations when being assessed.

16.2 Theoretical Framework

When students construct their answer to PISA science items, they combine the processes of reading and understanding the questions and of solving a scientific task. Therefore, in order to reconstruct the answering strategies involved when students answer PISA items, we chose a theoretical framework linked to mental representation and aspects of behavior when solving problems or answering questions.

Many studies in mathematics education related to reading and solving mathematical tasks consider word problems (e.g., Powell et al. 2009). According to Ostehölm (2007), most of the studies seem to see a separation between the process of reading and the process of solving. Our chosen framework is based on a theoretical model which assumes that we cannot completely separate the reading and the solving tasks. In their 2010 study, Bergqvist and Osterhölm analyze connections between the process of reading and the process of solving a mathematical task, focusing on mental representation based on Kintsch's theory (1998) and the mathematics education perspective focusing on facets of behavioral aspects of task-solving based on Lithner's theory (2008).

Kintsch's theory (1998) describes the mental representation of texts by distinguishing between three different levels or components: the surface component, referring to the encoding of the words and the phrases themselves; the textbase, representing the meaning of the text, that is, the semantic structure of the text; and the last level corresponding to the associative processes linked to the reader's prior knowledge.

We already showed in previous studies that low achievers who have difficulties solving PISA items do not construct a useful and relevant representation of the problem (Le Hebel et al. 2014). This has been frequently observed in other studies about problem-solving processes in mathematics (Cummins et al. 1988; Stern 1993; Hegarty et al. 1995) and in science (see review in Hoskinson et al. 2013).

The second part of the theoretical model is based on a theory developed by Lithner (2008), who divides all types of reasoning into two major categories: *imitative reasoning* (memorized reasoning, i.e., remembering a whole answer and algorithmic reasoning or in other words remembering an algorithm and calculating an answer) based on surface properties of the task and *creative reasoning*, new to the solver and flexible, based on the scientific content of the task.

The theoretical model includes a cyclic component that allows the behavioral component to affect the mental representation and not only the other way around. The first reading of the text (or a part of it) creates a mental representation that can lead the student either to get to the end of the task by giving a final answer with the activation of prior knowledge or stopping the task or to employ a strategy in a wider sense like rereading the text, choosing, recalling, constructing, discovering, or guessing (Lithner 2008).

Physics education researchers have been investigating problem solving in physics for the past three decades (Hsu et al. 2004), studying how students solve problems (Larkin et al. 1980) and exploring the role of conceptual knowledge in solving problems (Reif 2008). Hoskinson et al. (2013) propose that solving authentic, complex biology problems requires many of the same skills as in solving physics problems.

Jacobson (2001) studied the different approaches in problem solving between scientific experts in the field of complex systems and novice undergraduate students. He concluded that significant differences were found both at the conceptual level and at the level of basic epistemological presuppositions and beliefs.

Hegarty et al. (1995) compare problem-solving strategies of unsuccessful and successful problem solvers. They observe that unsuccessful problem solvers base their solution plan on numbers and keywords that they select from the problem (the direct-translation strategy), whereas successful problem solvers construct a representation of the situation described in the problem and base their solution plan on this representation (the problem-model strategy).

For the authors, the unsuccessful problem solvers looked back at parts of the problem more than successful problem solvers did, thus suggesting that they were struggling to figure out how to solve the problem. Furthermore, when successful problem solvers make errors in remembering word problems, they are more likely than unsuccessful problem solvers to remember the situation described in the problem and less likely than unsuccessful problem solvers to forget the specific relational keyword used in the problem (e.g., less or more). They conclude that this pattern is consistent with the idea that successful problem solvers are more likely to construct a meaningful representation of the situation described in the problem, base their solution plan on this representation, and thus develop a “problem-model strategy” as labeled by Hegarty et al. (1995). In contrast, unsuccessful problem solvers are more likely to reread the problem, to focus on keywords or numbers rather than on variables and meaningful relations and thus develop what the authors called a “direct-translation strategy.” Other studies show that a direct-translation strategy may be used by unsuccessful problem solvers on other problems than those presented in the Hegarty et al. (1995) study.

The direct-translation strategy is in line with the result that some students are less successful than others at differentiating relevant from irrelevant information in word problems (e.g., Littlefield and Rieser 1993).

In their study, Hegarty et al. (1995) used relatively simple and familiar types of tasks, so it can be assumed that the better achieving students used a *memorized reasoning*, as determined by Lithner (2008), because they probably had knowledge of specific methods for solving these kinds of tasks.

In our study, some tasks in PISA require *creative reasoning* as labeled by Lithner (2008). Furthermore, the external representations (graphs, schedules, etc.) proposed in PISA items can influence students’ achievements, depending on whether or not these external representations are different from those available during the teaching. Authors like Ainsworth and Th Loizou (2003) (Schnotz and Kürschner 2007) show that the format of representations can influence the effects on metacognitive learning strategies. Some tasks using one kind of representation are more difficult to perform after having learned another kind of representation during the teaching.

The aim of our research combining the analysis of students’ mental and behavioral processes is to answer the following questions:

– Which answering strategies do low achievers use when they construct their answer to PISA items? In what way do low achievers’ strategies differ from those of high achievers? Do these strategies depend on the competencies that the items evaluate?

16.3 Procedure

In order to study the students’ answering strategies when they construct their answer to PISA science items, we proceeded in two steps: first we carried out an *a priori* analysis of PISA units, and secondly we analyzed data collected when students construct their answers. As this study continues in the same vein as our previous research, we refer the reader to our previous publications (Le Hebel et al. 2014) for more details about the procedure. The PISA main assessment consists of a series of units. Each unit has an introduction with a leading text and possibly photos, drawings, or diagrams presenting a situation followed by a series of questions called items (an example of an introduction and one item is given in Fig. 16.1).

In summary, we selected 23 relevant items from 10 PISA science 2006 units, based on different criteria: the diversity of scientific knowledge required for the item (knowledge of science or knowledge about science), the different scientific domains tested, the usefulness or not of the introduction, the question format, the competency evaluated, and the scores obtained in France compared to OECD average scores.

CLOTHES

Read the text and answer the questions that follow.

A team of British scientists is developing "intelligent" clothes that will give disabled children the power of "speech". Children wearing waistcoats made of a unique electrotextile, linked to a speech synthesiser, will be able to make themselves understood simply by tapping on the touch-sensitive material.

The material is made up of normal cloth and an ingenious mesh of carbon-impregnated fibres that can conduct electricity. When pressure is applied to the fabric, the pattern of signals that passes through the conducting fibres is altered and a computer chip can work out where the cloth has been touched. It then can trigger whatever electronic device is attached to it, which could be no bigger than two boxes of matches.

"The smart bit is in how we weave the fabric and how we send signals through it – and we can weave it into existing fabric designs so you cannot see it's in there," says one of the scientists.

Without being damaged, the material can be washed, wrapped around objects or scrunched up. The scientist also claims it can be mass-produced cheaply.

Source: Steve Farrer, 'Interactive fabric promises a material gift of the garb', *The Australian*, 10 August 1998.

Question 1: CLOTHES (S213Q01)
Can these claims made in the article be tested through scientific investigation in the laboratory?

Circle either "Yes" or "No" for each.

The material can be	**Can the claim be tested through scientific investigation in the laboratory?**
washed without being damaged.	Yes/No
wrapped around objects without being damaged.	Yes/No
scrunched up without being damaged.	Yes/No
mass-produced cheaply	Yes/No

The correct answers are (in order) Yes, Yes, Yes and No.

Question 2: CLOTHES (S213Q02)
Which piece of laboratory equipment would be among the equipment you would need to check that the fabric is conducting electricity?
A Voltmeter B Light box C Micrometer D Sound meter

The correct answer is A.

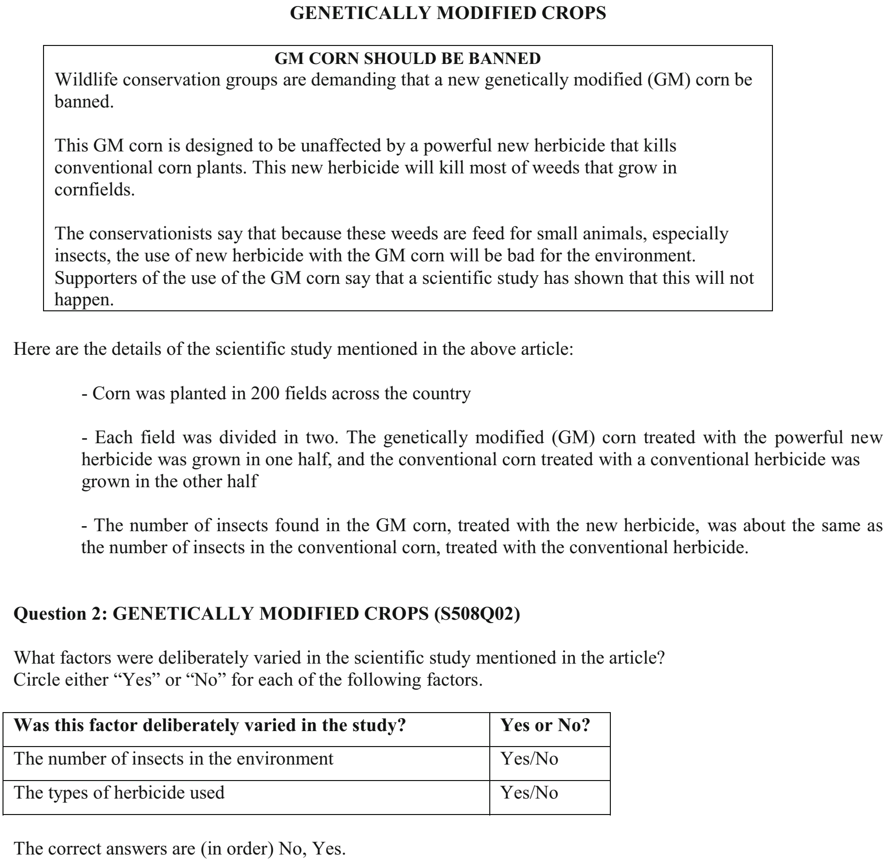
Fig. 16.1 Example of Pisa Science 2006 item – clothes

The second step consisted of an analysis of answering processes taken from students' oral and written data when they construct their answer. The students were videotaped working in pairs, which allowed us to analyze their verbal and gestural productions when they are reading the text and solving the task. We proceeded to "explicitation interviews" (Vermesch and Maurel 1997) immediately after the written test, where we asked the students to clarify the thinking processes they used to answer the questions. Transana software (http://www.transana.org) was used to analyze the videotapes. We collected audio-taped and/or videotaped data from 9 sets of 15-year-old students who answered the questionnaire in pairs and 3 students who answered individually. In other words, 12 written questionnaires were collected. Seven students were from grade level 10, attending a suburban upper secondary school displaying social diversity and were high level achievers. Fourteen students were from grade 9 in middle secondary school (as in France students can repeat a class). These 14 students came from two schools situated in a disadvantaged neighborhood and were low-level students.

All students (21) had the same 23 items from 10 PISA units in their questionnaire. Data were analyzed by three different researchers, who conferred to obtain a common analysis in the case of different interpretations.

16.4 Data Analysis

We analyzed the answering processes of the 21 students for the 23 selected items. We present our method of analysis for items of two released units (Figs. 16.1 and 16.2) to show how we proceeded. Unfortunately we are not able to present other items, because they are confidential.



GENETICALLY MODIFIED CROPS

GM CORN SHOULD BE BANNED

Wildlife conservation groups are demanding that a new genetically modified (GM) corn be banned.

This GM corn is designed to be unaffected by a powerful new herbicide that kills conventional corn plants. This new herbicide will kill most of weeds that grow in cornfields.

The conservationists say that because these weeds are feed for small animals, especially insects, the use of new herbicide with the GM corn will be bad for the environment. Supporters of the use of the GM corn say that a scientific study has shown that this will not happen.

Here are the details of the scientific study mentioned in the above article:

- Corn was planted in 200 fields across the country
- Each field was divided in two. The genetically modified (GM) corn treated with the powerful new herbicide was grown in one half, and the conventional corn treated with a conventional herbicide was grown in the other half
- The number of insects found in the GM corn, treated with the new herbicide, was about the same as the number of insects in the conventional corn, treated with the conventional herbicide.

Question 2: GENETICALLY MODIFIED CROPS (S508Q02)

What factors were deliberately varied in the scientific study mentioned in the article?
Circle either “Yes” or “No” for each of the following factors.

Was this factor deliberately varied in the study?	**Yes or No?**
The number of insects in the environment	Yes/No
The types of herbicide used	Yes/No

The correct answers are (in order) No, Yes.

Fig. 16.2 Example of Pisa Science 2006 item – genetically modified crops

The first example is the item coded S213Q01 from the released unit clothes (Fig. 16.1). It is a complex multiple choice question. The competency tested in this item according to PISA is "recognizing questions that are possible to investigate scientifically." For this item, the students need to make connections between the information in the introduction and the propositions in the item. They need to be able to grasp what a scientific investigation is and that an economic analysis is not a scientific investigation.

Scores obtained for this item in OECD countries and in France show a PISA level of difficulty of 4 (48 % give the right answer in OECD countries and similarly in France). Most low achievers from our sample did not answer this item correctly. They globally fail on the 4th proposition "the material can be mass produced cheaply," for which they tick "yes." We illustrate the answering strategy they used with the example of the exchange from a pair of low achievers St14/St15, who ticked "yes" to the four propositions. In this excerpt, students check each proposition: "washed without being damaged," "wrapped around objects without being damaged," "scrunched up without being damaged," and "mass produced cheaply":

St14 So, these claims made in the article reported above.
St15 Yes, it said so.
St14 Can they be tested through a, yes, er, yes?
St15 Yes, it said so.
St14 Either yes or no, no they cannot be washed without being, without being, ah, OK, OK, OK, that's right.
St15 No, but it's written here. It says so
(St15 shows the leading text).
St14 No, but that's right, so.
St15 Wait, without being damaged, the material can be washed, wrapped around objects, or scrunched up
(St15 reads aloud this sentence from the text of the leading text).
St14 Yeah.
St15 Cheaply, it means, er, not expensive? Doesn't it? I think so…
St14 Yeah.
St15 So it is cheap.
St14 Yeah.

As in this excerpt, the students match the words from the text of the leading text with the words of the four propositions included in the item. They do not understand the aim of the question, which is whether the four claims made in the article can be tested through scientific investigation. Instead, they transform it into: "is the proposition right or not." The following interview confirms this matching strategy:

R So, how did you proceed for this question?
St 14 here, I picked the answers from the texts.
St 15 Yeah.
R So you came back to the text?
St14 Yeah.

R To answer all of this.

St 15 Last paragraph.

R Last paragraph, can you, can you tell me exactly?

St14 So washed without being damaged, it is written here

(St14 shows the text of the unit introduction and reads the text)

St14 "Without being damaged, the material can be washed"; the scientists claim that it can be produced, er.

St15 Wrapped, wrapped around objects.

St14 Wrapped around objects, scrunched up. The scientist also claims it can be mass produced cheaply.

This answering strategy of transforming the question's aim and combining it with the matching words can be observed with other items with low achievers. When they transform the aim of the question, their strategy becomes more relevant. In this example, if the question becomes "are the propositions right or wrong," their answers are correct.

Our second example is the item coded S213Q02 in the same "clothes" unit. It is a multiple choice question. According to PISA, the competency tested is "explaining phenomena scientifically." The right answer is A (voltmeter). This item shows high scores in OECD countries (79.4 %) and in France (81.1 %). Most of our students, even low-achieving students, give the right answer. High achievers know that the voltmeter is related to electricity, and they answer directly in a few seconds, and most of time, low achievers proceed by elimination of the other propositions, as illustrated below with the reported exchange between students 8 and 9:

St8 Which piece of laboratory equipment would be among the equipment you would need to check that the fabric is…

St9 A voltmeter, no?

St8 Wait.

St9 Yes, the volt!

St8 Wait.

St9 When you compare with a pullover.

St8 Wait, wait!

(St8 goes back to the item introduction)

St9 Do you think it says so?

St8 Certainly not.

St9 When we check electricity, a voltmeter! We can proceed by elimination: a sound meter, it's for sound.

St8 Yes.

St9 Micrometer.

St8 I do not know. Light box, I don't know.

St9 I would say voltmeter. Voltmeter is stuff with volts, isn't it?

St8 Yeah.

St9 When you move your pullover, imagine, it makes electricity, when you rub it.

St8 Yeah, maybe…

In this exchange, even if students cannot immediately find the right answer, St9 made a link between "the volt" and electricity. To convince St8, he tries to proceed by elimination. Although they do not know the meaning of light box and micrometer, they finally chose the right answer, "voltmeter."

The last example is the item coded S508Q02 from the released unit genetically modified crops (Fig. 16.2).

The competency tested according to PISA is "recognizing the key features of a scientific investigation." It is a complex multiple choice question. Scores obtained for this item in OECD countries and in France show a PISA level of difficulty of 2 (61 % give the right answer in OECD countries and 72 % in France). Low achievers from our sample did not succeed, and their PISA credit for this item is null, meaning that their answer is considered wrong. They frequently answer the first proposition correctly: "The number of insects in the environment was a factor which was deliberately varied in the study." We illustrate one type of answering strategy we observed among low achievers with the example of the exchange from the pair of students St8/St9. To the question "Was this factor deliberately varied in the study?" they respectively ticked "yes" to the first proposition "the number of insects in the environment" and "no" to the second proposition "the types of herbicide used."

(Student 8 first reads the item aloud and then they try to answer)

St8 So, the number of insects in the environment…look *(St8 goes back to the item introduction)* especially insects, the use of the new GM corn will be bad for the environment. So the number of insects in the environment…did they talk a lot about the type of herbicides used?…No, they did not talk about it.

St9 Er, the number of insects in the environment, er.

St8 So yes, because they talk about it…

(St 8 reads aloud)

St8 Was this factor deliberately varied in the study? So, this factor, they talked about insects, so yes. And I think the type of herbicide used.

St9 No, they did not vary them.

St8 No, they only talked once about it, so no.

St9 Er, yes. They made it vary, er, wait, no.

St8 But they talked. They talked only once about it! If it was varied, they would have said…I don't know…they would have mentioned another herbicide!

The students take into account the importance of an idea in the leading text. For them, the more certain words are mentioned in the text, the more important the idea is, and so this idea would most likely be the answer. They look for the frequency of some words in the leading text and the proposed answers. They made a type of quantitative word matching which, for them, underlines the emphasis of the idea. They transformed the question into "what is the most important factor." They consider that what is the most frequently expressed in the text must be the most important and a key to the solution. This is a stereotypical strategy that may have been shown to work in some cases in class, but it fails to proceed to the cognitive process required for the construction of a mental model.

The following interview confirms this answering strategy:

R So, what factors were deliberately varied in the scientific study mentioned in the article: the number of insects in the environment? The types of herbicides used? And you answer yes for the first, and no the second, so could you explain how you proceeded?

St9 Er…

St8 Because they were talking a lot about the insects in the environment, because they mentioned in the text that the conservationists say that because these weeds are food for small animals, especially insects, the use of the new herbicide with the GM corn will be bad for the environment. So we thought that they were talking a lot about the insects in the environment because it is important, because if we use that and that insects die because of that…er…I think it is more important than the types of the herbicide used, so that's it.

R So, actually between the two factors that were proposed, you chose the most important?

St8 Yes.

These three examples illustrate how we use data from both the video of students' solving actions and then that of students' explanations of those actions to describe different answering strategies displayed by the low achievers while they treat a question and transform it.

16.5 The Observed Answering Strategies Developed by Low Achievers While Solving PISA Items

We observed that low achievers frequently give an answer (right or wrong) using different strategies without understanding the question, as illustrated in the three examples above.

As shown above in the first example (item S213Q01), low achievers can focus on certain words or groups of words in the question or leading text and try to match these keywords with the propositions. A variation of this strategy can be observed for some items, as illustrated in the third example (item S508Q02). Students focus on the "quantitative frequency" of an idea in the unit leading text. Sometimes the format and the wording of the question do not permit them to find a simple short cut strategy, and as they do not construct a problem model, they find themselves in difficulty and so they transform the question in order to be able to answer it. They are not always conscious of using this type of subterfuge. However, choosing at random can sometimes be their strategy in multiple choice items. We also frequently observed that to make their choice among the propositions, low achievers can associate action verbs in the question and the possible answers. For instance, they associate "cooling" and "reducing" or "decreasing" and "evaporate," which is consistent with the fact that their apprehension of the text remains superficial.

All the above strategies echo other studies in mathematics education research (e.g., Hegarty et al. 1995), in which it is concluded that unsuccessful problem solvers base their solution plan on keywords that they select from the problem and fail to construct a model of the whole situation described in the problem, basing their solution plan on this model.

These strategies of matching words or groups of words in the unit's leading text and the propositions, or associating action verbs, are observed in multiple choice items. These answering strategies can lead to the right answer (for instance, S476Q03 or S268Q01), but it can just as easily lead to the wrong answers (for instance, S213Q01). In the case of open answers, we observed how low achievers who do not have a mental representation of the item's goal can build a sentence with a grammatical routine integrating words and formulations picked out from the unit's leading text and/or core question. The answer they construct is not linked to the question, but to elements of the situation described in the leading text; however, it sometimes makes no sense at all, and the students do not stop to check that it does.

As we showed in our previous study (Le Hebel et al. 2012, 2014), low achievers have difficulty in constructing relevant and stable representations of the unit and item aims. Sometimes they initiate a reflection on a vague representation which appears in only one or two utterances and which is not evoked again while they discuss the answer. They replace it immediately with another unstable representation and so on.

In terms of the *didactic contract*, defined as the reciprocal expectations of the teacher and the students, these expectations can be specific to the taught knowledge (Brousseau 1982). In the situations that we observed, it is very likely that low achiever students do not expect to solve some kinds of questions that are asked in PISA. For instance, in the examples illustrated above (S213Q01 and S508Q02) and other unreleased PISA items, in which this kind of question is asked: "Which of the following pieces of research is it most likely that the scientists were investigating?" or "Can these claims made in the article questions be tested through scientific investigation in the laboratory?" or "What factors were deliberately varied in the scientific study mentioned in the article?" – we observe that low achievers are not able to identify themselves with scientists or to build an abstract representation of what scientific questioning may mean in the situation proposed.

Moreover, we observed that most of the time, for questions requiring a more creative reasoning defined by Lithner (2008) as new to the solver, flexible, and based on the scientific content of the task, low achievers are not aware that they have to construct or mobilize a new element of knowledge. When they read the question, they are not able to identify the gap between the initial state and the expected final aim of the task. They are not aware of what is expected of them in order to solve the task. For Hegarty et al. (1995) if low achievers use the direct-translation strategy so much, it means that this shortcut strategy is effective for many of the word problems they are asked to solve. Similarly, we can hypothesize that the kind of task in science requiring a more *creative reasoning*, as in PISA, is not so usual in science teaching in French schools and that low achievers try to apply rules and use the strategies which they had already found to be successful.

As Hegarty et al. (1995) mentioned in their study, we observed that low achievers go back more often to the leading text than the high achievers. However, some PISA items require the information from the leading text in order to solve them, and others are totally independent from the leading text content. We analyzed whether low achievers go back to the leading text even if it is of no use in solving the item.

For instance, for the item labeled S213Q02, illustrated above, to answer the question "which piece of laboratory equipment would be among the equipment you would need to check that the fabric is conducting electricity," we do not need to read the unit leading text. It does not supply any information that could help students choose between the four propositions. Low achievers from our study did not go back to the leading text, except one pair of students (St8/St9), who quickly understood that it is of no help. Low achievers focused on the four propositions (voltmeter, light box, micrometer, sound meter) and proceeded by elimination. They finally made a link between "the volt" and electricity.

In Table 16.1, we report for each pair of students whether they go back to the leading text or not in the case of items independent from the unit leading text (13 out of 30). Students 1 to 6 are high achievers, and students 8 to 19 are low achievers. We observed that for the majority of items except S213Q01 (probably because the four propositions have a similar formulation to the last sentence of the leading text), low achievers mostly do not go back to the leading text. They seem to be aware that they will not get any useful information for solving the item from the leading text. They have the beginning of a correct answering strategy. However, PISA assessment of low achievers does not enable us to assess which parts of the task low achievers are effectively able to solve. This is in line with our previous studies (Le Hebel et al. 2014), for which we concluded that PISA competencies should be refined in order to evaluate the scientific literacy competencies for low achievers.

Finally, we observed that low achievers are limited to only a few stereotypical strategies, related to the lack of or the low stability of the representation they build from the leading text and core questions of the items. In addition, they often show a lack of knowledge, a limitation in their vocabulary as well as difficulty in staying concentrated and motivated. In contrast, high achievers diversify their answering strategies as they adjust them to the mental model and metacognitive processing, monitoring their understanding of the text in relation to the question goal. The reading process of the text and question is accompanied by a self-explanation permitting them to identify the gap between the initial situation and the final goal. They understand that the question can be dissociated from the leading text and that they may need to import some knowledge in order to solve the item. Even if their answer is wrong, they understand the aim of the item. They are able to go further in the discussion about the item and to project their results further (discussion about the consequence of an experiment for instance), even if it is not required in the question.

Low achievers' answering strategies are linked to the question format (open answer, multiple choice, etc.). However, we could not find any relation between the answering strategy employed by low achievers and item competency.

Table 16.1 Data showing if students go back or not to the leading text while solving PISA item for items with high independence between the leading text content and the item

	St1/St2	St3/St4	St5/St6	St8/St9	St10/St11	St12/St13	St14/St15	St16/St17	St18/St19
S213Q01	Ninc	Ninc	Ninc	Y	Nans	N	Y	Y	Y
S213Q02	Ninc	Ninc	Ninc	Y^1	Nans	N	N	N	N
S268Q01	N	N	N	N	Nans	Nans	N	N	N
S268Q06	N	N	N	Y^1	Nans	Nans	N	N	N
S408Q01	N	N	N	N	N	N	N	N	Y
S408Q05	N	N	N	N	N	N	N	N	N
S426Q03	N	N	N	Y	Nans	N	N	N	N
S476Q03	N	N	Nans	N	Nans	N	N	N	N
S485Q02	N	N	Nans	Nans	Nans	Nans	N	N	N
S495Q01	N	N	N	Y	N	N	N	N	Y
S495Q02	N	N	N	N	N	N	N	N	N
S495Q03	N	N	N	Y^2	N	Nans	Nans	N	N
S498Q04	N	N	N	N	Nans	Nans	N	N	N

N students do not go back to the leading text, *Y* students go back to the leading text, Y^1 students go back to the leading text, but they understand it will not be useful, Y^2 students go back to the previous item, *Nans* students do not give any answer, *Ninc* the question is not included in the questionnaire for these students

16.6 Conclusion, Implications, and Perspectives

In conclusion, we observe that low achievers have difficulty in constructing relevant and stable representations of PISA unit and item goals. They often employ few stereotypical answering strategies, mostly with a very low understanding of the unit and item aims, when they construct their answer. Most of the time they are unaware that they transform the question in order to be able to answer it. Some of these strategies bring to mind certain strategies already identified in mathematics education, such as the "direct-translation strategy" for example. We observed that in terms of didactic contract, low achievers do not expect to solve some kinds of tasks from PISA: for instance, when they are asked to identify themselves as scientists or experts. Contrary to high achievers, they are not aware of what they have to supply to solve the task. We believe that if they make use of answering strategies without understanding the question's aim as they show in our study, it is because they have already experienced them successfully in class when they managed to solve certain science tasks or in other disciplines such as mathematics. Thus, maybe a first step in comprehension strategy learning would be to present low achievers science tasks for which "direct-translation strategy" does not lead to a correct answer.

Nevertheless, we observed that low achievers can employ the beginning of correct strategies. They are able to identify when the leading text is necessary or not and to go back to the leading text to get information to answer the question. Unfortunately, PISA assessment does not allow us to evaluate the competencies employed by low achievers.

This study could help science teachers to become aware of low achievers' problem-solving strategies and to adapt their teaching in order to improve said problem-solving strategies. They could help low achievers to monitor their own strategies and to block the "low-cost" and shortcut cognitive habits developed in a school system where long texts complemented by diagrams or context-rich problems are not frequently used as learning resources. Increasing self-assessment capacities in the teaching of the sciences and supplying tools or teaching material for a self-explanatory process of scientific texts (again, complemented by diagrams or context-rich problems) are certainly important aspects that French schools need to emphasize. Ainsworth and Burcham (2007) show that such self-explanatory processes, if used and performed as the students read the texts of biology or physics, augment their learning.

Moreover, our research could be of interest to science teachers dealing with student assessment and in particular for low achievers. As we observed, low achievers, in spite of large difficulties, are able to grasp the beginning of correct strategies, and it could be important that teachers identify and assess these strategies.

In our future research, in order to continue this work, we propose to ask low achievers to solve some PISA science 2015 items for which we will have previously provided some available assistance that they can use if they get stuck. The aim is to assess as precisely as possible the effective competencies employed by low achievers while solving PISA science items.

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Chapter 17
Teaching Material to Introduce Students with Hearing Loss to Scientific Reasoning and Working: A Contribution to the Development of Inclusive Chemistry Education

Adejoke Adesokan and Christiane S. Reiners

17.1 Rationale

In recent years, the idea of inclusive education has evolved into a significant topic in school classes around the world. The origin of this current development is the *Convention on the Rights of Persons with Disabilities*, which was published by the United Nations (2006) and ratified by the German Federal Government in 2009. According to paragraph 24, the main purpose of the convention with regard to education is to create a school system where every student is welcomed and supported with the help of appropriate forms of teaching and learning. So far, questions about dealing with diversity and heterogeneity in science education arose from the fundamental belief that every individual is different and from growing pluralism in German school classes due to migration (Tajmel and Starl 2009). In order to meet the challenges of inclusion education, differentiated knowledge on the students' learning preconditions and learning difficulties is demanded to create appropriate learning environments in science classes (Stefanich et al. 2001). Up to now, very few studies and concepts exist, which address teaching science to students with special needs as well as teaching science in inclusive learning environments (Markic and Abels 2014). Some findings suggest that science education seems to be particularly suitable for inclusive learning environments due to the opportunity of hands-on activities like experiments, options for visualization as well as group learning activities (McGinnis and Stefanich 2007). Introducing students to scientific reasoning and working is undoubtedly one of the main goals in teaching science. Therefore, these topics are incorporated into both national and international educational

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standards in the range of epistemological competence (Standing Conference of the Ministry of Education and Cultural Affairs of the Länder in the Federal Republic of Germany 2005, National Research Council 1996; American Association for the Advancement of Science 1993). In terms of scientific reasoning and working and epistemological competence, formulating hypotheses and questions, doing experiments, reporting on experiments as well as using models to explain scientific phenomena are competences to be acquired in chemistry lessons. Furthermore, the knowledge of the students in this area can also contribute to the acquisition of scientific literacy, which serves as a guiding concept in science education all over the globe (Organisation for Economic Co-operation and Development 2006). However, what specific learning difficulties special needs students may have in chemistry and what teaching material can be used as a support have not been examined sufficiently. As there is a strong need for research on this topic, this project aims to make a contribution to this current debate. Since this topic is understudied in chemistry education research, the study focuses exemplarily on DHH students to receive detailed and specific information on a certain target group. This paper describes part of a qualitative research project, which aims to develop teaching material to introduce DHH students to scientific reasoning and working. The innovative aspect of the teaching material is that it is adapted for the needs of special education students and is also expected to contribute to the development of inclusive learning environments. Since students with hearing loss are rarely represented in inclusive education so far (Federal Ministry of Education and Research 2014), this project was carried out in schools for the deaf and hard of hearing. In respect of the increasing requirements placed on teachers in inclusive settings, information on the effect or influence of the special needs on teaching and learning chemistry and insights into the creation of learning environments in special needs schools, the gained knowledge can be further developed and thus can contribute to inclusive education. The outcome of the project will be used to make recommendations for inclusive teacher education (e.g. Fig. 17.1).

The project, which is divided into three phases, is highly connected to teaching practice and its practitioners. In the first phase, difficulties of DHH students in chemistry classes were detected, and the general framework in schools for the deaf and hard of hearing was analysed. Based on the results of the first phase, teaching material to support students with hearing loss in chemistry classes was developed with the help of experienced special needs teachers in the second phase of the research project. Finally, the support programme was evaluated in schools for the deaf and hard of hearing in the third phase. For the purpose of this paper, we focus on challenges that DHH students in chemistry classes face and the introduction of the support programme (phases I and II). The evaluation of the support programme, which was subject to the third phase of the project, will not be presented in this paper.

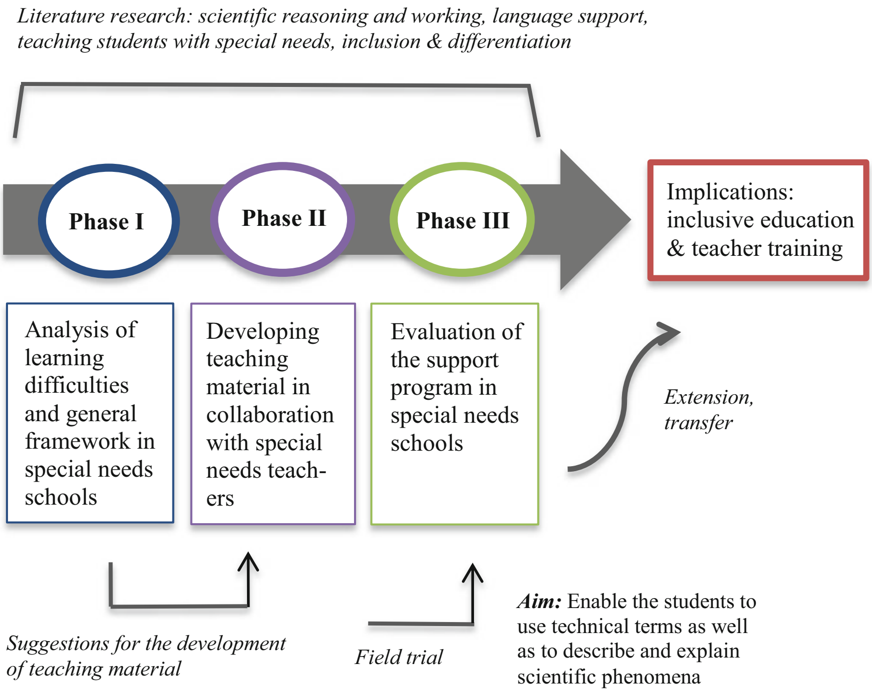

Fig. 17.1 Project overview

17.2 Guiding Questions and Research Methods (Phase I)

In order to approach this fairly unexplored topic in science education research, the formulation of widespread guiding questions was regarded as reasonable. In the first phase of the project (e.g. Fig. 17.1), subject-specific challenges of students with hearing loss were analysed; framework conditions of schools for the deaf and hard of hearing were detected as well as applied strategies and tools in teaching and learning chemistry. The survey was concerned with the following guiding questions:

- *What is the general framework in schools for the deaf and hard of hearing like?*
- *What are the special needs of DHH students in chemistry classes?*
- *What teaching material do special needs teachers in schools for the deaf and hard of hearing use in chemistry?*
- *What do special needs teachers recommend for the development of teaching material to support DHH students in chemistry?*

The research concerning the framework conditions in schools for the deaf and hard of hearing included a description of the student body (e.g. status of hearing,

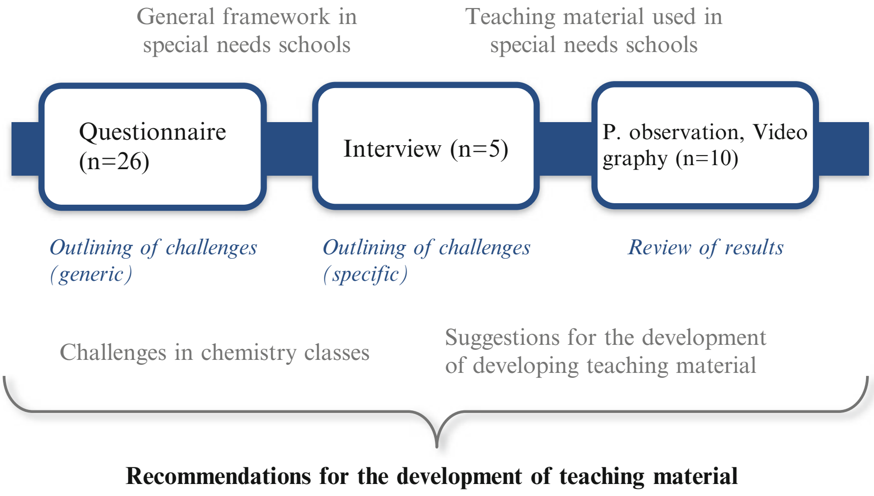

Fig. 17.2 Design of study (phase I)

applied forms of communication, composition of the class, additional special needs of students with hearing loss), evaluation of laboratory equipment as well as training of teachers. The aim of the first phase was to structure the unexplored topic in order to derive development objectives and to formulate research questions. In order to answer the guiding questions, a qualitative and explorative study with a three-step approach was designed (e.g. Fig. 17.2).

17.2.1 Questionnaire

In the first step of this study, open-ended questionnaires were used to survey special needs teachers. The survey was used to address the first two guiding questions, including the challenges of the students as well as the conditions in special needs schools. With the aim of building long-term cooperation with the teachers, the survey was sent to schools for the deaf and hard of hearing in different German states including North Rhine-Westphalia, Lower Saxony, Hesse, and Rhineland-Palatinate. The locations were chosen because they were in close geographical proximity to the authors' site. The number of chemistry teachers in schools for the deaf and hard of hearing was determined by a telephone survey beforehand. Based on the outcome, it became apparent that the number of (trained) chemistry teachers in schools for the deaf and hard of hearing is small, which was already pointed out by Wagner and Bader (2006). Due to the lack of trained chemistry teachers in schools for the deaf and hard of hearing, all teachers with teaching experience in chemistry or science were included in the sample, regardless of whether they were formally trained in these subjects. The number of questionnaires ($n=26$) equals return rate of 65 %.

17.2.2 Interviews

To receive further information on topics addressed in the questionnaire, selected teachers ($n = 5$) who had participated in the previous survey were asked to attend in-depth interviews. Only those teachers had been invited to participate in the interviews who expressed a high interest in the study. Furthermore, the aim of the interviews was to address the third and fourth guiding question. This included information on applied teaching material in chemistry as well as proposals for the development of learning aids, which were adapted for the needs of DHH students. Based on the results of the questionnaire, an interview manual was created to process semi-structured interviews. Moreover, the interviews helped building long-term collaborations with the teachers. This collaboration was used in the second and third phase of the project to develop and evaluate the developed teaching material.

17.2.3 Videography, Participant Observation

In order to review the results of the questionnaires and interviews, videography and participant observation were applied (Flick 2009). Teachers who attended this study also participated in both questionnaire and interview survey. For this purpose, chemistry lessons ($n = 10$) in sixth and ninth grade in several schools for the deaf and hard of hearing were analysed. During the classroom observation, the actions of the students and teachers were evaluated. The purpose of the observation was to check whether the statements of the teachers (e.g. concerning the challenges of the students in chemistry lessons as well as the material and strategies they use) correspond to their teaching practice. Based on prior results, a semi-structured observation manual was created to process the observations. Since the questionnaire and interview focused on the perspective of the surveyed teachers, videography and participant observation were intended to give insights into the students' perspective as well. Furthermore, the aim of this study was to gain additional suggestions and hints for the development of a support programme to support students with hearing loss in chemistry, which was looked at in the second phase of the project.

17.2.4 Analysis

The data were analysed with the help of *qualitative content analysis* (Mayring 2002), in which the process of forming categories is guided by research questions and theory. To analyse both questionnaire and interviews, the categories were created out of the collected data. To analyse the observations, the categories were

Table 17.1 Overview of the extensive category system concerning the second guiding question

Main categories	Subcategories
Language skills	General language skills
	Technical terms
	Subject-specific sign language
Foreknowledge	Everyday life experience and knowledge
	Use of media
Communication	Communicational needs
	Communications systems
Epistemological competence	Developing hypotheses and questions
	Following experiment instructions
	Reporting on experiments
	Abstract models
	Problem-oriented thinking
Teaching staff	Chemistry teachers in special needs schools
External factors	Time
	Equipment
	Curriculum

Table 17.2 Overview of the category system concerning the second guiding question

Subcategories	Text example(s)
General language skills	'A lot of time is required to explain everyday terms as well as technical terms, didactical reduction cannot be avoided.' (L21 - Questionnaire)
Subject-specific sign language	'It is not easy to teach chemistry to deaf students […], because most of the technical terms do not exist in sign language.' (L143 – Interview)
Reporting on experiments	'Due to language difficulties, the students often need linguistic support in order to describe their observations' (L72 – Interview)
Models/abstraction	'It is difficult to teach complex matter like models due to language difficulties. It is always necessary to simplify and to visualize abstract topics.' (L173 – Questionnaire)
Teaching staff	'The problem is not the students. The problem is that we don't have enough trained chemistry teachers in special needs schools.' (L221 – Questionnaire)

determined in advance based on the developed category system of the questionnaire and interview. The categories found were divided into main categories and subcategories and are displayed in the tables (e.g. Tables 17.1 and 17.2). The items of the questionnaire, interview manual and observation manual were created by the first author. The data set was also reviewed by other researchers.

17.3 Results (Phase I)

The presentation of results in this paper focuses on the challenges of DHH students in chemistry, which addresses the second guiding question. Certainly, the results concerning the teaching material and strategies special needs teachers use as well as their proposals for the development of new material will also be taken into consideration. The results concerning the challenges of DHH students in chemistry lessons are shown in Table 17.1 and were divided into main categories and subcategories (e.g. Table 17.1) and bracketed in the running text. Relevant text examples for each category are shown in Table 17.2 (e.g. Table 17.2).

According to the teachers' statements, students with hearing loss are often faced with challenges with respect to language as well as the acquisition of scientific reasoning and working. Their language difficulties become especially apparent, when it comes to reading, text apprehension and vocabulary (general language skills). These problems often lead to a limited ability to adopt new technical terms in chemistry into their active vocabulary (technical terms). From the point of view of the surveyed teachers, reading skills and lexicon of DHH students are rarely age appropriate but necessary to understand scientific texts. Therefore, fewer technical terms to avoid linguistic overload and the modification of scientific texts are requested. Moreover, most of the terms used in science to describe and explain phenomena are not represented in German Sign Language (GSL), which represents a major challenge for students with sign language as their first language (subject-specific sign language). The absence of subject-specific sign language was already pointed out in a study by Lang et al. (2006) in terms of American Sign Language (ASL). Since most sign languages follow a specific pattern concerning word formation, similar results are expected and shown with regard to GSL (Schmitt-Sody and Kometz 2012), although GSL and ASL are completely different languages. A number of studies indicate that low linguistic skills often lead to lower achievements in science learning in general (Wellington and Osborne 2001). When it comes to students with hearing loss, there are special linguistic challenges. Depending on the time of the occurrence and the degree of the hearing loss, the loss of perception can have a huge impact on the acquisition of vocabulary, writing and speaking skills, which can affect learning in chemistry. Furthermore, a hearing loss can also lead to a limited access to everyday information and a lack of general experience (everyday life experience and general knowledge). Depending on the degree of hearing loss, information from media like television, radio, as well as newspaper cannot be used to an extent that is compared to the use students with sound hearing organ (use of media). As a result, DHH students often have lower level of subject-specific knowledge. According to the teachers, there are fewer links in terms of introducing new topics in chemistry classes. Therefore, the teachers stated that the goal in chemistry lessons in special needs schools is not only to teach topics that are incorporated in curricula, but also to increase the general knowledge of the students (e.g. Table 17.2).

The students often require linguistic support in order to form hypotheses and questions *(developing hypotheses and questions)* as well as to describe and explain scientific experiments *(reporting on experiments)*. Therefore, it cannot be assumed that DHH students are able to describe experiments linguistically on their own. Referring to the statements of the teachers, reporting on experiments takes place less often or is highly prestructured to avoid linguistic overextension. It is likely that this modified version of test protocol, which usually aims to be a learning aid, is not meeting the requirements. From the point of view of the teachers participating in the study, there are also challenges when it comes to models and other abstract topics in chemistry due to language difficulties *(abstract models)*. As a result, certain topics have to be highly simplified concerning language and content. Although difficulties in using and understanding models are general problems (Barke et al. 2011), the teachers stated that the use of simple language and visualizations like specific models and drawings is even more important in teaching DHH students. Another key component is the lack of (trained) chemistry teachers in special needs schools, which was mentioned by the teachers. Most of them participated in certificate chemistry courses, and others were autodidactic (chemistry teachers in special needs schools). In addition, most schools for the deaf and hard of hearing in Germany neither have a specific curriculum nor sufficient material that is adapted for the needs of special needs students. Therefore, teachers have to follow the standards of mainstream schools, which often fail to succeed (curriculum). For that reason, teachers have to adapt the material and textbooks, as many materials are not appropriate for special needs schools. Accordingly, the teachers explicitly requested new material, which is adapted for the needs of DHH students.

17.4 Research Questions (Phase II)

The current study revealed a number of aspects where science education research would be necessary. As some of the presented challenges in schools for the deaf and hard of hearing were more of an organizational and structural nature (e.g. lack of trained chemistry teachers, curriculum), not all aspects can be influenced by research in chemistry education. It became apparent that in respect of DHH students, language difficulties occur, which often lead to difficulties in describing and explaining scientific phenomena, which is associated with scientific reasoning and working. Since teaching scientific reasoning and working is an essential task in chemistry, the second phase focuses on the following research questions:

How can DHH students be supported in:

1. *Using technical language*
2. *Describing*
3. *Explaining experiments also by using models*

In order to answer these research questions, a support programme was developed in the second phase of the project. Since the quality of lessons is not only influenced by innovative tools and material but also by the teachers' competence (Hattie 2013), the non-specialist teachers should benefit from the developed teaching material as well and, therefore, were included in the process of developing the material. The methodological approach to the development and the support programme itself will be discussed in the following section.

17.5 Development of the Support Programme (Phase II)

After the completion of the first phase of the project, teaching material to support the students in using technical terms as well as to describe and explain scientific phenomena was developed. The process of developing the support programme was based on participatory action research (PAR) and was supported by special needs teachers (Kemmis and McTaggart 2007). The starting point of the cooperation with the teachers was the interview survey in the first phase of the project (e.g. Fig. 17.2). Teachers were asked about the material they use as well as for proposals for the creation of new material during the first phase. Based on the interviews, meeting and talks took place on a regular basis. Despite the fact that the teachers were not formally trained in chemistry, their teaching experiences in special needs schools and their initial experiences in inclusive learning environments were beneficial for the collaboration. The research method aims to strive for collaboration between researcher and teachers to improve teaching and learning. Following the concept of PAR, new concepts can be modified and evaluated in learning groups in an iterative process (e.g. Fig. 17.3).

In a first step of PAR, a draft of the support programme was developed, and the chemistry lessons were planned with the help of the special needs teachers ('plan'). As a second step, the draft was tested in chemistry lessons in schools for the deaf and hard of hearing. The chemistry lessons were held by the cooperating teacher, while the lessons were observed by the researcher (or by the first author) ('act and observe'). In a third step of PAR, reflective discussions took place between teachers

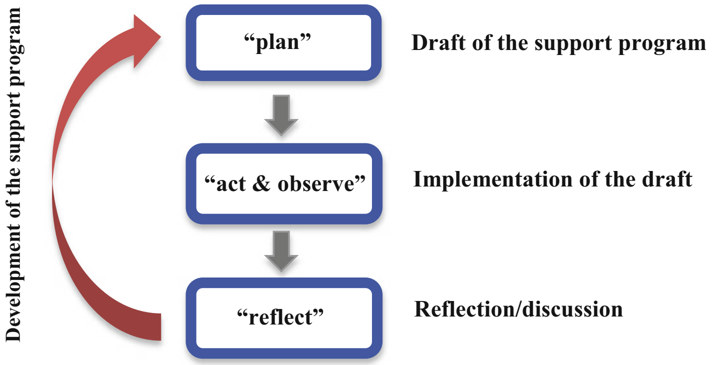

Fig. 17.3 Process of PAR to develop the support programme (Kemmis and McTaggart 2007)

and researcher ('reflect'). Based on the results of the discussion, the support programme was improved and tested in the following cycle of PAR. The cycles were repeated until satisfactory results were achieved. After a first draft of the support programme was developed and pilot tested, the assessment of additional teachers was used to modify and optimize the material. For this purpose, a short questionnaire, worksheets and instructions for the use of the material were sent to schools for the deaf and hard of hearing. The teachers ($n = 15$) were asked about the practicability of the support programme, and they were also asked about ideas for improvement. The questionnaires were analysed in the same way as the questionnaires in the first phase of the project (e.g. Sect. 14.2.4). General information as well as theoretical substantiation of the support programme will be described in the following.

17.5.1 Information About the Support Programme

The support programme was created based on the 'solution concept' for introductory class in chemistry. During the teaching unit, which lasted roughly six weeks, the students created solutions from sugar and water or salt and water, respectively, and used separation processes to get the source material back. Since creating test protocols is an important aspect of scientific reasoning and working, the students were asked to report on experiments and were assisted in doing so. Initially, the description of the solution process took place on the macroscopic level. In order to deepen the understanding of the students, the submicroscopic level was introduced as well. The interpretation of the experiments was grounded on the basic concept 'matter-particle relationship' (Schecker and Parchmann 2007). Since the students were not familiar with the particle model, they were not expected to deduce the model on their own. Thus, the particle model was introduced with the help of the teachers. Based on the outcome of PAR, visualization, language support and structuring were found as important principles. Therefore, the principles were used to introduce DHH students to scientific reasoning and working.

17.5.2 Visualization

Due to anthropological preconditions of students with hearing loss, other sense organs and alternative ways of communication are needed to support the students' learning processes (Marschark and Hauser 2008). Thus, not only written language was used to report on experiments. In contrast to the usual form in which experiments are documented, drawings were added to describe the experiments. In this case, drawings and images were used for a variety of purposes such as visualizing tasks, reporting experiments and as a diagnosis tool. As example for visualizing tasks, a graphic designer was appointed to visualize the experiment instructions of the experiments by creating images. According to the special needs teachers, this is especially valuable for students with lower reading skills, so that they can derive the tasks from the images. Furthermore, the students describe and explain their observations of the conducted experiments graphically on both macro- and submicroscopic level. Moreover, the drawings of the students allow the teachers to identify misconceptions and concepts of the students, which was pointed out by Prechtl (2011) before considering chemistry photostories. It must be assumed that the potential of the drawings as an instrument of diagnosis in this case is similar to the tool stated by Prechtl. But most importantly, drawing allows students with low linguistic skills to participate in discourses about scientific phenomena. In the view of scientific literacy being a guiding concept in science teaching, the acquisition of visual literacy (Vasquez et al. 2010) is also requested. Visual literacy describes the ability to gain knowledge and information from visual presentations such as images, figures and graphics. Therefore, it is necessary to support the acquisition of these abilities in chemistry as well. To contribute to the acquisition of visual literacy, a graphic designer created pictograms relating to scientific working and reasoning. The pictograms refer to key terms like assumptions, material, conducting, observing and explaining experiments. It is expected that through the use of visual representation and written language, the terms are best recognized and remembered. With the help of alternative forms of communication, the transition from observation to interpretation was supported as well. On the one hand, the students create drawings from their observation, which correspond to descriptions on the macroscopic level. On the other hand, the students explain their concept of the phenomena by creating concrete models from modelling clay. Additionally, the descriptions were retransferred to submicroscopic level in an additional task (e.g. Fig. 17.4).

17.5.3 Language Support

In science lessons, different types of language difficulties may occur. As there is a need for language support on the part of the students (e.g. Table 17.1), articles on the subject of language teaching were included into the theoretical framework of the study. Especially articles with a focus on students with German as a second language were considered (Tajmel and Starl 2009), and they turned out to be particularly valuable for this study. Although the cause of language difficulties is completely different, some similarities between second language learners and students with hearing loss do exist. This may be the case for (profoundly) deaf students with GSL as their first language, which among others distinctly differs in terms of grammar from the German language (Leuninger and Happ 2005). According to the teachers, reporting on experiments poses a challenge for DHH students due to linguistic difficulties. Therefore, language support was realized in the support programme including different exercise formats in the worksheets in terms of scaffolding (Gibbons 2002). Scaffolding describes a help system which offers learning aids at the beginning, and later the help is narrowed, and the goal is to reach the 'zone of

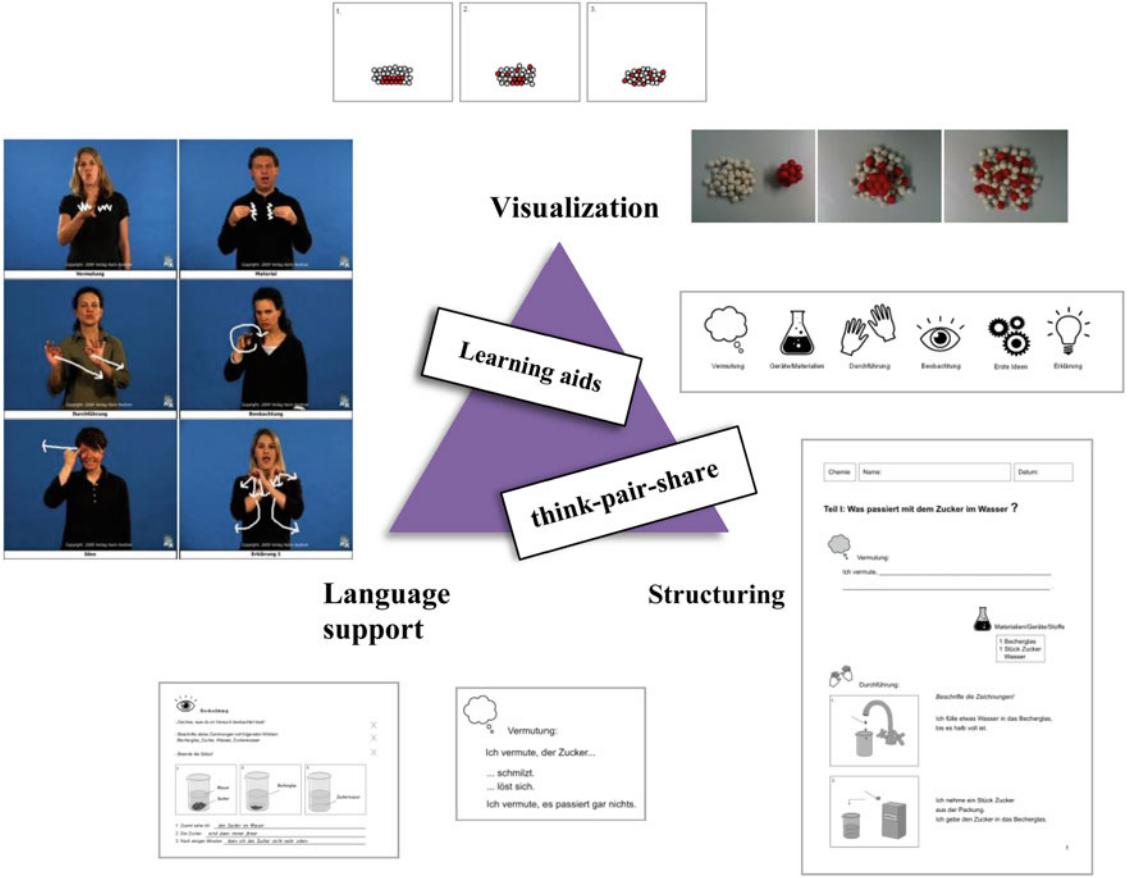

Fig. 17.4 Overview of the support programme

proximal development' (Vygotsky 1978). Therefore, more structured formats were chosen at the beginning of the teaching unit, whereas towards the end less structured formats were applied. For example, fill-in-the-blank texts and suggestion of sentences were used. It would be desirable that the students acquire typical linguistic structures used in test protocols with the help of the exercises. In order to apply the technical terms, one task was to label the drawings and images in the worksheets. Technical terms were introduced successively to avoid linguistic overextensions. Word cards and objects like laboratory equipment were used. Furthermore, the pictograms were supplemented by technical terms of a German Sign Language dictionary by Kestner (2009) like assumption, material, doing experiments, observing and results to address language support in GSL as well (e.g. Fig. 17.4). As there are very few technical terms in the GSL dictionary, new signs were invented, e.g. to introduce the terms of laboratory equipment. The introduction of more abstract terms like 'solution' was differentiated from the term 'heterogeneous mixtures of material', which was already known. To support students with low reading skills, the visualized instructions of the experiments, which were mentioned before, are supplemented by descriptions using plain language, which aims at supporting people with learning difficulties. The guidelines of plain language include instructions on sentence structure, font, font size and text form (Inclusion Europe 2009). These recommendations did not only correspond with the proposals of the teachers, but were included as compensations for any disadvantages students with special needs might have. Those were specified for final examinations (Standing Conference of the Ministry of Education and Cultural Affairs of the Länder in the Federal Republic of Germany 2011). For example, students with hearing loss get worksheets with modified language and an extended work time.

17.5.4 Structuring

In view of the diagnosed learning difficulties of the students, the teachers and researcher assumed that the students would have been overexerted in respect of introducing scientific working and reasoning in terms of 'open inquiry' independently. For this reason, a structured version of scientific working and reasoning in the sense of 'structured inquiry' was chosen (Blanchard et al. 2010). In order to introduce the students to scientific reasoning and working, questions and data collection methods were given; describing and explaining of observations were left to the students. This form of structuring is highly recommended for science classes in primary schools and a means to support underachieving students in working more independently (Windt et al. 2014). However, it is desirable to lead the students to less structured forms of scientific working later on. The structured form merely plays the role of a scaffold. Besides, based on the outcome of several studies (e.g. Organisation for Economic Co-operation and Development 2007), underachieving students are more likely to benefit from structured learning environments compared to less structured learning environments; this form of scientific working was chosen as a first introduction. However, it would be desirable to introduce the students to open forms of scientific working and reasoning (guided or open inquiry) at a future date, so that ‘structured inquiry’ functions as a scaffold. As mentioned in the previous section, pictograms were created to visualize an example of scientific working. Not only did the pictograms serve as visualization but also to structure the learning process of the students. Although the students may have limited reading skills, they understand and recognize the assignments based on the pictograms. To support the students in creating the drawings, three spaces were provided in the worksheets to describe observations respectively interpretations (e.g. Fig. 17.4). The reason for this instruction is the assumption of the teachers that the students might create less elaborated drawings, if there is no further indication on the comprehensiveness of the drawings.

17.5.5 Additional Learning Aids

Since the students did not use worksheets with different requirements, which were applied as a form of internal differentiation initially, this option was no longer considered. Instead, learning aids, which can be used optionally, were provided to enable the students to work independently. The learning aids did not only include hints to build on previous knowledge, they also contained solutions to review the results independently (Stäudel and Franke-Braun 2008). According to the teachers, the availability of differentiation tools was especially important, since special needs classes are very often highly diverse. For example, students with additional special needs (e.g. learning and behavioural problems), students with German as a second language and high-achieving students with mild disabilities were educated together. To provide additional support, the overall process of the support programme was embedded in the cooperative learning technique ‘think-pair-share’ (Lyman 1981) to support collaborative learning of students with different preconditions. This measure, which is concise and clearly structured, is not only recommended to introduce new subject matter with the help of different classroom formats; it can be applied to support language and communication skills, which is an important development objective in every special needs school.

17.6 Overall Summary and Perspectives

The main research goal of this project was to identify challenges of DHH students in chemistry and to develop teaching materials that were adapted for their educational needs (e.g. Fig. 17.4). Since the students struggle in using technical terms, describing and explaining scientific experiments, the support programme aims to address and support these skills in view of learning about scientific reasoning and working. To meet the educational needs of DHH students, principles like visualization, language support and structuring were discovered to play a decisive role. In the third phase, the support programme was successfully evaluated in classes of DHH students (*n* = 23) over a six-week period. The success of the support programme was predominantly measured by analysing the students' work results (*n* = 92) based on specific criteria, which were balanced by the results of the students' self-assessment as well as external assessment by the teachers. Lastly, the teachers were asked for feedback in a final questionnaire. As the evaluation of the support programme in an inclusive setting was not part of the project, this could be the focus of further studies. However, it is likely that students without specific special needs or students with German as second language would benefit from special attention on visualization, language support and structuring to support the use of technical language and to describe and explain scientific phenomena in an inclusive setting as well. Considering that future teachers have to be prepared for teaching in inclusive settings, specific seminars in chemistry education will be included into the teacher training at the University of Cologne based on the results of the present project.

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Chapter 18

From General Science Teaching to Discipline-Specific Science Teaching: Physics Instruction and Students' Subject-Related Interest Levels During the Transition from Primary to Secondary School

Lena Mareike Walper*, Katharina Pollmeier*, Kim Lange, Thilo Kleickmann, and Kornelia Möller

18.1 General Framework and Conditions of Science Teaching in the Transition from Primary to Secondary School

The transition from primary to secondary school is a defining characteristic of the German education system (Koch 2008). After having finished fourth grade of primary school, German students transfer – depending on their prior achievement – to one of several different tracks of secondary school. Students with the lowest

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*Both authors contributed equally to this research article and share main authorship.

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achievement usually transfer to the ‘Hauptschule’, a kind of basic general education comprising 6 years of schooling, subsequently called ‘lower secondary school’. Students with the highest achievement usually transfer to the ‘Gymnasium’, subsequently called ‘grammar school’. This track provides an intensified general education comprising 8 to 9 years of schooling and prepares students for university.

Irrespective of the particular track of secondary school, the (former) primary school children face significant changes in the structure of science teaching, by the time they enter the new schools. The subject of general science, which encompasses natural sciences and social studies at the primary school level, does not retain its original form. A closer look at the science component of the German school curriculum shows that there is a preponderance of combined sciences taught at grades 5 and 6 (students aged 11–12), or an integrated single science subject. In the following year, however, science is separated into different subject disciplines (Möller 2014). In accordance with the changes to the pedagogical framework, corresponding changes in the form of the science teaching and in the professional background of the teaching personnel are also in evidence. Primary school teaching staff is normally only generally educated in science. They usually have limited content knowledge of individual scientific disciplines and a more school-oriented approach to the field, whereas science teaching staff at secondary schools tends to be more subject specialists with a stronger content knowledge of their discipline, but with less overall pedagogical interest (Gess-Newsome 1999; Harlen 1992; Möller 2014).

The study presented herein examines a) to what extent students perceive these changes in instructional quality when moving from primary to secondary science education and b) to what extent the students’ interest levels in science change during that period. Since it has been firmly established that, in particular, the students’ interest in physics declines at the secondary school stage (Daniels 2008; Hoffmann et al. 1998), this study concentrated on the area of physics-related teaching.

18.2 The Change in Science Teaching Associated with the Transition from Primary to Secondary School

In the research of science education, constructivist theories are considered as important for both teaching and learning and are also often cited in the promotion of performance-related and motivational goals (Treagust and Duit 2008; Wandersee et al. 1994). In this regard, there is a particular focus on the discussion of theoretical learning approaches to so-called ‘conceptual change theories’, on theories of situated cognition and on social-constructivist approaches, which promote an understanding of learning as an active social and contextual construction process (Gerstenmaier and Mandl 1995; Reinmann-Rothmeier and Mandl 1998; Treagust and Duit 2008). Scientific learning, which aims at theoretical and practical knowledge, should create possibilities for restructuring prior knowledge (Treagust and Duit 2008), for the use and acquisition of concepts from real-life immediate and meaningful contexts (Stark 2003), for a joint exchange and analysis of assumptions and explanations (Mietzel

2007) and for an accessible and clear language in the teaching (Wagenschein 1992). Earlier findings (Bredderman 1983) indicated that hands-on activities, such as self-executed experiments, should by themselves contribute to motivational target areas. Current investigations suggest that such activities should be combined with reflective processes in order to produce a positive effect on motivational learner outcomes (Holstermann et al. 2010; Jocz et al. 2014; Potvin and Hasni 2014).

So far, there have been relatively few studies covering science or physics-related teaching with respect to the characteristics identified here; longitudinal studies focusing on the transition from primary school to secondary school have been missing entirely. Overall, German and international studies show that hands-on activities are used relatively frequently in primary schools, whereas teaching aimed at developing understanding through questioning is less common. Furthermore, children are encouraged towards their own research and discovery, whereas taking notes from the board is a more marginalised activity (Gais and Möller 2006; Logan and Skamp 2008; Rennie et al. 2001). For secondary school education, there is evidence that instruction is often more teacher centred, which leaves only limited space for independent learning. Experiments often take the form of demonstrations, whereas real-life or application-specific references play a lesser role in secondary school teaching (Danaia et al. 2013; Reyer et al. 2004; Seidel et al. 2007). Moreover, with regard to students' perceptions of physics teaching at the secondary school stage, there are signs of gender differences. Labudde and Pfluger (1999) found that boys perceive more subject relevance to their daily lives than girls do. The same applies to students' perception of 'teaching for understanding' within science instruction (Reyer et al. 2004).

18.3 The Change in Levels of Interest in Science Associated with the Transition from Primary to Secondary School

In accordance with the educational concept of *scientific literacy*, science teaching should not only build up discipline-specific knowledge but also aim to generate positive motivational orientations (OECD 2006). In this respect, Prenzel (2000) argues that a scientifically literate person should at least have a slightly pronounced interest in terms of open-mindedness towards science. Although a deep, pronounced interest in science is thereby not regarded as absolutely necessary, it is considered as pedagogically desirable (Prenzel 2000).

In terms of the 'person-object theory of interest', the concept of 'interest' refers to a special relationship between a person and an object (Krapp and Prenzel 2011). This relationship is characterised by a high subjective evaluation of the object of interest (value-related valences). Furthermore, it implies that the person has positive emotional experiences while engaging with the object (feeling-related valences; Krapp and Prenzel 2011). Additionally, it is assumed that an enduring interest leads to a broad knowledge of the object and is characterised by the desire to learn more about it (cognitive-epistemic component; Krapp and Prenzel 2011). Such a deeply anchored and relatively permanent individual interest can be contrasted with the situational interest, a state, which is mainly caused by external stimuli. In the context of school, these stimuli can be identified in the arrangement of the learning environment, for example (Krapp and Prenzel 2011).

Although much emphasis has been placed on the importance of building up science-related interests, it has also been established that the students' average interest levels in science and school science undergo a significant decline during the secondary school phase (e.g. Barmby et al. 2008; Daniels 2008; Hoffmann et al. 1998; Hutchinson et al. 2009). A large body of research referring to the students' 'attitudes' (a construct closely related to the students' interest levels) towards science and school science seems to confirm this downward trend (e.g. Barmby et al. 2008; George 2006; Gottfried et al. 2001; Reid and Skryabina 2002; Sorge 2007). As for the UK, the findings of the current ASPIRES project indicate that British students continue to enjoy their science lessons in secondary schools and still hold positive attitudes towards school science by the ages of 12 to 13 (DeWitt et al. 2014). However, German studies suggest that the students' interests in science – as far as the discipline physics is concerned – decline at the secondary school stage (Daniels 2008; Hoffmann et al. 1998). Physics-related interests show the steepest decline immediately after the introduction of subject-specific physics teaching (Hoffmann et al. 1998). In addition, girls already manifest a lower general interest level in physics at the very start of the secondary school education (Hoffmann et al. 1998). Furthermore, they are less likely to continue with physics when it is no longer compulsory (Mujtaba and Reiss 2014).

In contrast to the findings identified at the secondary level, findings of the representative school studies of IGLU-E, TIMSS 2007 and TIMSS 2011 indicate that German fourth grade students have a relatively positive attitude towards general science lessons and consider the content as meaningful and relevant (Kleickmann et al. 2012; Prenzel et al. 2003; Wittwer et al. 2008). In addition, IGLU-E suggests that primary school students are curious and open-minded towards selected science topics ('Animals and Plants', 'Experimenting and Methods of Investigating') and the related scientific working methods (Prenzel et al. 2003). As for the TIMSS 2011 study, no significant gender differences were established with regard to the motivational outcomes (Brehl et al. 2012). To summarise the findings, positive motivational orientations towards the 'general science' subject with its multiple perspectives (including the natural sciences) by the end of students' primary school phase stand in contrast to the predominantly occurring problematic developments in the subsequent secondary school phase, which particularly holds for the German school system.

18.4 Research Question

The diverging findings for primary and secondary schools on the design of science teaching and the manifestation of student interest levels in the sciences cannot be completely compared and referenced to each other due to the differing nature of their subject content (general/natural sciences at the primary school level vs. natural sciences/physics at the secondary school level). However, they reveal the significance of the interface between the schools. Moreover, they invite the question whether the downward trend observed, along with the gender differences in the physics-related interest ratings of the secondary school students, could be conditioned by the perceived changes in the teaching style which accompany the switch from primary to secondary school. Since no appropriate longitudinal studies have been available in Germany so far, this research question will be examined within the context of the PLUS project.[1] In the current article, two central variables of the project will be analysed: the perception of the physics-related instruction and the development of the physics-related interest levels, each in the context of the transition from the final year of primary school (German grade 4, students aged 10) up to the third year of secondary school (German grade 7, students aged 13–14). Special emphasis is placed on the following research questions:

- How does the students' perception of the physics-related instruction change?
- How do the physics-related interest levels of the learners develop (both situational interest in physics-related instruction and individual interest in physics)?
- Are there any gender-specific differences in the students' perception of the instructional design and in the development of their physics-related interest levels?

18.5 Method

18.5.1 Overall Design and Sample

In order to answer the research questions, we used longitudinal study data from the PLUS project. The study took place in the German state of North Rhine-Westphalia and was carried out from 2008 to 2013. The participating schools were located both in rural and in urban areas and represented different geographical regions of the state. Based on an initial survey of 1,396 fourth graders in their last year of primary school (av. age 10.27 years, 46.8 % female), 568 students could be pursued through their transition into the first year of secondary school (fifth grade, av. age 11.57 years). In the sixth grade (av. age 12.61 years), 452 students continued to take part in the study and by the seventh grade (av. age 13.55 years) 443 did so. Of these 443 students, data from 348 students (46.8 % female) could be collected for each measurement time

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[1] 'PLUS' is a German abbreviation for '*P*rofessionswissen von **L**ehrkraften, naturwissenschaftlicher **U**nterricht und Zielerreichung im Übergang von der Primar- zur *S*ekundarstufe', meaning 'Students' transition from primary into secondary school – professional knowledge of teachers, science instruction and student outcomes in science'. The PLUS project was funded by the German Research Foundation (*D*eutsche *F*orschungs*g*emeinschaft, 'DFG') and is embedded within the DFG research group '*nwu* Essen' (abbreviated from the German '*N*atur*w*issenschaftlicher **U**nterricht', meaning 'science teaching').

(‘matched students’). This data mainly concerns students who made the transition to a German grammar school or to a German lower secondary school, which form the two extremes of the German school system from a performance-related perspective. The 348 students who continuously took part in the study came from 131 different secondary school classes. Compared to their classmates, the matched students did not differ much in terms of cultural capital (determined by an item on the approximate number of books at home) or the language spoken at home. However, in comparison with a representative sample for North Rhine-Westphalia that came from the 2006 Progress in International Reading Literacy Study (PIRLS), the matched PLUS students, on average, had access to more books at home (40.7 % vs. 32 % of students with >200 books at home; Stubbe et al. 2008) and spoke German at home more frequently than the comparison group (85.1 % vs. 74.6 % of students with response ‘always’; Schwippert et al. 2008). Thus, the PLUS sample must be considered as a slightly positively selected sample.

All of the questionnaires used within the longitudinal survey were completed by the end of each school year. Whereas the individual interest levels in physics could be annually surveyed, all of the instruction-related constructs (student ratings of teaching and situational interest levels) were limited to those school years in which physics-related instruction was actually given. Since German schools at secondary level are free in deciding how to schedule the number of physics lessons prescribed by law, the timetables for physics instruction differ between schools. Within the PLUS project, seven different teaching patterns were identified.

As shown in Table 18.1, these characteristic teaching patterns are strongly interrelated with the type of school the students were attending. For example, pattern 1 contains primarily lower secondary school students, since they usually took part in physics-related science instruction on a continuous, albeit limited, basis, whereas patterns 2–6 concern mainly grammar school students.

Table 18.1 Overview of the seven resulting teaching patterns

Pattern	MT1 4th year primary	MT2 1st year secondary	MT3 2nd year secondary	MT4 3rd year secondary	*N MT*	*N* students	Predominant type of secondary school
1	X	X	X	X	4	129	Lower secondary school
2	X	o	X	X	3	58	Grammar school
3	X	X	o	X	3	66	Grammar school
4	X	X	X	o	3	25	Grammar school
5	X	X	o	o	2	20	Grammar school
6	X	o	X	o	2	151	Grammar school
7	X	o	o	X	2	20	Lower secondary school

X physics teaching took place, *o* no physics teaching, *MT* measurement time

18.5.2 Analytical Method

In order to analyse the longitudinal changes in the students' ratings of their physics-related instruction and of their physics-related interests, variance analyses with repeated measurements (repeated-measures ANOVAS) were carried out. To account for gender-specific differences, a corresponding between-subjects factor was included in the analysis. Students with missing data for individual measurement times were eliminated from the respective partial analysis by means of a listwise deletion.

An important prerequisite for carrying out variance analyses with repeated measurements relates to the homogeneity of the variances and the covariances for the different measurement times. In cases where this prerequisite was not satisfied, the Huynh-Feldt correction was used.

To determine the practical relevance of statistically significant results, we calculated the effect size η^2_p*(partial eta*^{2}*)*. By taking into account Cohen's (1988) taxonomy, $\eta^2_p \approx .01/.06/.14$ is considered as small/medium/large effect (Bühner and Ziegler 2009).

18.5.3 Data Collection Instruments

The development of the data collection instruments made it necessary to consider the specific requirements of the target group. Given that the students were in the wide age range from about 10 to 14 years, the questionnaire made relatively low demands on the students' level of reading competence and on their working memory capacity.

The basic concept of the students' questionnaire for their rating of physics-related instruction was formed by the moderate-constructivist learning theories described above. On this basis, five scales were operationalised: cognitively activating students' experiments, practical activity, daily reference, student-generated explanations and lack of clarity. With the exception of the scale for practical activity (three response items), each scale of the students' questionnaire has five response items, which they could answer by using a four-level Likert scale (from 'totally disagree' to 'totally agree').

As Table 18.2 shows, the internal consistency of the test can be described as acceptable to good on the basis of Cronbach's alpha values of 0.64–0.85 for the different measurement times. The five-factor structure of the questionnaire accepted on the basis of theory could be confirmed for all measurement times through confirmatory factor analyses ($.936 \leq \text{CFI} \leq .975$, $.031 \leq \text{RMSEA} \leq .056$, $.801 \leq \text{WRMR} \leq 1.047$).

The questionnaire for the students' interests comprises questions on both the students' individual interest levels in physics and their situational interest levels in physics-related instruction. Both constructs were thereby recognised on the basis of a four-level Likert scale with the aid of five (individual interest) and six (situational interest) items, respectively. Given that the items on the situational interest refer to the immediately preceding physics-related instruction, the students should be thinking back to their last two physics topics in class. In order to identify the

Table 18.2 Scales for establishing the student ratings of physics-related instruction

Scale *Item examples*	*α* 4th year primary	*α* 1st year secondary	*α* 2nd year secondary	*α* 3rd year secondary
Cognitively activating students' experiments	.68	.79	.80	.83
We could often observe something that did surprise us				
Practical activity	.66	.82	.83	.85
We could run many experiments by ourselves				
Daily reference	.73	.79	.79	.82
Our teacher asks us again and again to give examples of our everyday-life experiences				
Student-generated explanations	.64	.77	.81	.83
Our teacher is interested in our explanations				
Lack of clarity (negatively formulated)	.64	.69	.73	.72
Our teacher often explains with foreign words we do not understand				

Table 18.3 Scales for identifying the students' individual interest levels in physics and their situational interest levels regarding physics-related instruction

Scale*Items examples*	α 4th year primary	α 1st year secondary	α 2nd year secondary	α 3rd year secondary
Individual interest level in physics	.81	.82	.85	.86
I absolutely want to learn more about these topics				
Situational interest level in physics-related instruction	.79	.86	.86	.86
I always looked forward to the lessons				

individual interest levels in physics, the students were presented with three typical themes from physics as reference points. These themes were *sound, magnetism* and *light*, as these are taught in conformity with the current curricula in North Rhine-Westphalia at both the primary school level and the secondary school level.

As reflected in Table 18.3, Cronbach's alpha coefficients for all four measurement times indicate a satisfactory-to-high reliability of the scales employed. Confirmatory factor analyses on the basis of available cross-sectional project data support the distinction between the constructs that was assumed in the theory. In addition, evidence could be found for a strong measurement invariance of both interest scales between the final year of primary school (German grade 4) and the second year of secondary school (German grade 6). This data supports the conclusion that the measurements of the constructs in primary school and in the early phase of secondary school have been conducted equivalently and can therefore be compared to each other (Kleickmann 2011; Tröbst et al. 2015).

18.6 Results

The following sections give report on the longitudinal survey results that correspond to the research questions mentioned above. At first, the findings on the students' perception of physics-related instruction are presented. As a second step, the parallel development of the students' physics-related interest levels is reported. The third research question relates to both of the two previous ones. Therefore, the gender-specific results will be considered within the two chapters which deal with the first two research questions, respectively. However, they will only be mentioned, if significant differences between boys and girls are in evidence.

Whereas the development of the individual interest levels in physics could be continuously analysed from the final year of primary school to the third year of secondary school (students of ages 10–14), the analyses of the remaining constructs were carried out separately for the students who belonged to the teaching patterns outlined above. Subsequently, result reports are given for the four most common patterns (1, 2, 3 and 6), which exhibit a sample size of at least 30 students. Due to the strong interrelations of the teaching patterns and the different types of secondary school, solely the learners of the predominant school type of each pattern have been taken into consideration within the respective analyses. Hence, it was not possible to draw statistical comparisons onto how the students' perception of their physics instruction and the students' interests in this school subject develop within the different types of secondary school. In these cases, comparisons between grammar school students and lower secondary school students can only be carried out in an approximate and descriptive manner.

18.6.1 Findings on the Students' Perception of Physics-Related Instruction

The variance analyses for the students' perception of physics-related instruction show that the 52 students who were continuously taught physics from their final year of primary school until the third year of secondary school (pattern 1) exhibit a marked decline in four of the five characteristics tested (see Fig. 18.1).

The declines are significant without exception ($p < .001$), with medium to large effects ($.10 \leq \eta^2_p \leq .29$), and appear similarly among boys and girls. Thus, when considering the between-subjects factor of *gender*, neither significant main effects ($.181 \leq p \leq .901$) nor interactions of the factors of *time* and *gender* ($.299 \leq p \leq .825$) are in evidence. Students perceive a particularly significant decline for the category of practical activity between the final year of primary school and the first year of secondary school ($\eta^2_p = .29$). By contrast, the change in the perceived clarity of the instruction ($\eta^2_p = .10$) is less pronounced, although a negative trend was likewise evidenced. The slight fall in ratings seen for 'daily references' in Fig. 18.1 does not become statistically significant ($p = .056$). Figure 18.1 indicates that the

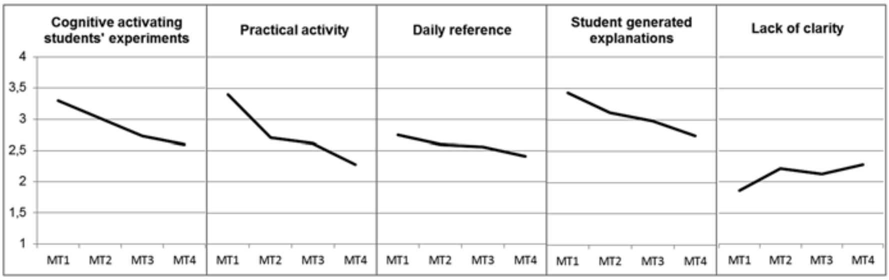

Fig. 18.1 Mean values of lower secondary school students' ratings of instruction – pattern 1 (*MT* measurement time; lack of clarity: The higher the value on this scale, the more unclear the students rate their instruction to be.)

strongest changes are observed from the final year of primary school to the first year of secondary school (i.e. grades 4 to 5) and from the second to the third year of secondary school (grades 6 to 7), respectively. Supplementary separate analyses confirm that the lower secondary school students do not manifest any significant differences in their ratings between their first and second year at secondary school ($.122 \leq p \leq .736$).

As already shown with the lower secondary school students (pattern 1), we also observe significant declines with large effects among the grammar school students (patterns 2, 3 and 6) in (almost) all scales (see Table 18.4). It is exclusively in the patterns 2 and 3 that no significant changes over the time period can be established for the scale of 'daily references', with $p = .275$ and $p = .107$. In pattern 6, similarly, there are significant changes in all scales showing a negative effect on average. Thus, learners' responses likewise show declines in their ratings over time. Throughout all patterns, the students perceive that practical activities – when compared with the other teaching characteristics – show the steepest decline over time.

When considering the between-subjects factor of *gender*, we did not observe any major effects ($.052 \leq p \leq .685$) in patterns 2 and 3. Nevertheless, there are interactions between the factors of *time* and *gender* in pattern 2 in the three scales 'cognitively activating students' experiments' (F (2, 56) = 3.157, $p = .050$, $\eta^2_p = .10$), 'student-generated explanations' (F (2, 56) = 4.016, $p = .023$; $\eta^2_p = .13$) and 'lack of clarity' (F (2, 56) = 4.331, $p = .018$, $\eta^2_p = .13$), each involving average effects. Figure 18.2 illustrates how the split between the genders for the three cases, particularly between the second and third years of secondary school (i.e. grades 6 to 7), significantly widens. During this period, girls perceive more teaching characteristics that promote understanding than boys do.

In pattern 6, we observe significant gender differences only for the scale of '*lack of clarity*' (F (1, 122) = 52.405, $p = .002$; $\eta^2_p = .08$). Accordingly, girls rate their teaching at both measurement times to be somewhat clearer than the boys do. An interaction between the two factors of *time* and *gender* is not found.

Table 18.4 Results of the variance analysis with repeated measurements for the ratings of instruction for the different patterns and subsamples

Scale	*df*	*F*	*p*	η^2_p
Pattern 2 – grammar school students, N = 30				
Cognitively activating students' experiments	2, 58	10.714	<.001	.27
Practical activity	2, 58	12.374	<.001	.30
Daily reference	2, 58	1.321	.275	.04
Student-generated explanations	2, 58	10.026	<.001	.26
Lack of clarity	2, 58	11.091	<.001	.28
Pattern 3 – grammar school students, N = 44				
Cognitively activating students' experiments	1.834, 78.876[a]	14.496	<.001	.25
Practical activity	2, 86	37.723	<.001	.47
Daily reference	2, 86	2.297	.107	.05
Student-generated explanations	1.712, 73.604[a]	8.708	<.001	.17
Lack of clarity	1.796, 77.230[a]	13.506	<.001	.24
Pattern 6 – grammar school students, N = 124				
Cognitively activating students' experiments	1, 123	31.843	<.001	.21
Practical activity	1, 123	54.802	<.001	.31
Daily reference	1, 123	11.395	<.001	.09
Student-generated explanations	1, 123	24.557	<.001	.17
Lack of clarity	1, 123	52.647	<.001	.30

[a]Adjustment for variance in accordance with Huynh-Feldt correction

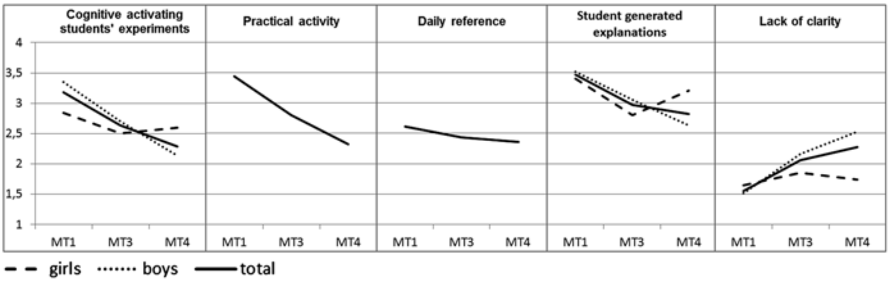

Fig. 18.2 Mean values of grammar school students' ratings of instruction – pattern 2 (*MT* measurement time)

18.6.2 Findings on the Development of Physics-Related Individual and Situational Student Interest Levels in the Transition from Primary to Secondary School

As shown in Table 18.5, the result of the variance analysis indicates that students' individual interest levels in physics undergo a significant decline between the final year of primary school and the third year of secondary school (grades 4 to 5). The

Table 18.5 Results for the two-factor variance analysis with repeated measurements and gender as between-subjects factor for the individual interest levels in physics

Source of variation	*df*	*F*	*p*	$\eta^2 p$
Individual interest levels in physics – students from all types of secondary schools, N = 327				
Measurement time (MT)	2.85, 924.69[a]	224.18	<.001	.41
Gender	1, 325	14.09	<.001	.05
MT × gender	2.85, 924.69[a]	1.451	.228	.00

[a] Adjustment for variance in accordance with Huynh-Feldt correction

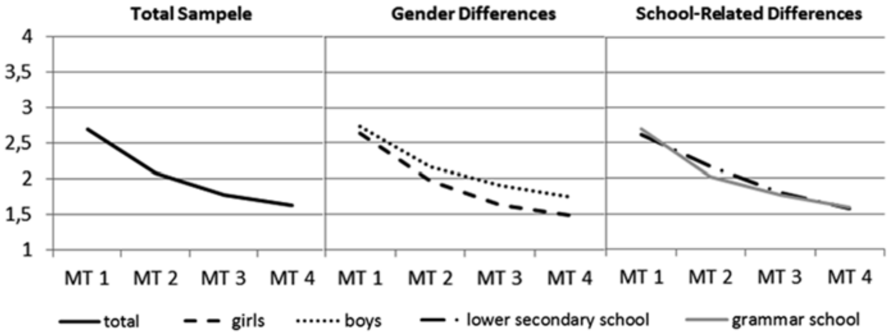

Fig. 18.3 Mean values for learners' individual interest levels in physics for the whole sample and the subgroups observed (*MT* measurement time)

effect ($\eta^2_p = .41$) observed invites the conclusion that there is a high practical relevance of the result. This finding is not only evident in the whole sample but also applies equally to students in grammar schools and in lower secondary schools. After the inclusion of the between-subjects factor for *type of secondary school* into the analysis, we see neither evidence of a significant main effect for the between-subjects factor ($p = .769$) nor an interdependency of the factors *time* and *type of secondary school* ($p = .303$). In terms of the development of their individual interest level in physics, it does not seem to matter whether the learners enter a grammar school or a lower secondary school after the primary school phase ($\eta^2_p = .00$ for the main effect and the interaction; $N = 276$*)*. By contrast, the gender of the learners has a notable, albeit small ($\eta^2_p = .05$), effect on the manifestation of the individual interest level in physics (see Fig. 18.3). In contrast to this main effect of gender, the interaction of the factors *gender* and *time* is not significant. However, the descriptive findings (see Fig. 18.3) indicate that the gender differences in the students' final year of primary school are smaller than in the subsequent years. Supplementary variance analyses for the individual measurement times confirm this impression. They provide evidence that the gender differences in the final year of primary school cannot be ranked as significant, $F\ (1, 325) = 1.753$, $p = .186$, $\eta^2_p = .01$. Beginning from the first year of secondary school, however, the individual interest levels in physics differ significantly between the genders.

Table 18.6 Results of the variance analysis with repeated measurements (and gender as between-subjects factor) for the situational interest levels in physics-related instruction for the patterns 1, 2, 3 and 6.

Source of variation	*df*	*F*	*p*	$\eta^2 p$
Pattern 1 – lower secondary school students, N = 49				
Measurement time (MT)	2.81, 132.02[a]	17.05	<.001	.27
Gender	1, 47	3.02	<.001	.06
MT x gender	2.81, 132.02[a]	2.72	.050	.06
Pattern 2 – grammar school students, N = 30				
Measurement time (MT)	2, 58	60.57	<.001	.68
Pattern 3 – grammar school students, N = 45				
Measurement time (MT)	2, 88	58.80	< .001	.57
Pattern 6 – grammar school students, N = 124				
Measurement time (MT)	1, 123	157.60	< .001	.56

[a] Adjustment for variance in accordance with Huynh-Feldt correction

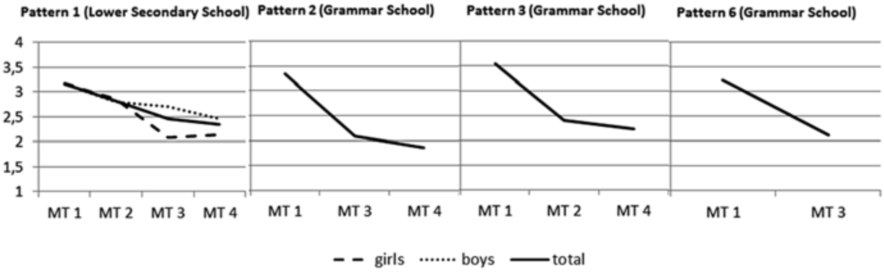

Fig. 18.4 Mean values for situational interest levels of learners in physics-related instruction for patterns 1, 2, 3 and 6 (*MT* measurement time)

A look at the situational interest levels in physics-related teaching shows evidence for a significant decline in all four patterns observed. As can be seen from Table 18.6, the declines are highly significant across all patterns. When compared with the lower secondary school students (pattern 1), an even more marked decline can be noted among the grammar school students (pattern 2, 3 and 6) for their situational interest levels between their final year of primary school and their third year of secondary school ($.56 \leq \eta^2_p \leq .68$).

Figure 18.4 further supports the conclusion that the massive slump in the situational interest levels coincides with the transition to grammar school, i.e. with the introduction of grammar school-type physics instruction. This appears to affect boys and girls to an equal extent, given that the situational interest levels do not differ significantly among the grammar school students ($.116 \leq p \leq .859$). Compared to the grammar school students, the situational interest levels of the lower secondary school students decline more slightly after the school transition. However, there are gender differences herein that can be observed after the end of the first year at secondary school. As Fig. 18.4 shows, the gap between the genders widens significantly in the second year of secondary school. In the third year, those differences in favour of the boys remain clearly visible, albeit a little diminished. This observation corresponds to the significant main and interaction effects that can be found after the inclusion of the between-subjects factor of *gender* in the analysis (see Table 18.6).

18.7 Discussion and Outlook

When combined, the findings from the longitudinal study presented herein indicate that the transition from primary school to secondary school in North Rhine-Westphalia involves a negative development in students' ratings of physics-related instruction. At the same time, there is a marked and simultaneous drop in both the learners' physics-related individual and situational interest levels. Since the PLUS sample can be described as slightly positively selected in terms of cultural capital, the downward trends may be even more pronounced in the overall student population.

Whereas the uniform decline of the students' individual interest levels could also be explained by a development-related differentiation of this long-term interest, the sharp decline of the situational interest levels after the transition to secondary school, which is particularly pronounced for grammar schools, points to a specific influence of the school learning environment. The analyses show that learners perceive a clear decline in cognitively activating students' experiments, in practical activities, in student-generated explanations as well as in the clarity of the instruction in their physics-related teaching. Against this background, the downward trend in situational interest could be connected with these pedagogical changes. Initial findings from further cross-sectionally applied investigations within the PLUS project (Tröbst et al. 2015) support this assumption. Beyond that, qualitative data from supplementary interviews with 18 children of the quantitative PLUS sample indicate that particularly the perceived difficulty of physics instruction as well as practical activities seem to play a key role for the students' interest in school science (Walper et al. 2014). Recent findings from the ASPIRES project seem to confirm these results. The study revealed that British secondary school students whose attitudes towards school science remained positive did not find science more difficult in secondary than in primary school. Moreover, the authors reported that most of the students with increasingly positive attitudes towards school science experienced either more exciting experiments or an increased number of practicals within secondary education (DeWitt et al. 2014). To further underpin these results and to identify in more detail how the changes in the learning environment influence the students' interest development, further analyses shall be carried out with the longitudinal data of the PLUS project.

When the ratings of instruction and the physics-related interest levels are compared between girls and boys, a notable finding in the data pattern emerges. Whereas lower secondary school students seem to rate their instruction almost identically, the situational interest level of the girls in their second and third years of secondary school is distinctly lower than that of the boys. At grammar schools, an opposite pattern can be observed: Here, the girls give increasingly more positive ratings than the boys for their physics instruction throughout the entire time period on the basis of the teaching characteristics identified, but the situational interest levels of the genders do not appear to differ from each other. It is possible that these seemingly paradoxical effects can be explained by the higher individual interest level of the boys. It would thus be possible that a more strongly defined prior interest in physics compensates possible weak points of the instruction, whereas the form and style of the teaching could be more significant for the girls who, on average, approach the subject with a lower initial interest level. This assumption is supported by the findings of further studies which have indicated that girls react in a more sensitive way than boys to an increase in the quality of the physics teaching (e.g. Wilhelm et al. 2012).

The presented analyses on the average development processes cannot explain the extent to which the teaching characteristics analysed herein influence the development of the students' level of interest at the individual level. More advanced analyses are planned within the PLUS project in order to pursue the question over the connection of both constructs during the transition phase from primary to secondary school at the individual level. In the course of this, the broad sample available should be better exploited with the aid of the process of multiple imputation of missing values. Furthermore, the underlying multiple-layered structure of the data (such as the nesting of the students within different classes) will be taken into consideration, which was not the case in the analyses of variance presented here.

Despite the occasionally small subsamples involved, the findings presented here underline the subject-specific significance of the transition from primary school to secondary school. Against this background, we can hope that this system-related interface will enjoy a stronger focus of attention in primary and secondary science education in the near future. Both science education researchers and (future) teaching staff should be open to issues associated with physics-related instruction at the respective adjoining school level in order to combat the obstacles more effectively than they have been able to in the past. The theme should also receive additional consideration in the education and training of teaching personnel.

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Chapter 19
Second Chance Schools in Greece: A Critical Analysis of Science Teachers' Views and Practices on Designing Scientific Literacy Curricula

Spyros Kollas and Krystallia Halkia

19.1 Introduction: The Context of Second Chance Schools

In Greece, Second Chance Schools (SCSs) were instituted in 1997 and are financially supported by the European Commission (EC). It is an experimental EU programme which strives to deal with the social exclusion of adult dropouts who have not completed their compulsory education. The SCSs attempt to bridge the gap between 'those who know' and 'those who do not know', as defined in the mid-1990s in the EC's 'White Paper on Education and Training'. In that report, the risk of a rift in a contemporary scientific and technological society was acknowledged:

> It is a rift between those that can interpret; those who can only use; and those who are pushed out of mainstream society and rely upon social support: in other words, between those who know and those who do not know.

In this regard, the EC draws attention to 'the importance of adequate scientific awareness – not simply in the mathematical sense – to ensure that democracy can function properly. Democracy functions by majority decision on major issues', and for this reason it is critical for individuals 'to learn how to make informed choices both as individuals and as members of a community' (EC 1995).

In Greece, most of the SCSs' students come from socially vulnerable populations (e.g. the unemployed, economic immigrants, prisoners, minorities – especially

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Romany people and Greek Muslims – the elderly, etc.). The SCSs' main purpose is to help the aforementioned social groups 'to start participating in the cultural, political and economic life in society, but also to enable them to change their status in the society'. The way to fulfil this objective is by promoting curricula designed with an emphasis on each subject's literacies. In SCSs, literacies not only consist of the ability to read, write and do math; more than that, they include the competences required to act in real-life situations, namely, to solve problems, to work in groups, to use interpersonal skills, etc. The period of study in SCSs is two years (instead of the three years of formal education), and learners who graduate acquire a certificate equivalent to that which is awarded to a graduate of formal lower secondary education (IDEKE 2003).

As mentioned above, the target group consists mainly – though not exclusively – of adult school dropouts. Thus, it is important that a student's second chance at learning differs drastically from his/her first experience in formal education. According to IDEKE reports (2003), adult dropouts would prefer not to return to a learning environment in which they have not previously been successful, which means that the main features of the education being offered to them need to be significantly different from those of the formal school system. For this reason, the content of the curriculum of each subject taught in SCSs is flexible, in order both to meet the individual needs and interests of students and to serve the goal of active and meaningful learning.

Due to the different characteristics of SCSs' target groups (i.e. different interests, cultural contexts, and personal, vocational and social needs), teachers in each school have to design and develop curricula concerning their subject. The present study focuses on Greek science teachers' views on what scientific literacy signifies in the context of SCSs and also on how to develop a curriculum aiming at reintegrating students into society through scientific literacy.

19.2 Theoretical Background

19.2.1 Defining Scientific Literacy

The term 'scientific literacy' most probably appeared for the first time in 1958. Paul Hurd used it to express the need for public support of science in the USA in order to vigorously respond to the Soviet launch of the Sputnik satellite (Laugksch 2000). Since then, scientific literacy is considered to be an essential part of general education and culture all over the world (Popli 1999), and nowadays the term has come to mean 'what the general public ought to know about science' (Durant et al. 1993). This definition seems to be a vague one since (a) it can have different meanings and interpretations because there are several views of what the public ought to know about science and (b) there are different implications based on who 'the public' is considered to be (Laugksch 2000).

Along these lines, De Boer (2000) argues against seeking a narrow or precise definition of scientific literacy. According to him, scientific literacy should be conceptualized broadly enough for local school districts and individual classroom teachers to pursue the goals that are most suitable for their particular situations by utilizing the content and methodologies that are most appropriate for them and their students. This argument is consistent with the way SCSs function, but presupposes the teachers' ability to recognize the special educational needs of their students when transforming the scientific knowledge into content knowledge.

19.2.2 Visions of Scientific Literacy Curricula

To support teachers in rethinking the conventional school culture of science education and to design innovative curricula that both meet the needs of the learners and equip them to become informed citizens of twenty-first-century society, science communities use terms such as scientific literacy as educational slogans (Aikenhead 2002). After reviewing a large number of curricula aiming to develop students' scientific literacy in order to investigate the way this aim is conceptualized, Roberts (2007) identified two different perspectives as regards scientific literacy:

(a) Vision I 'gives meaning to scientific literacy by looking at the products and processes of science itself. This approach envisions literacy *within* science'.
(b) Vision II 'derives its meaning from the character of situations with a scientific component, situations that students are likely to encounter as citizens. This vision can be called literacy *about* science-related situations'.

According to Bulte (2007), the distinction between these two perspectives can be interpreted in terms of the need for a transition in curriculum designing focus from *science literacy* (Vision I) to *scientific literacy* (Vision II).

19.2.3 Vision II Curricula: The Focus on Literacy Approach

19.2.3.1 Literacy About Science-Related Daily Life Situations

A characteristic curriculum exemplar that attempts to make this transition is Twenty First Century Science, which aims not only to provide the first stages of training in science but also to stress science for effective citizenship (Roberts 2007). It recognizes that citizens are consumers of scientific knowledge rather than producers of it and argues that in most cases students will encounter scientific knowledge implicitly embedded in artefacts and processes in their lives (Millar 2006).

Although Millar's perception of scientific knowledge strongly implies a Roberts' Vision II point of view for scientific literacy, Twenty First Century Science focuses on skills, competences and knowledge from the perspective of what modern society 'demands' for its future citizens, ignoring the unique micro-characteristics and needs of a specific population (Roberts 2007). This is a macro-view of scientific literacy (Laugksch 2000).

19.2.3.2 Literacy About Sociopolitical Issues

The aim of developing students' active citizenship skills through science education is reflected in numerous studies, especially in the field of STS programmes (Kolstø 2001; Hodson 2002; Levinson 2006; Ratcliffe 2009; Lee et al. 2013; Van Dijk 2014). Some of these studies, however, hold a more radical view of scientific literacy – i.e. 'critical scientific literacy' – by giving prominence to the political interests and social values underlying the scientific and technological practices. From their perspective, global citizen character attributes can be cultivated in students by the promotion of argumentation skills through value-laden activities involving controversial socioscientific issues. This approach links the ideology of education with social reconstruction (Kolstø 2001; Hodson 2002; Levinson 2006).

19.2.4 Adult Scientific Literacy: The Focus on the Context-of-Situation Approach

19.2.4.1 Literacy About Science-Related Situations Derived from Students' Everyday Lives in a Local Community

Clearly, the 'focus on literacy approach' becomes significant in the context of curriculum designing for marginalized population. In addition, the corresponding literature (Layton et al. 1986; Barton 1998; Roth and Lee 2004; Dos Santos 2009) emphasizes that the context of the daily life science-related situations or socioscientific issues raised has a strong influence on the knowledge students bring to bear on those issues (i.e. 'situated learning'). 'It is the real-ness of a situation and the relation with students' experiences that makes knowledge meaningful' (Layton et al. 1986). Implementing a micro-approach, Layton has developed a curriculum for adults, called Science for Specific Social Purposes (SSSP), which focuses on the vocational life of the students (Layton et al. 1986). This is a micro-view of curriculum designing (Laugksch 2000).

As a result of their work with marginalized groups, Roth and Lee (2004) highlight the importance of context-based learning and design a programme based on activity theory. In their view, the collective activities done by the students to develop skills and to acquire scientific knowledge for participation in community life are both the means and the main goal of learning. These activities take place in real contexts that are derived from students' experiences and cover a variety of areas, ranging from personal matters, livelihood and leisure, to activism or organized protest (Roth and Lee 2004).

19.2.4.2 Literacy About Science-Related, Sociopolitical Issues Meaningful for Students' Everyday Lives

From a more radical point of view, Dos Santos adopts a Freirean approach towards humanistic science education, i.e. a type of education which will prepare students to be socially responsible and to take responsible sociopolitical action in order to change the inequitable social reality they live in (i.e. 'education for liberation'). To achieve these goals, it is essential for teachers to explore students' cultural and social contexts and to focus on those experiences which reveal the contradictions inherent in modern society – i.e. 'the chasm between living conditions of oppressors and the oppressed' – in order to engage students in discussions and to empower their commitment to sociopolitical actions involving socioscientific issues relevant to their lives (Dos Santos 2009). This approach to scientific literacy is based on a strong social and political stance.

Along with Dos Santos, Angela Barton approaches the education of marginalized populations (e.g. homeless children) through critical ethnography. She emphasizes that educating marginalized students is not just a process of transforming argumentation about socioscientific issues from the global to the local community level. Rather, it is a process of facilitating students to see beyond the set of values, beliefs, bodies of knowledge and styles of communication biased in favour of those who hold the most power in society and empowering them to confront 'a world fraught with inequalities and injustices that shape the students' lives'. The success of this approach depends on the teachers' ability to confront the student's world, to adopt the students' stance and to utilize the students' experiences as the basis for meaningful discourse to reveal the social injustices (Barton 1998). Dos Santos' and Angela Barton's research reveals that the teachers' cultural values and ideologies play an important role in enabling them to develop and apply a curriculum based on their marginalized students' living experiences and contexts of living.

19.2.5 A Synopsis of the Literature

The different perceptions of curriculum designing presented above are summarized in Table 19.1.

While Table 19.1 attempts to classify in a general way some basic approaches to scientific literacy curriculum designing found in the literature, it would be rather limited to consider these approaches as distinct categories since in most curricula, more than one approach can be traced. Instead, it would be more fruitful if the several approaches of scientific literacy curricula could be depicted in the form of a spectrum, which unfolds from the most traditional point of view (i.e. a focus on the content of science) to the most radical (i.e. a focus on sociopolitical issues) (Fig. 19.1).

Table 19.1 Different approaches to scientific literacy curriculum designing

Vision of scientific literacy		Curriculum exemplar	Curriculum content
Macro-view	Roberts' Vision I Science literacy	Benchmarks for Science Literacy (AAAS)	Focuses on the content of science For example, concepts, laws, developing scientific skills
	Roberts' Vision II IIa, literacy about science-related situations	Twenty First Century Science (Millar)	Uses media articles or general interest daily life situations to create learning contexts that a citizen may encounter in his/her life For example, keeping healthy, air quality, the Earth's place in the universe
	Roberts' Vision II IIa, literacy about sociopolitical issues	Critical Scientific Literacy (Hodson)	Uses real-world issues that have a scientific, technological or environmental dimension to reveal the underlying political interests and social values For example, freedom and control in science and technology, water and mineral resources
Micro-view	IIb, literacy about science-related situations that are derived from students' everyday lives in a local community	Science for Specific Social Purposes (Layton)	Addresses the science needed to cope with daily life situations For example, vocational life
		Scientific Literacy as a Collective Praxis (Roth and Lee)	Addresses science as and for participation in community life For example, personal matters, livelihood, activism
	IIc, literacy about science-related, sociopolitical issues meaningful for students' everyday lives	Scientific Literacy for Liberation (Dos Santos)	Addresses socioscientific issues critical for students' lives in order to generate social and political discussions and empower students' commitment to sociopolitical actions For example, social inequality which prevents people from satisfying basic human needs, such as access to health care

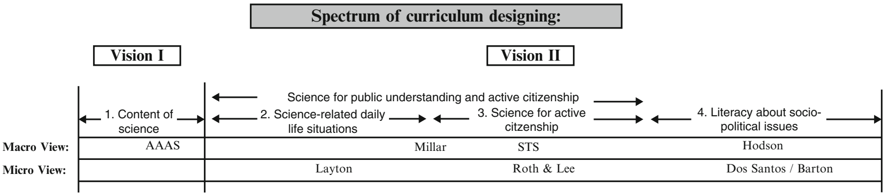

Fig. 19.1 Spectrum of curriculum designing: emphasis on different aspects of scientific literacy

19.2.6 Conceptualizing Scientific Literacy in the Context of SCSs

Considering the type of population SCSs address, Layton's approach, with its emphasis on the importance of context-based curriculum designing based on students' personal, vocational or social lives, seems to be aligned with the stated aims of SCSs, i.e. '[for students] to start participating in the cultural, political and economic life in society, but also to enable them to change their status in the society'. Furthermore, in our view, such a curriculum could be enriched with a more social and political stance (i.e. Barton's and Dos Santos' curriculum exemplars) by incorporating socioscientific issues from the students' lives that provide examples of how struggle is necessary to bring about social equity and justice.

19.3 The Study

The present study aims to trace Greek SCSs' science teachers' views and practices regarding the meaning of scientific literacy in Greek SCSs and to trace which aspects of scientific literacy and which specific students' needs those teachers take into consideration when planning their annual scientific literacy curriculum. For this purpose, eleven semi-structured interviews of science teachers/designers of science curriculum were conducted.

The research sample consisted of eleven SCSs' science teachers from different areas of Greece (five from Athens and six from various provinces). They have a variety of academic backgrounds (six physicists, two chemists, two geologists and one biologist; two of them have a master's degree in studies relevant to adult education or curriculum designing) and different teaching experiences in adult and formal secondary education (six are experienced teachers and five are novices; two teach in prison SCSs).

The interviews consisted of three groups of especially developed questions aiming to shed light on the science teachers':

1. Awareness of their students' special characteristics (i.e. students' motives, personal and social needs, interests, etc.) by exploring (a) whether/to what degree a teacher is aware of his/her students' special characteristics and (b) on which specific students' characteristics, experiences and needs he/she focuses on in order to be able to develop a meaningful context-based curriculum (micro-view).
2. Views about the meaning of scientific literacy in the context of SCSs. A group of questions was developed in order to explore whether/to what degree a teacher gives priority to (a) science itself, (b) his/her students' need to cope with everyday life situations (practical utility aim) or (c) his/her students' social need to participate and/or change their status in society (active citizenship aim, critical active citizenship aim).

3. Perceptions and practices about designing and implementing a scientific literacy curriculum in the context of SCSs. A group of questions was developed in order to explore science teachers' implications in curriculum design (i.e. what criteria a science teacher considers when choosing his/her scientific literacy curriculum's content to ensure that the specific needs of his/her students are addressed).

The analysis of the science teachers' answers to the above three groups of questions revealed their perceptions about the kind of scientific literacy curriculum they consider as appropriate for their adult students. Based on his/her curriculum emphases, each teacher's position in the spectrum of scientific literacy approaches was identified according to the scheme presented in Fig. 19.1.

19.4 Results

The content analysis of the SCSs' science teachers' responses to the interview questions was based on the grounded theory, a method of generating a theory inductively from a corpus of data (Strauss and Corbin 1990). During the content analysis, we focused on finding whether or not the science teachers' perceptions and practices regarding curriculum designing are affected by (a) the structures and the content of science, (b) science-related situations that a student may encounter in his/her everyday life as a citizen or (c) the special needs of the specific student population. We also sought for correlations between the kind of curricula science teachers design and their teaching experiences and studies.

The content analysis of SCSs' science teachers' responses to the first group of interview questions (i.e. questions regarding their views about their students' special characteristics) is presented in Table 19.2.

The results indicate that Greek SCSs' science teachers seem to share a rather simplistic and stereotypic view of their students' special characteristics. They mainly focus on their students' interests, which may be construed as the teachers' first attempt to take their students' characteristics into account when designing their own curricula. However, in order for teachers to be able to design context-based curricula related to their students' needs, such a focus would need to be expanded and further developed. Only two experienced science teachers (one of whom works in a prison school and the other in a school in one of the provinces) attempted to give more descriptive comments about their students' lives and needs. These comments, which clearly express SCSs' students' motives for returning to school and also paint a picture of the difficult circumstances in which many SCSs' students find themselves, are presented below.

> Comment by a science teacher working in a prison school about the reasons his students (prisoners) came to school: 'In the beginning, their motive for attending was that by doing so, their prison sentence might possibly be reduced. But afterwards, they realized that jail is a very bad "school" which produces specific attitudes, ways of thinking and modes of life (that will keep them marginalized and outside the world of law-abiding citizens), whereas

Table 19.2 Science teachers' awareness of their students' special characteristics

Type of references	Exemplar of science teachers' references	No. of science teachers	No. of references
To students' cultural and social characteristics	'Romany people's reasoning tends to be based on pseudoscientific explanations (e.g. "fate affects our lives")', or 'students coming from rural areas are interested in environmental and astronomical issues (e.g. seasonal changes). However, when I teach astronomy, they tend to rely on religious beliefs (e.g. "heaven is in the sky") and often question the scientific views'	4	9
To students' main reasons for dropping out of school	'Boys had to help their parents in agricultural work', or 'women got married very young', or 'they were bad students'	4	4
To students' motive for returning to school	'To get a degree and find a job' or 'they feel it is a way to confront their social marginalization'	8	15
To students' attitudes towards school science	'They have a defensive attitude about hard science issues' or 'they associate school science with solving exercises (in physics, chemistry, etc.) that require advanced mathematical skills; thus, from the very beginning, they feel hostile towards school science'	8	8
To students' interests	'They are interested in everything related to their lives (health issues, winemaking, nutrition, etc.)' or 'they are interested in astronomical issues (e.g. the solar system)'	11	39

> the SCSs could be considered as a "window of opportunity" in their miserable lives, through which they could gain the necessary confidence, knowledge and social skills to move on'.
>
> Comment by a science teacher working in a provincial school about his students' social characteristics: 'People come to the SCSs because they want to reintegrate into society. Some people feel ashamed (and so do their families) because they are illiterate. Many of them want to become autonomous citizens, to gain confidence and respect, and to be able to participate in the social discourse of their local community. SCSs help them to develop skills, to change attitudes and beliefs'.

The inability of science teachers to focus on the specific context of the environments in which their students live and the difficulties they face seems to affect both their views about the meaning of the notion of scientific literacy and their practices when designing their own annual scientific literacy curriculum: They tend to define scientific literacy through science itself and to design either theory-laden curricula (Vision I) or curricula addressing science-related issues of general interest raised frequently in the media (Vision II, macro-view).

Table 19.3 presents the Greek SCSs' science teachers' views regarding the meaning of scientific literacy in the context of SCSs which resulted from the content analysis of science teachers' responses to the second group of interview questions.

Table 19.3 Science teachers' views regarding the meaning of scientific literacy in the SCSs' context

Science teachers' views	Number of science teachers
Vision I: 'to acquire basic knowledge and skills of science' or 'to become familiar with the scientific method (i.e. observation, prediction, experimentation, conclusion)'	6:5 novice, 1 experienced
Vision II, active citizenship aim – macro-view: 'to be able to participate in discussions of general interest about science-related issues raised by the media' or 'to make decisions as informed citizens about socioscientific issues'	2:2 experienced
Vision II, practical utility aim – micro-view: 'to be able to understand issues that concern their daily lives through science (e.g. health issues, winemaking, etc.)' or 'to gain confidence and a more rational way of thinking'	3:3 experienced (includes the two teachers mentioned above who gave more descriptive comments about their students' characteristics)

Table 19.4 The kinds of curricula science teachers design to meet students' scientific literacy needs

Kind of curriculum	Science teachers' profile and practices
1. Curriculum oriented towards the content of science (e.g. Newtonian laws) (Vision I)	*5: Novice, with no experience in adult education* Their previous teaching experience in formal education and their academic background are the main factors which guide their choices when planning their annual SCSs' curriculum. Their students' culture seems to have little effect on their choices and practices
2. Curriculum aiming at supporting participation in the social discourse about science-related issues and decision making about socioscientific issues (e.g. pros and cons of using nuclear energy) (Vision II, macro-view)	*3: Experienced* All of them focus on science-related issues of general interest (e.g. the weather, earthquakes, the human body, radiation, technology, etc). Two of them include socioscientific issues in their curriculum
3. Curriculum aiming at providing familiarity with science-related daily life situations (e.g. health issues, fertilisers for agriculture) (Vision II, micro-view)	*3: Experienced, with awareness of their students' characteristics* They seem to be affected by the context of their students' lives, especially by their students' vocational environment

The content analysis of the science teachers' responses to the third group of interview questions regarding their own report of planning and implementing a scientific literacy curriculum reveals three major categories of curricula (Table 19.4). We should point out that the experienced teacher mentioned in Table 19.3 who defines scientific literacy in terms of *science literacy* (Vision I) developed a curriculum that aims at familiarizing his students with everyday phenomena (e.g. earthquakes), and therefore, his curriculum is classified in the second category of curriculum design in Table 19.4. The science teachers' practices are further discussed in detail below.

1. *Curriculum oriented towards the content of science*

In the first category of curriculum designing described in Table 19.4 above, all the science teachers are inexperienced in adult education. They hold that 'Students should acquire basic science skills and should be familiar with concepts of science that are considered as essential requirements in upper secondary education'. Science teachers in this curriculum-type category identify the needs of their students and the aim of their social inclusion as being the attainment of an upper secondary education degree, even though most of them did not even know how many of their students actually planned to continue their studies in the formal education system when they were asked.

Because of the goals which these teachers have set for their students, their benchmark for choosing the most appropriate curriculum content is that of the formal lower secondary education curriculum. Influenced by their own academic studies, they focus on physics and chemistry, teaching such traditional principles as measurement units, mechanics, the structure of matter, the periodic table and chemical reactions and relying on related exercises. Moreover, they believe that the acquisition of this kind of knowledge equips students with the skills to interpret daily life and to reintegrate into society: 'By solving exercises in Mechanics, students acquire the kind of thinking and skills needed for solving problems they encounter in their lives'.

These perceptions and practices of empowering students through scientific knowledge and an academic degree are rather simplistic, since school science skills can rarely be transferred to the uncertain, changing and complex context of issues students encounter in their daily lives (Levinson 2006; Osborne 2007). This type of education subordinates the individual to the needs of society rather than educates him/her in order to take responsible sociopolitical action (Dos Santos 2009). Therefore, it can be characterized as *instruction*, which is something wholly different from *education* (Efstathiou 2009).

Furthermore, few of the science teachers report that they try to raise the scientific awareness of their students through the science content they teach, while others report that they stress aspects of the nature of science (mainly the history of science). The goal of guiding students to develop scientific awareness is reflected in the following statement by one of the science teachers: 'To be introduced to the scientific method and scientific thinking'. These teachers seek to develop their students' scientific awareness by applying the typical sequence of observation, hypothesis, experiment and conclusion.

Science teachers with studies related to the nature of science set a different learning goal, namely, 'to gain an appreciation about the way scientific knowledge has evolved into what we believe today or how we have achieved technological achievements' or 'to understand the operation of the natural world'. Working towards that end, they present their students with a curriculum which focuses on the unity of the natural world from the macrocosm to the microcosm and also provide examples of historic moments that changed the way we interpret the natural world.

To conclude, when designing scientific literacy curricula, the science teachers in this category do not take into account the culture or needs of their students, especially when these curricula are addressed to Romany people, immigrants or prisoners. During the interviews, the science teachers admitted that it is their teaching experiences in formal education along with their academic backgrounds that guide them to design curricula that focus on concepts and methods of science. As a result, their students are confronted with learning environments which had led many to become dropouts in the first place and are forced to work towards goals which are of no interest or use to them. Moreover, those few science teachers who try to stress aspects of the nature of science and to develop their students' scientific awareness express views that reveal a positivistic view of the scientific method, scientific thinking and the way scientific enterprise evolves.

We should point out that a number of teacher professional development studies (Huibregtse et al. 1994; Hewson et al. 1999; Bartholomew et al. 2004; Pintó 2005) support the above-mentioned findings related to the practices of the inexperienced science teachers. According to the literature, teachers' beliefs and practices often mirror the way in which they themselves were taught. 'Just as students develop complex and elaborate conceptions of the natural world, teachers are similarly expected to develop generalized conceptions of teaching, which affect their practices, based on their own extensive experience in formal education as learners' (Hewson et al. 1999). Most science teachers are themselves 'products of an archetypal education which has largely ignored the epistemic base and nature of its own discipline'. Hence, teachers of science tend to hold 'outmoded positivist or empiricist views' of the nature of science (Bartholomew et al. 2004).

2. *Curriculum aiming at supporting participation in the social discourse about science-related issues and decision making about socioscientific issues*

Science teachers with previous experience in SCSs recognize the importance of supporting decision making in socioscientific issues: 'It is very crucial for the students' social inclusion to be able to participate in discussions about issues raised in the media and to make decisions as an active citizen about socioscientific issues'.

Science teachers in this category frequently use media articles to develop a meaningful learning context for their students. The articles they choose are relevant to science topics of general interest (e.g. the human body, earthquakes, radiation, etc.). However, they rarely integrate socioscientific issues among the topics they offer to students, although two of the teachers did include pertinent issues as the last topics in their curriculum, namely, arguments for and against nuclear energy and pros and cons of technology.

Furthermore, as regards the implementation of science-related issues of general interest, the teachers argue that the interpretation of daily life phenomena (e.g. earthquakes, radiation) is inherently complex and therefore presupposes the need to teach the corresponding content of science (i.e. concepts and principles). Thus, in their attempt to help students acquire the necessary knowledge, teachers overemphasize the science aspect; consequently, this kind of learning context is less meaningful for students and resembles the teaching practices of the teachers of the first category.

3. *Curriculum aiming at providing familiarity with science-related daily life situations*

Science teachers in this category are experienced teachers in adult education with awareness of their students' characteristics (mainly their interests and their personal and vocational needs). In their view, 'students should be able to explain physical phenomena that affect their lives and to interpret daily life through science'.

To achieve that goal, they choose topics relevant to their students' personal and vocational life (e.g. health issues or the weather or fertilisers for agricultural workers). Yet in some cases, based on the way science teachers describe their approach to such issues, they seem to focus more on the *information/knowledge needed to explain the phenomena* and less on the (a) *interconnections between scientific knowledge and students' needs or values* and (b) *skills needed to apply this knowledge to everyday life situations* which are essential to achieve the aim of providing familiarity with science-related daily life situations.

While this kind of science curriculum designing strongly implies Vision II and does have some connection with the students' context of living, it still ignores the students' social needs for both participation in community life and sociopolitical commitment to struggle to change the institutions of society that oppress their lives. As mentioned in the Theoretical Background section of this paper, these aspects of scientific literacy are considered as being crucial for such marginalized student populations (Barton 1998; Roth and Lee 2004; Dos Santos 2009).

19.5 Discussion and Implications

This study aimed at investigating Greek SCSs' science teachers' views on how they understand the SCSs' aim of promoting scientific literacy in order to equip students to overcome social exclusion and whether their students' personal, cultural and social needs are taken into account in the curriculum design. The results showed that SCSs' curriculum designing fell into three major categories and that a teacher's previous classroom experiences and academic backgrounds determined the curriculum type. However, the three types of science teachers' curriculum designing identified by the analysis (numbered 1–3 in Fig. 19.2) were found to have some overlapping characteristics which led us to depict them as parts of a spectrum than as three distinct categories (i.e. a science teacher may intend to design a curriculum to promote active citizenship, but the structure of his/her curriculum also gives emphasis to the goal of facilitating students' acquisition of the scientific knowledge and skills required to continue their studies in upper secondary education).

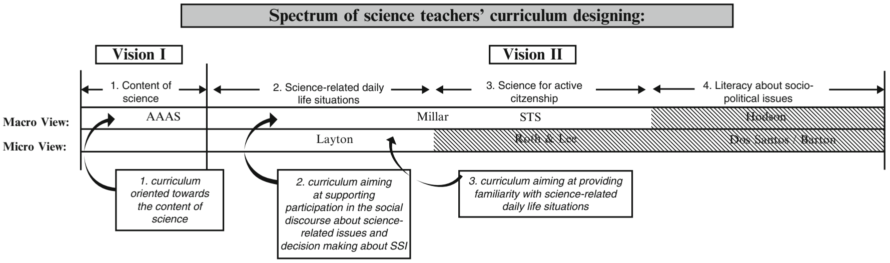

Fig. 19.2 Spectrum of science teachers' curriculum designing: emphasis on different aspects of scientific literacy

Figure 19.2 depicts the aspects of scientific literacy the SCSs' teachers focused on (i.e. where the curriculum emphases are, numbered 1–4 in Fig. 19.2) in correlation with the corresponding theoretical approaches. The hatched areas of the spectrum indicate the kinds of curricula that are not used by science teachers. Each curriculum classification in the spectrum seems to be related to the teacher's level of experience in adult education.

As mentioned previously, the less experienced science teachers (who comprise a large portion of the general population of science teachers in Greek SCSs) focus on teaching the content of science (Type 1 curriculum design). For them, the lower secondary education science curriculum acts as an exemplar, and, furthermore, they are very much affected by their field of studies when they choose the content they plan to teach. These teachers tend to ignore the characteristics of the target group they are addressing.

On the other hand, experienced Greek SCSs' science teachers who attempt to make a transition from Vision I to Vision II curricula tend to emphasize teaching scientific phenomena related to students' interests. In this case, their main concern is promoting skills for participating in discourses regarding issues frequently raised in the media. Such curricula seem to resemble Millar's curriculum, although activities for students' engagement in socioscientific issues (Type 2 curriculum design) – an aspect that Millar highlights as essential for developing decision-making competences – are rarely incorporated in the curriculum design of the Greek science teachers.

Moreover, some science teachers in this category, even when they develop the corresponding teaching content to introduce some science-related media articles, quite often still seem to be limited and drift away from the scientific knowledge embedded in those articles. That is why some curricula of the Type 2 curriculum design have characteristics of Vision I curricula and in practice could be identified in the 'content of science' area of the spectrum.

Science teachers with the most experience in adult education acknowledge their students' special needs and thus design curricula focused on applied scientific knowledge that will be useful for their students' future lives. However, in their attempt to identify the micro-characteristics of their learners, they seem to perceive and more readily draw on the characteristics of the vocational and personal lives of the learners. These curricula have similarities with Layton's and Roth and Lee's curriculum exemplars, but the social aspect of students' needs which is highlighted in Roth and Lee's approach is left out (Type 2 curriculum design).

For many teachers, encultured in the habitus of traditional science teaching, developing curricula oriented towards their students' culture and needs requires a paradigm shift in the way they view the nature of science, the aims of science education and their own role within the context of the design and delivery of the curriculum (i.e. a reconstruction of their own *ideology of science teaching*) (Geddis 1991; Bartholomew et al. 2004; Day and Bryce 2011). From the discussion presented above, it appears that as Greek science teachers gain teaching experience in SCSs, they minimize the extent to which they are affected by their academic backgrounds and previous teaching experiences in formal education, and they shift their interest to the recognition of the context of their SCSs' students (although this point needs further research). Thus, experienced science teachers seem to make significant progress in setting meaningful goals to the students and in giving curriculum emphasis to aspects of their students' daily lives, thereby increasing their students' chances of success in social inclusion.

However, none of the Greek science teachers seem to adopt a radical perspective for curriculum designing since sociopolitical issues related to the specific social and cultural context of their students (the Dos Santos approach) are totally excluded. The teachers' inability to approach the social contexts of their students' lives and to interconnect the living conditions and problems of the individual with the broader, systemic problems of society is not related to the teaching experience of the science teachers, but rather relates to the teachers' own cultural and ideological backgrounds (Barton 1998).

19.6 Conclusions

From the literature, we were able to identify a number of science curriculum types appropriate for students from marginalized populations, such as the students in Greek SCSs. The literature highlights the need for context-based learning based on students' personal, vocational or social experiences, as well as the crucial role of meaningful sociopolitical issues in promoting critical thinking skills and for cultivating characters empowered to struggle for the reconstruction of society.

The present study showed that the experienced SCSs' science teachers were able to make the transition from *science literacy* curricula (Vision I) to *scientific literacy* curricula (Vision II). They were able to recognize the need to explore their students' interests and, to some extent, their students' personal or vocational experiences as means of designing meaningful learning contexts. However, SCSs' science teachers fail to focus on their students' social context of living and the related daily difficulties they face, a shortcoming which hinders teachers from developing the corresponding curricula aiming at supporting students' participation in the local community or empowering students to take responsible, sociopolitical action.

For this reason, it seems necessary for the Greek SCSs to choose science teachers who are aware of the sociopolitical perspectives of science curriculum designing and, moreover, to support them by providing training in curricula designing for scientific literacy according to the sociocultural characteristics of their students. Through this process, the less experienced science teachers will be able to acclimate more easily to the priorities of the SCSs, and the more experienced ones will be able to develop their skills in curriculum designing. In this way, teachers will be able to develop meaningful learning contexts for their students and therefore provide their students with better opportunities for reintegration into – or even to struggle for reconstructing – society.

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