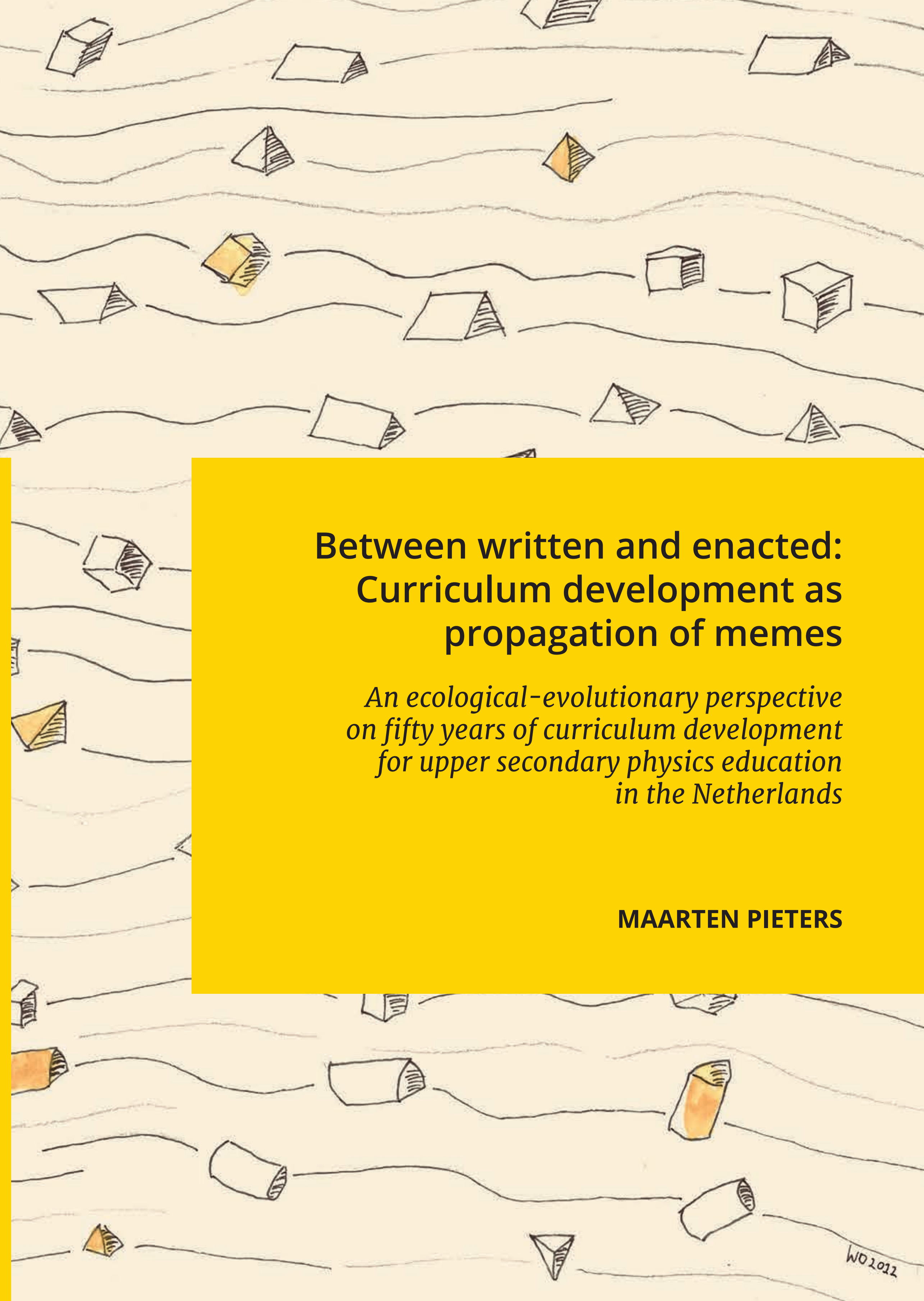

Between written and enacted: Curriculum development as propagation of memes

An ecological-evolutionary perspective on fifty years of curriculum development for upper secondary physics education in the Netherlands

MAARTEN PIETERS

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**Tussen geschreven en uitgevoerd:
Curriculumontwikkeling als voortplanting
van memes**

Een ecologisch-evolutionair perspectief op vijftig jaar
curriculumontwikkeling voor de bovenbouw van het
natuurkundeonderwijs in Nederland

(met een samenvatting in het Nederlands)

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CHAPTER 1

Introduction: curriculum scene investigation

1.1 Motivation

The idea for this study stems from disbelief. Disbelief at the extent of failures in curriculum development suggested by esteemed colleagues. One of those colleagues, a senior curriculum developer and researcher, said that one day he would write his memoirs and he would call them *50 Years of curriculum development: An anthology of failures*. Another colleague, very experienced in curriculum research, liked to talk of how in many curriculum renewals, only a small percentage of the targeted teacher group would use materials produced as part of such a renewal and an even smaller percentage would use them in the way intended. These personal impressions are supported by literature, stating in one way or another that curriculum innovations tend to fail, worldwide. Hall (1973, p. 1): "The educational experience of the past decade clearly documents that mere existence of educational innovations does not guarantee their use." Fullan and Pomfret (1977, p. 337) advocate to examine implementation: "to understand some of the reasons why so many educational changes fail to become established." Cuban (1988, p. 68) claims that "innovation after innovation has been introduced into school after school, but the overwhelming number of them disappear without a fingerprint." Fensham (1992, p. 790) notes that, in the 1970s, "evidence accumulated that many or most of the hopes and good intentions of the reformers were not being achieved in schools." Fullan (2007, p. 5) notes that "huge sums of money were poured into major curriculum reforms. . . . By the early 1970s, there was mounting evidence that the yield was minuscule, confined to isolated examples." Meltzer and Otero (2015, p. 452) state that "by the late 1980s, combined adoptions of the PSSC [Physical Science Study Committee], and Project Physics textbooks had dropped to around 10% of total adoptions." An exception is the evaluation of the most recent reform of the science exam program in the Netherlands (Ottevanger et al., 2018), which finds quite a number of enactments of the physics education commission's intentions reported by responding teachers.

So many examples of failure, also expressed by people who themselves had played an active role in curriculum development; why would anyone still want to invest in curriculum renewal? Here the disbelief comes to the fore. I was a high school student in the 1960s, a physics and teacher student in the 1970s, a physics teacher in the 1980s, and have been a science curriculum developer since the 1990s, visiting science classrooms and participating in teacher conferences. With due respect to my esteemed colleagues, I have seen that, through the decades, science curriculum developments in my country, the Netherlands, have not left the practice of teachers untouched. Classroom visits and conference workshops have shown me that quite a few science teachers do pay attention to students' preconceptions or do organize structured research activities for their students. Definitely, not all ideas from projects and reforms were ending up in the anthology of failures. But I did not know the extent to which such ideas had entered teachers' practices. And I became curious about how long it had taken for the ideas to get there, about which routes they had taken. Perhaps it is organized teacher development, rather than the teaching materials that are often used to promote curriculum renewals, that may explain why some ideas about the curriculum from the 1960s and 1970s have reached the practice of teachers in the following decades (Van Driel et al., 2001). But even then, the ideas may have arisen from curriculum innovations.

So, then, disbelief at the extent of curriculum development failures and curiosity about routes of curriculum ideas between projects and reforms and teachers' practices form the two major starting points for this study. I decided to focus on today's teachers' practices, to find the traces in those practices of a range of curriculum renewals from the past decades, and to try and understand, in hindsight, how certain ideas have come to be expressed in teachers' practices, even if only in the long run.

This retrospective way of looking, starting from today's practices, over a period that is longer than in most curriculum evaluations, is the basis of the perspective of this study: a way of looking at curriculum development inspired by evolution theory and ecology. Evolution theory inspires because it is patient and neutral, and because, in its modern combination with genetics, it describes how information may travel via units, like genes, and can be expressed under the right environmental circumstances. Ecology inspires because it focuses on the role of the environment and helps to think in systems. The attraction to an ecological-evolutionary way of looking at the developments was also inspired by approaches like Fullan's *Interactive factors affecting implementation* (Fullan, 2007, p. 87), a *practicality ethic* as described by Doyle and Ponder (1973), or the *teacher agency* model by Priestley et al. (2013).

An ecological-evolutionary way of looking is patient, open to relationships between appearances that at first sight appear to be different from each other, aware of influences from the environment, and cautious in judging outcomes. Thus, we may be less inclined to refer to differences in appearance as failures than when trying to find faithful reproductions of original designs, or an upscaling in terms of user numbers (Coburn, 2003). Some disqualify such differences as *slippage* (Westbroek et al., 2017), but if we interpret them in a way that empathizes with the situation of the teachers, we can call them *adaptation* (McLaughlin, 1976; Fullan & Pomfret, 1977; Westbroek et al., 2017) or *transformation* (Ogborn, 2002). This way of looking may help curriculum innovators to be less easily disappointed if proposed innovations are not implemented immediately, and more curious about encouraging and fostering the key ideas of renewals. Ogborn connects it to ownership (see also Coburn, 2003), when he asks (Ogborn, 2002, p. 142): "Is Advancing Physics 'my' project, or is it the property of the several hundred teachers now teaching and examining it?" Ogborn (2002, p. 142-143) also asks a "question of transformation": "Would the authors of the project recognize a lesson as belonging to it, if they sat in on a classroom? Do teachers 'deform' the original ideas? Or do they perhaps improve on them?" He answers these questions himself:

> So here now are my answers to my two questions. First, teachers, not the developers, are the true owners of a curriculum development. This is not

> a sentimental point, seeking to give importance to teachers. It is a point of practical necessity. To do a job well is to feel in charge. . . . Second, there is in a way no such thing as material 'being taught in the way intended'. That 'way' cannot, in the nature of communication itself, be 'transmitted' without change. (p. 146)

Curriculum renewals are frequent and widespread. They take place around the world, at scales ranging from delimited projects to nationwide reforms, involving various numbers of developers and teachers, their development lasting from a few up to more than ten years (Van den Akker, 2018). Some renewals are started by researchers or teachers who propose meaningful improvements for teaching and learning activities. Others are launched by organizations or governments, wishing to bring their national education more up-to-date with demands of society, often also based on research or feedback from practice. Of course, they all strive for their ideas to find their way into the practice of (other) teachers. For curriculum developers, whether in innovation projects or in large-scale reforms, it is important to better understand how to influence the environment of the teachers in such a way that the intentions initially owned by themselves – to echo Ogborn's words – can find their ways to and be expressed in the practice of the teachers, in enactments that are owned by the teachers.

1.2 Preview of the research perspective

A common way for curriculum evaluators to look at the relation between the curricula written by developers and curricula enacted by teachers is to investigate for given curriculum renewals to what extent the intentions of their initiators are expressed in teachers' practices following the renewal activities. Examples are studies by Van den Akker (1988b), Volman et al. (1995), Wierstra (1990), Ogborn (2003), and Ottevanger et al. (2018). These evaluations zoom in on a particular renewal, and their conclusions feed as data into more general studies on curriculum innovation. This study took an inverse perspective. Reports on teachers' practices were examined, including content and pedagogy, and investigated to what extent the intentions of curriculum renewals from several decades are reflected in those practices. This perspective describes the basic approach of this study: identify expressions of curriculum intentions in today's teacher practices, zoom out from these practices and look back at renewals. This retrospective approach was combined with the more usual method of studying what some major renewals intended, in order to find a set of curriculum intentions that could serve as indicators of influences, or of lacking influences, between teachers and developers, in both directions.

The phrase *expressions of curriculum intentions* anticipates the conceptual framework, further explained in Chapter 2, which regards a curriculum as an expression of intentions. Thus, the term *curriculum* can refer to what has been written down by the developers of a curriculum renewal, as well as to a teacher's practice. In both, intentions are expressed about the content and purpose of what students should learn and how best to organize that, a formulation that connects to Walker's definition of curriculum (Walker, 1990, p. 5): "The curriculum refers to the *content* and *purpose* of an educational program together with their *organization.*"

Thus, we arrive at a distinction between the *written curriculum*, in which developers express their intentions in words, and the *enacted curriculum*, in which teachers express their intentions in actions. In this study, the term *developers* refers to individuals or groups of individuals who are involved in the development of a curriculum at the scale of a country. They can be involved in various ways, like members of a project team, reform commission, pilot teachers, or authors of sample teaching materials. The term *teachers* will in this study refer to teachers in their roles as classroom teachers of their own students. A teacher in a role as developer for the national scale is included in the term *developers*.

The terminology of *enacted curriculum* and *written curriculum* corresponds to typologies of curriculum representations further discussed in Chapter 2.

Both written and enacted curricula are defined in terms of what is expressed. The term *express* is deliberately used, it stays close to the terminology of genetics and evolution theory, in which genes, as units of information, travel through generations of organisms and populations, in which this information is expressed. The concept of *gene* inspired Dawkins (1976/2016, p. 249) to define the *meme* as "a unit of cultural transmission." For this study, curriculum intentions are visualized as memes that, depending on fitting circumstances, may travel from developers to teachers or from teachers to developers. This perspective borrowed from genetics and evolution theory is combined with an ecological perspective (also part of evolution theory): an organism's environment influences its chances to survive and procreate and thus influences the chances of the genes expressed in that organism.

1.3 Central case of this study

For this study, into the traces of a range of curriculum renewals from the past decades in today's teachers' practices, a focus on one case, that of one school subject in one country, was chosen. This case was upper general secondary physics education, at the national level, in the Netherlands since 1970. This comprises two school types: the two-year *havo* (senior general secondary education), preparing for higher professional education, and the three-year *vwo* (pre-university education). The study focused on the four exam programs developed and implemented since 1970, two innovation projects that addressed the entire physics curriculum, and on practices as reported by 13 teachers in the years 2017 and 2018. Practicing teachers were interviewed as well as stakeholders who had been active in or around curriculum renewal activities in the past decades, and written sources were studied. Chapter 3 will elaborate the various approaches of the substudies carried out.

One reason for the choice of this case is that there have been several innovation projects and formal reforms since the 1970s in Dutch physics education. Another reason is that my personal involvement as a physics teacher and as a science education developer in the Netherlands gives a good overview of and quick access to many of the key players in those reforms. In addition, the case of physics education in the Netherlands is also interesting in an international context, as the projects and reforms have always been strongly influenced by science curriculum development projects in other countries, such as *PSSC* (Physical Science Study Committee, 1960) and *Project Physics* (The Project Physics Course, 1970) from the United States, the British *Nuffield Science Teaching Project* (Nuffield Advanced Science: Physics, 1971), and the German IPN's *Physik im Kontext* (Duit & Mikelskis-Seifert, 2010). Some of the Dutch innovations have in turn also inspired curriculum innovators in other countries, appearing from publications in research and professional journals (e.g., Aikenhead, 2003; Fensham, 2009). The limitation to the physics education case does not exclude a wider science education orientation: many of the discussions in the course of its development, as well as its curriculum intentions, have been similar to those for the other science subjects, such as on research skills, use of contexts, widening the scope of science education, and concept development. And when it comes to the relation between curriculum development and teacher development, and the possible usefulness of concepts borrowed from evolution theory and ecology, this study may help understanding such developments regardless of school subjects.

Several types of renewals have been studied for this case, some were *projects* developing innovative practices and materials for teaching and assessment, and others were *reforms* of the curriculum, laid down in legal standards. As countdown, we take the reform of the exam program by the Commission for the Modernization of the Physics Curriculum (CMLN, 1974), which was implemented in 1976. This commission limited itself to a "content innovation" and pleaded for "a fundamental research of objectives and from the pedagogical approach" (p. 7), before a curriculum could really be modernized. This recommendation, next to more general curriculum discussions in Dutch secondary education, led to several larger and smaller innovation projects, one of which is the PLON-project (e.g., Eijkelhof et al., 1986). The results of PLON were reflected in the 1991 reform, prepared by the Working Group Exam Revision Physics (WEN, 1988). This reform also used the results of a project for developing a differentiated approach to physics teaching, DBK, included in this study too. A next reform of the exam program was implemented in 1998, prepared by the science commission of the Stuurgroep Profiel Tweede Fase (1995b), as part of an entire reorganization of upper secondary education. The most recent reform was implemented in 2013, prepared by the Commission for the Renewal of Second Phase Physics Education (Commissie Vernieuwing Natuurkundeonderwijs havo/vwo) (2010), following a five-year project period of consultations and pilot testing. All these reforms are included in this study. Innovation projects as well as reforms will be addressed in this study with the collective term *renewals*. The renewals and the criteria for their selection will be described in Chapter 4.

For a good understanding of the context of this case, it is useful to know some characteristics of the upper secondary education system and of physics education in the Netherlands. These too will be described in Chapter 4.

1.4 Main research question

I motivated this study from a desire to examine whether the results of curriculum innovations appear in the curricula enacted by teachers when considering a longer period than a few years after each innovation. Furthermore, I was curious to see whether the perspectives of evolution theory, genetics, and ecology would yield a better understanding of the ways in which written curricula and enacted curricula might influence each other than do evaluations of renewals that look for faithful copies of developers' elaborations, especially if they take place only a short period of time after a project period, or implementation of a reform. I also hoped that a few lessons can be learned from this study that can be useful for future curriculum renewals. Given the choice for the study case, as explained in 1.3, this led to the following twofold main research question:

> *To what extent do enacted curricula in upper general secondary physics education in the Netherlands reflect the intentions of renewals expressed in written curricula initiated since the 1970s and what factors may have influenced the expression of the renewals' intentions in teachers' enacted curricula?*

The term *factors* also addresses the people who have been of influence, *actors*, to prevent the repeated use of the long designation *actors and factors*.

This main research question has been investigated in an exploratory way, in four qualitative substudies, each guided by a subquestion and each conducted with its own method of data collection and analysis.

1.5 Structure of the thesis

Chapter 2 explains the conceptual framework and terminology used in designing and executing the study. Chapter 3 describes the design of the study as a whole, the research questions of four substudies we carried out, and some indicators used across the substudies. Chapters 4 through 7 describe, for the successive substudies, their design, results, and conclusions. In Chapter 8, conclusions are drawn from the study as a whole, its design and results are discussed, as well as its implications, and new and unanswered questions.

CHAPTER 2

Conceptual framework

2.1 Introduction

In Chapter 1, the main research question for this study was introduced:

> *To what extent do enacted curricula in upper general secondary physics education in the Netherlands reflect the intentions of renewals expressed in written curricula initiated since the 1970s and what factors may have influenced the expression of the renewals' intentions in teachers' enacted curricula?*

The case studied was upper general secondary physics education in the Netherlands. The perspectives from which the study looked at the relationship between renewals at the national scale and current teachers' practices were inspired by a typology of curriculum representations and by the patient and neutral way in which evolution theory, genetics, and ecology look at phenomena.

This chapter will elaborate these perspectives and the terminology in the research question as the conceptual base for this study: curriculum representations as expressions of intentions (2.2), evolution as a metaphor (2.3), and factors affecting enacted curricula (2.4). Sources from literature used to help develop these perspectives will be discussed in the corresponding sections.

2.2 Curriculum representations as expressions of intentions

Developers of curricula for the national scale as well as teachers teaching their own classes intend students to learn certain content and to develop certain skills. This case study compared what developers and teachers intended, and who and what has influenced them. This section will explain the terminology used: what is meant by a curriculum, a developer (who, after all, can also be a teacher), and a teacher (who, after all, can also be a developer).

Starting point is that both developers and teachers have intentions about what students should learn, about how to organize that learning in time, supported by activities and resources, and about what and how to assess that learning (Van den Akker, 2009). The word *curriculum* is used to refer to the expression, in texts and practices, of those intentions. It stays close to Walker's (1990, p. 5) definition of *curriculum* as referring to "the *content* and *purpose* of an educational program together with their *organization*." The definition used in this study still leaves much open, such as the degree of detail, the form of a text (e.g., oral, written, printed, or digital), the practical organization (e.g., classroom, online, or blended teaching), or the scale (from one student, one classroom, one school up to a country as a whole).

In line with Walker's (1990) definition, the term *curriculum* is not only used in this study to refer to the substance or content of teaching and learning, the "what", but also to the "how" of teaching, as opposed to other descriptions that include only the "what" (e.g., Stein et al., 2007, p. 321).

As for the distinction between developers and teachers in this study: the term *developers* refers to individuals or groups of individuals who are involved in the development of a curriculum at a national scale, which is meant to get shape into the practices of all teachers in the target group in the country, in this case physics teachers in upper general secondary education. Developers can be involved with large-scale curriculum development efforts in various ways, for example as members of a curriculum reform commission, as pilot teachers who give feedback in a project, or as authors of sample teaching materials. Their backgrounds can vary from higher education professors, schoolteachers, educational researchers, and teacher educators to physicists from universities or industry. The term *teachers* refers to teachers in their roles as classroom teachers of their own students and as developers of the lessons and assessment practices for their own classes. In their possible role as developers on a national scale they are included in the term *developers*.

Teachers express their intentions in their preparation and teaching practices: lessons, semester plans, assessment tasks and plans, and sometimes also in self-developed teaching and learning materials; these expressions include the way they interpret and use textbooks from educational publishers. Developers express their intentions in written documents, such as recommendations for exam programs, sample teaching materials, oral presentations at conferences, or articles in scientific or teacher journals.

Curricula have various forms and serve various functions. The term *curriculum* appears with a large number of adjectives for those forms and functions (Goodlad, 1979; Schmidt et al., 1996; Stein et al., 2007; Thijs & Van den Akker, 2009; Remillard & Heck, 2014; Rosiek & Clandinin, 2016). For the terminology to be used in this study, adjectives are needed that match the distinction between the ways teachers and developers express their intentions, respectively, about what students should learn and how to organize that learning in time: their curricula.

A terminology that relates to the different types of participants in the education system is used by Schmidt et al. (1996) as well as Thijs and Van den Akker (2009), who distinguish the *intended*, the *implemented*, and the *attained* curriculum. This classification builds on a finer categorization, in six forms, by Goodlad (1979). The intended curriculum is connected to developers; it comprises, in Goodlad's refinement: a vision, a rationale or basic philosophy underlying a curriculum (the *ideal* curriculum), and intentions as specified in curriculum documents and/or materials (the *formal/written* curriculum). The implemented curriculum is connected to teachers; it combines: the curriculum as interpreted by users, especially teachers (the *perceived* curriculum) and the actual process of teaching and learning (the *operational* curriculum or curriculum-*in-action*). The attained curriculum is connected to students; it combines: the curriculum as experienced (the *experiential* curriculum) and learned by students (the *learned* curriculum).

A difficulty in using this typology for the purpose of this study is that it strongly connects intentions to the level of developers and that it might be interpreted as if the actions of teachers in their classrooms are only an implementation of those developers' intentions. This study places as high a value on teachers' intentions as it does on those of developers, as equivalents to be compared in a neutral way. This neutrality also matches with the ecological-evolutionary perspective chosen for this study, see Section 2.3.

An alternative typology is that of Stein et al. (2007, p. 321), who distinguish a *written*, *intended*, and *enacted* curriculum, in which they describe the intended curriculum as "referring to a teacher's plans for instruction." This classification meets the need to acknowledge teachers' intentions. However, in this case the term *intended curriculum* leaves out the developers' intentions, which makes Stein et al.'s definition of an intended curriculum ill-suited for use in this study. But their concepts of *written* and *enacted curriculum* get close to the concepts we need. By written curriculum they mean what is on the printed page (p. 321) and they state that their denotation of written curriculum is equivalent with what Schmidt et al. (1996) call "intended": intended by the developers. In the conceptual framework of this study, the term *written curriculum* best reflects the expression of developers' intentions, if, as opposed to Stein et al. (2007), elaborations in textbooks (other than sample teaching materials produced by developers themselves) are left out from its denotation.

Stein et al. (2007) define the *enacted curriculum* as "what actually takes place in the classroom." Remillard and Heck (2014, p. 711) also use this term and define it as "the interactions between teachers and students around the tasks of each lesson and accumulated lessons in a unit of instruction." Thus, the term *enacted curriculum* fits the description used in this study of teachers' actions as expressions of *their own intentions*, which may or may not include teachers taking written curricula into account.

Based on the above, two types of curriculum appearances were used in this study to examine the intentions of developers and teachers: *written* and *enacted curricula* are defined for this study as expressions of these intentions.

In this study, the term *written curriculum* refers to exam programs recommended by a reform commission or an innovation project to be prescribed nationally, to the mandatory exam programs following those recommendations, and to sample teaching materials, publications, and other accounts by which developers express their intentions about what students are expected to learn and how that learning can best be organized. It is restricted to what is offered at the national level. A written curriculum may include what is recommended to the ministry to be prescribed, as well as what is recommended to teachers, authors, and other actors as ways to elaborate the prescription.

It may include references to subject matter, containing content and skills, as well as to pedagogical approaches.

In this study, the term *enacted curriculum* refers to teachers' practices, in lessons and units of instruction at various time scales, and where applicable also in homemade teaching material, by which teachers express their intentions about what students should learn and how that learning should be organized. An enacted curriculum functions at the micro level, apart from what a teacher shares with colleagues in school (meso level), in professional learning communities, or at conferences.

These two formulations with the term *curriculum* overlap with the various curriculum forms as defined by the researchers that were discussed. Forms that are not included in these two types are textbooks (part of the written curriculum for several researchers), the perceived curriculum (meaning the way teachers interpret intentions as specified in curriculum documents and/or materials), and the attained curriculum (what students experience and learn). In the conceptual framework for this study, these forms are included in the factors influencing the enacted curricula and mediating between the written and enacted curricula, see Section 2.4.

The study's focus on the enacted curriculum should not be interpreted as a *curriculum enactment perspective* in the sense described by Snyder et al. (1992, p.418) as a perspective from which "curriculum is viewed as the educational experiences jointly created by student and teacher." The difference is that this study focuses on what teachers report about their enacted curriculum, whether or not jointly created with students, and regardless of the extent to which their practices match what others may desire. This latter perspective is coined the *fidelity perspective* by Snyder et al. (1992,p. 405), to characterize a view on curriculum development in which developers formulate "desired practices", as opposed to the enactment perspective.

Apart from their authors or actors, written and enacted curricula differ in system level. Goodlad (1979) distinguishes the *societal* or system level (macro), the *institutional* or school level (meso), and the *classroom* level (micro). Thijs and Van den Akker (2009, p. 10) refine those levels in five segments by adding the international level (supra) and the level of the individual learner (nano). A written curriculum, as examined in this study, contains expressions on the macro level (e.g., recommendations for attainment targets), the meso level (e.g., recommendations for STEM cooperation in schools), and the micro level (e.g., sample teaching materials). An enacted curriculum contains expressions on the nano level (actions on individual student level), on the micro level (actions on classroom level), and on the meso level (cooperation with colleagues on school level).

Written and enacted curricula differ in how they influence one another. Developers can advance the expression of their intentions in teachers' practices through national regulations and the national exam system. Conversely, for an individual teacher to influence a written curriculum, at the macro level, he or she needs to join a development project or reform commission, and thus be a developer him/herself. Other ways can be, for example: respond to or participate in discussions about draft proposals by development teams, join a committee of the teachers' association, have the results of a professional learning community published.

Box 2.1 *Description of some typical steps, actors and products in the development of a new physics exam program.*

The most recent innovation studied in this case study started in 2005 with the establishment, by the Minister of Education, of a commission with the mandate to develop a new exam program for physics education in havo and vwo. It was a response to the wish that had been expressed by the government, the scientific community, and business, to attract more students to a career in science and technology. The renewal commission was composed of physicists from higher education, research, and business, and high school physics teachers. In this case, the renewal commission was supported by a project group that carried out a multi-year pilot. The commission drew up a vision document, based on experiences reported by physics teachers in the preceding years, research findings on physics education, and experiences with physics curriculum projects in other countries. This document was discussed in regional meetings with a total of about 200 teachers. The vision document described the *why* and *what* of curriculum intentions, regarding the content to be taught, its organization, and the testing of that content. Discussion meetings were organized also at the annual conference of physics teachers. Based on the vision document and feedback from teachers and other stakeholders, a draft examination program was drawn up in 2006, consisting of broadly formulated attainment targets to be attained and tested in high stakes external and internal final exams. This exam program was going to be tested in a pilot with 35 teachers at 15 schools. For this pilot, the exam program was elaborated in pilot teaching materials and at the same time in a concept-syllabus detailing the attainment targets in specifications with which the constructors of the central national exams set to work. The students at the pilot schools were tested in internal school exams and central exams constructed for the pilot. The exam program, the teaching materials, and the syllabus, and later the central pilot exams, showed concretizations of the curriculum intentions. Starting in 2007, the pilot teachers taught their lessons according to the new program for three years. The teachers met five times a year with members of the commission and project group to share their experiences with the enacted curriculum and make recommendations. These recommendations related to the pilot teaching materials, but also to the syllabus and the exam program. The constructors of the national exams also came up with questions and suggestions for the syllabus. As of 2009 (havo) and 2010 (vwo), the results of school exams and national exams from the pilot could be used to adjust the concept syllabus and the concept exam program. The experiences of students and teachers, and the results of the central pilot exams were evaluated by the commission and by external evaluators. The results of the evaluation were also used for adjustments to the concept syllabus and the concept exam program. At the end of 2010, the commission delivered a report to the Minister, advising on the new exam program with recommendations for teaching approaches, ways of examination, and teacher training. In 2011, the minister commissioned the Netherlands institute for curriculum development SLO and the board for national examinations CvTE to technically complete the exam program and to convert the syllabus for the pilot teachers and students with the final adjustments into a syllabus for all teachers and students. The author teams of the various publishers started to write their books and professional development was set up in regional cooperation between universities, colleges, and schools. In 2013, the new exam program became compulsory nationwide; in 2015 (havo) and 2016 (vwo), the first national exams were held.

By *curriculum development* is meant: the whole of processes that lead both to a written curriculum and to the curricula that are enacted by the teachers, for the targeted subject and level. This definition includes the study by developers of enacted curricula and feedback by teachers to developers, and therefore allows for a cyclic or iterative nature of curriculum development. Such a cycle can be an innovation project with pilot classroom trials, or a reform that results in a prescribed exam program, or a combination of both. The term *curriculum renewals* summarizes such projects and reforms.

In this study's terminology, the intentions that teachers and developers express in, respectively, enacted and written curricula are called *curriculum intentions*. Or, in other words: written and enacted curricula are defined for this study as expressions of curriculum intentions. In section 2.3, the key role of curriculum intentions for this study will be explained.

For the most recent physics education renewal as an example, Box 2.1 gives a brief outline of the steps that curriculum intentions went through on their way from the written curriculum to the enacted curriculum, and vice versa, in the context of a typical exam program renewal in upper secondary education in the Netherlands. More information on the upper secondary education system and on physics education in the Netherlands is given in Section 4.2, about the context of the renewals studied.

Earlier renewals differed from this process either because no pilot was included in the development of an exam program, or because no new exam program was developed following a project with pilot teachers. But the sequence of these other innovation projects and formal exam program reforms contains similar elements to this most recent renewal, with innovation projects to a certain extent in the role of pilots whose results were used by reform commissions without their own pilot.

2.3 Evolution as a metaphor

This study regards today's teachers' enacted curricula, as well as the written curricula from several renewals in the past five decades as expressions of the curriculum intentions of teachers and developers, respectively. The word *expression* is a loan from genetics and evolution theory, with their image of units of information (genes) traveling through generations of organisms and populations, in which this information expresses itself. Chapter 1 explained the interest in an evolutionary perspective for looking at the traces of curriculum renewals, as opposed to curriculum evaluations that look at what happened with the intentions of a certain development project or reform in the enacted curricula immediately following that project or reform. Many of those evaluations tend to report failing implementation of the curricula that the developers proposed, or, more positively, adaptations by teachers that explain why curricula are not enacted exactly as intended by developers (Hall, 1973; Cuban, 1988; Fensham, 1992; Fullan, 2007; Meltzer & Otero, 2015), although the evaluation of the most recent reform of the science exam program in the Netherlands (Ottevanger et al., 2018) finds quite a few enactments of the physics education commission's intentions reported by responding teachers. Chapter 1 referred to the disbelief that today's enacted curricula would not, or only poorly, reflect the developers' intentions that had been expressed in written curriculum during the past 50 years. Could it be that current enacted curricula show a lot of kinship with written curricula from decades ago, if we were to examine "the DNA" of those enacted curricula? Just as DNA research in plant systematics has led to other insights into species kinship than what for a long time was based purely on outer appearances (Gradstein, 2009).

Many authors have already stressed the metaphoric power of evolution theory, eloquent examples are Richard Dawkins in *The Selfish Gene* (1976/2016) and Daniel Dennett in *Darwin's Dangerous Idea* (1996), and praised it because of its conceptual elegance, or cursed it because of its inevitability: once you have understood the idea of evolution, you see evolution everywhere (hence a "dangerous idea"). Dawkins generalized the concept of *gene* to *meme*, a unit of cultural transmission, which can transmit information without necessarily having a physical vehicle such as DNA. Likewise, for this study curriculum intentions are visualized as memes, which travel through generations of expressions. The meme metaphor for curriculum development is also used by Priestley (2007, p. 60), who uses an image in which memes "combine to form the cultural software . . . which both constrains human thought and action, and also enables creativity; memes are encountered, and assimilated into human thought, reproducing and mutating in the process." My study uses a narrower image of memes and ascribes constraints and incentives influencing human thought and action to individuals' biographies and environments, in which memes may or may not come to expression. The notion of environment expands the set of metaphors with ecology. Section 2.4 will get back to this, about factors influencing the enacted curriculum.

An image of those curriculum intentions propagating between those two expressions, developers' documents (written curriculum) and teachers' practices (enacted curriculum), is sketched in Figure 2.1. The curriculum intentions, in their role as memes, are displayed in the center as abstract shapes, like triangles or diamonds. Displayed as animal pictures are the expressions of the intentions in a curriculum written by a project team or commission (the cloud on the left-hand side) and the enacted curriculum of a teacher, or the enacted curricula of all relevant teachers (the cloud on the right-hand side).

Figure 2.1 gives an impression of one of the cycles in curriculum development, with one written curriculum and one enacted curriculum, the latter as an aggregation of the enacted curricula of all teachers in the target group. In this image, teachers are influenced by curriculum intentions from developers and other sources, expressed by arrows from left to right, but teachers in turn may influence developers. Those influences are shown as arrows in the opposite direction, even if they work in a following cycle. Thus, the figure is a compromise between representing one and more cycles.

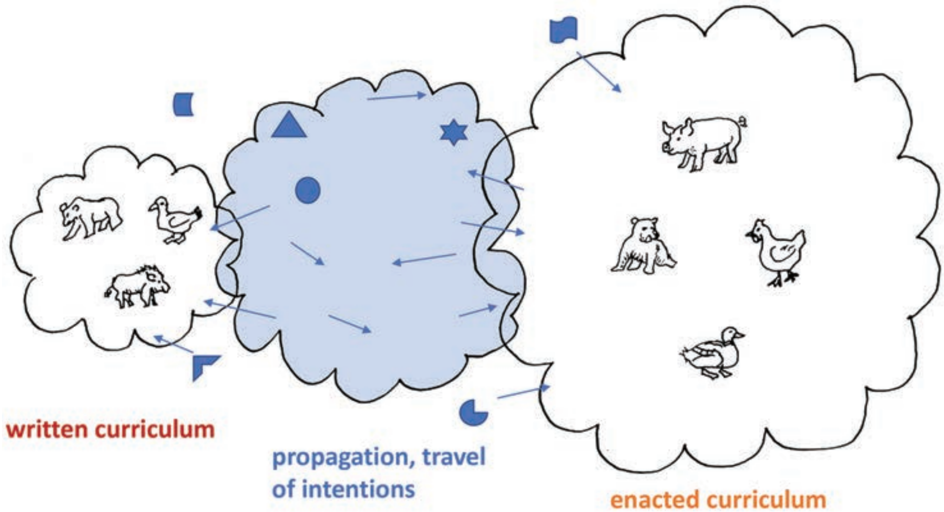

Figure 2.1 *Image of curriculum intentions traveling, as memes, between the written curriculum and the enacted curriculum.*

A perspective from evolution theory and genetics may help to understand processes of curriculum development by highlighting certain characteristics.

First, this perspective encourages recognizing similarities in dissimilar appearances. The "bears", for example, in the developers' and teachers' environments of Figure 2.1 are not completely similar, but they share a lot of genetic material. The basic similarities between curricula focused on in this study are their intentions, their memes. If we were to hear a teacher describe that, as a regular part of his lessons, he has students vote about questions and discuss their answers, we can recognize this as an expression of a curriculum intention summarized as *Advancing concept development*, which could have been promoted by an innovation project as "taking account of students' ideas." The terminology itself does not necessarily have to be reproduced, what counts is the underlying idea, the meaning of the terminology. As Dennett (1996, p. 354) puts it: "The meme is primarily a *semantic* classification, not a *syntactic* classification." The advantage of this tolerance in interpreting what teachers or developers say or write is that it helps avoid a disappointment lurking in a conceptual counterpart of evolution: the *design-and-upscale* metaphor. In this metaphor, creators design a prototype, test, and improve it, and engineers make it ready for large scale use. The evaluation of such upscaling often leads to frustration, if it looks for faithful copies of developers' elaborations, especially if it takes place after only a short period of time. The term *slippage* expresses the disappointment of designers (Westbroek et al., 2017). In an evolution metaphor, slippage can more neutrally be interpreted as the notion that memes are expressed in different ways under different circumstances. As mentioned in Chapter 1, a new expression can be indicated with a more positive word than *slippage*, for example with *adaptation* (McLaughlin, 1976; Fullan & Pomfret, 1977; Westbroek et al., 2017), in evolution language, or *transformation* (Ogborn, 2002). Coburn (2003, p. 4) comes to the upscalers' aid by offering a wider definition of scaling up than only "spread to additional sites", but, next to some other characteristics, also "consequential change in classrooms." If change becomes part of upscaling, as also shown in the quote about transformation from Ogborn (2002) in Chapter 1, then the *design-and-upscale* metaphor approaches the evolutionary metaphor. A difference that may remain is in the amount of control that upscaling engineers might want to have over that consequential change in classrooms. Coburn's proposals and Ogborn's reflections show how they also prevent disappointment by promoting the shift of ownership of a curriculum development process from developers to teachers.

A second quality of the evolution metaphor is that, in its ecological perspective, it draws attention to the *environment* in which a meme may or may not express itself. The phrase *survival of the fit* – or *fittest*, if memes compete with each other in the same environment – shows how not just the quality of a meme or just the quality of the environment determines whether a meme will be expressed or not, but that a fit between meme and environment is needed.

Using this perspective when studying curriculum development strengthens the awareness of the need to know the environment, the demand (or no demand) side of a development, just as much as one needs to know the key intentions of a renewal. For developers, the perspective helps to raise the awareness that environment development may be equally important as idea development. Coburn (2003, p. 6), in line with the ecological side of evolution theory, states that for sustainability, awareness is needed of the system in which a teacher works, "because classrooms are situated in and inextricably linked to the broader school and system, teachers are better able to sustain change when there are mechanisms in place at multiple levels of the system to support their efforts." Fullan points at the quality of the system when he notices about the fourth edition of his *The new meaning of educational change*, that (Fullan, 2007, p. 11): "there is a shift over the four editions from innovation to innovativeness." Priestley (2007, p. ii) concludes about innovation in schools that "processes [of curriculum making] are ineluctably social practices, and that those seeking to innovate in schools should pay attention to the social dimensions of change – the engagement of people with ideas and the social structures that impede, distort or promote change." This recognition of the role of the system in which a teacher works shows how the similarity of curriculum development processes to evolutionary processes does not condemn developers to passively wait to see which memes happen to survive in the available environments, but that influencing the environment can change selection pressures and thus influence the success of memes. Dennett (1996) argues that the travels of genomes, needed for biological possibilities to be realized, can go "'in the course of nature' – without human manipulation – or with the help of such artificial cranes as the techniques of traditional animal-breeding" (o.c., p. 118). This distinction in ways to travel, *in the course of nature* and *helped by artefacts*, inspires to distinguish propagation of curriculum intentions that are stimulated by deliberately taken implementation measures from propagation that apparently took place without such measures. That distinction will come back in Section 2.4.

A third characteristic of evolution theory that can inspire the study of curriculum development is its patience: new memes may be expressed only after some time, after changes in the memes' environment. Coburn (2003, p. 6) stresses the importance of sufficient time in curriculum reform for the sake of sustainability, as part of her concept of scale: "The distribution and adoption of an innovation are only significant if its use can be sustained in original and even subsequent schools." Still, Coburn argues here for enough time to secure for a longer period something that has already appeared, whereas the patience of an evolutionary perspective also means taking time for something that may yet appear.

Even though the evolution and genetics metaphor may offer a useful perspective, it also runs into limits when applied as a conceptual framework for this study.

One such limit lies with the concept of mutation. The patience of the evolution theory was mentioned as an inspiring characteristic, but the aspect of the time needed for allowing memes to spontaneously mutate is not borrowed. The memes, the curriculum intentions, are visualized as not mutating on their way between written and enacted curricula. This image deviates from Priestley's (2007) interpretation, who adds to the description of memes quoted above: "Memes are encountered, and assimilated into human thought, reproducing and mutating in the process" (p. 60). In the model used in this study, differences in appearance are ascribed to the systems in which the memes can be expressed. These systems are (groups of) developers and (groups of) teachers, respectively, each with their own biographies and working environments, which impose restrictions and offer incentives to each of them. Section 2.4 will get back to this.

For another limitation of the metaphor, Priestley's warning (2007, p. 60) applies that "the meme theorists tend to overstate their conception of memes, ascribing a sort of quasi-agency to them; thus, memes are said to compete actively for their places in human minds." Like Priestley, I do not ascribe agency to memes themselves, only to people, as part of the systems in which they act, who bring memes, i.e., curriculum intentions, to expression. There may be competition between curriculum intentions for time or other scarce resources in teachers' practices; that is not active competition by the intentions, but it is the teacher who is active by weighing their importance.

A third important limit lies at the absence of design in evolution. Darwin's theory only knows random variation and natural selection. In the perspective on curriculum development used in this study, a place is needed for design, for intended, plannable influences on the course of the evolvements, so that curriculum development is not just passively awaiting curriculum evolvement but can also apply designed selection pressure. And as opposed to evolution, which does not know preferences or a distinction between desired and undesired, design does have those categories.

2.4 Factors influencing enacted curricula

Which factors influence – stimulating or inhibiting – the expression of curriculum intentions? This is the second part of the main research question. For this study, a conceptual model for these influences has to focus on what factors are relevant for teachers, giving shape to their enacted curricula.

Some expressions in enacted curricula may have resulted from measures that developers take to support the implementation of a written curriculum, such as proposing legally established national attainment targets or providing sample learning materials. Some may have passed through other elements of the education system as steppingstones, elements of very different kinds, like teacher education, conferences, or textbooks. At the same time, teachers are no *tabulae rasae*. They have values about what they consider important, and beliefs about, amongst other things, effective education and the essentials of their subject. This section describes the models used in this study to analyze data about influencing factors, in which, as explained before, also actors are included. The perspective is inside-out: first, we look at the system of factors whose influences can directly be perceived by teachers themselves, then we zoom out to the factors surrounding that system.

Influencing factors experienced directly by teachers

A model was needed that helps structure the incentives and constraints from the environment of teachers, as well as biographical elements that they experience or have experienced, which may explain the origin of teachers' curriculum intentions and the way they express these in their enacted curricula. Many studies or models go into the question how teachers respond to change, like a curriculum reform or new subject content. Examples are the Concerns Based Adoption Model (Hall et al., 1973), the Interconnected Mode of Professional Growth (Clarke & Hollingsworth, 2002), or the study into the development of pedagogical content knowledge (PCK) following the introduction of new subject content (Henze et al., 2008). But for this study, a model was needed that organizes and explains teachers' experiences in a stable situation too, not necessarily as a response to a recent change. A model that offers useful components for analysis is the teacher agency model of Priestley et al. (2013), see Figure 2.2.

The output in this model is *agency*, "the way in which actors 'critically shape their responses to problematic situations' . . . something that is achieved through engagement with very specific contextual conditions" (Priestley et al., 2013, p. 188). This definition is not identical to the definition of an enacted curriculum used in this study, but, when applied to teachers as the actors, it is compatible. Moreover, the main components that the teacher agency model consists of may properly describe influences on a teacher's curriculum intentions as well as on their enactment.

Building on Emirbayer and Mische (1998), the authors distinguish three dimensions in the model (Priestley et al., 2013, p. 189–190). The iterational dimension refers to "the selective reactivation by actors of past patterns of thought and action, routinely incorporated in practical activity", shaped by experiences from life and professional histories. The projective dimension refers to "the intention to bring about a future that is different from the present and the past." The practical-evaluative dimension entails "the capacity of actors to make practical and normative judgements among alternative possible trajectories of action, in response to the emerging demands, dilemmas, and ambiguities of presently evolving situations." The horizontal arrows in the teacher agency model reflect the interplay between the three dimensions: past experiences influence intentions and judgments "in response to the emerging demands, dilemmas, and ambiguities of presently evolving situations" (p. 190).

For this study, several adaptations were made to this teacher agency model, after some trials to use its main components to analyze interviews with practicing teachers, and to show the role of feedback in the model. The results are shown in Figure 2.3. This model distinguishes teachers' values and beliefs from the incentives and constraints that teachers perceive from their *environment*. The values and beliefs, together with the teachers' personal history, are seen as the teachers' *profile*. Teachers' actions are influenced by both their profile and their environment. Their enacted curriculum affects the learning outcomes and attitudes of their students, which in turn are feedback for teachers as part of their professional history.

Some elements of the practical-evaluative dimension as described in the teacher agency model were selected and rearranged to be used in this study's model. The cultural aspects were limited to values and beliefs, distinguishing *ought*- from *is*-categories. *Values* refer to what teachers judge as a goal, for example what physics education ought to give students; *beliefs* refer to what teachers know or believe to be true, for example about the effectiveness of a didactical approach. This latter description concurs with Pajares' (1992, p. 316) summary of a *belief* as "an individual's judgment of the truth or falsity of a proposition." In his publication, Pajares distinguishes beliefs from values or attitudes, but does not define the term value itself. Parallel to his definition of belief, *value* is used in this study's model for "an individual's judgment of what a situation ought to be." The distinction thus made does not deny that values arise in part from beliefs and that beliefs develop through knowledge acquisition that is guided in part by values.

As for the other parts of the cultural dimension in the teacher agency model: *ideas* were not distinguished as a separate category at this level, as it would interfere with the connotation of ideas as curriculum intentions, travelling between the systems of developers and of teachers. And *discourse* and *language* were not used as separate categories but as elements of thought exchange that takes place in a social environment, in this study with colleagues and students in school or in a professional learning community, part of the structural aspects of the teacher agency model's practical-evaluative dimension.

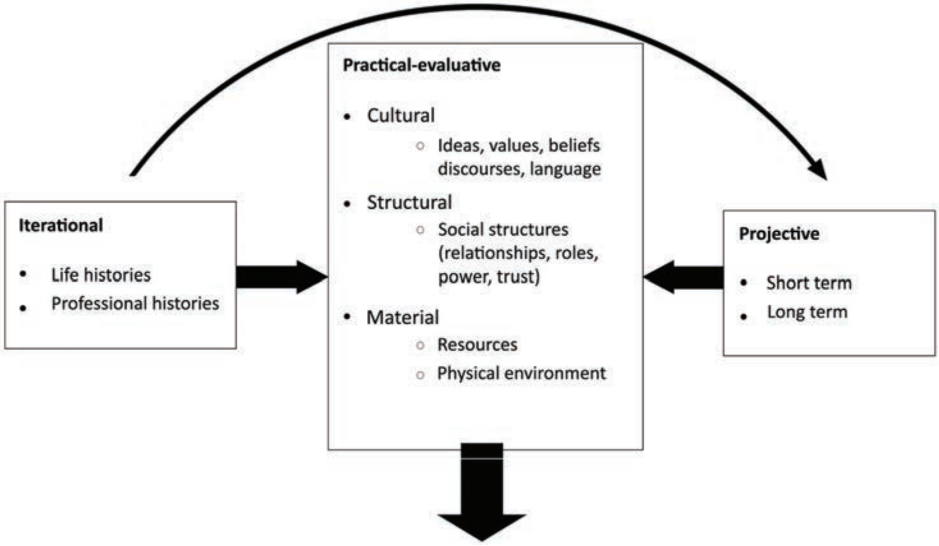

Figure 2.2 *Conceptual model for teacher agency by Priestley et al. (2013).*

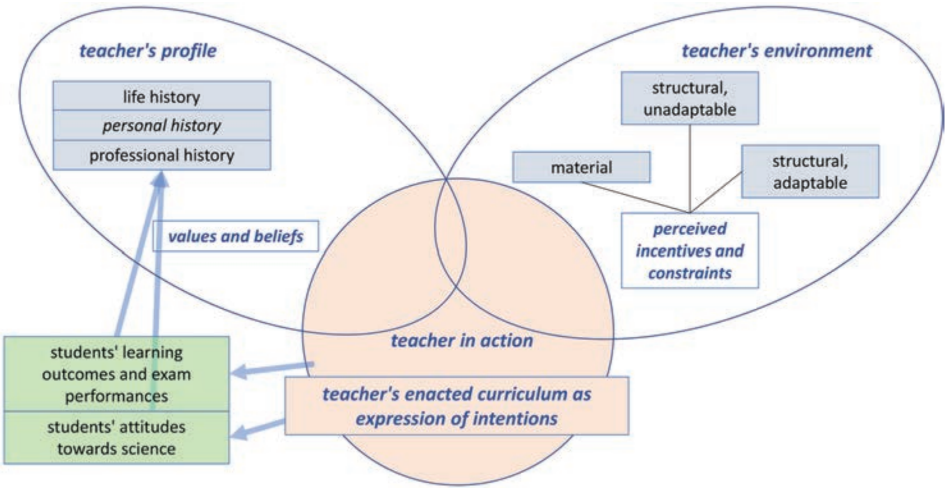

Figure 2.3 *Conceptual model for factors from a teacher's environment and profile, directly influencing a teacher's actions.*

Like the teacher agency model, this study's model includes *material* and *structural* aspects. These aspects apply to the environment in which teachers act, with all its incentives and constraints, such as their current classes, school, professional development provisions, legal prescriptions, and textbooks. The material aspects include textbooks and facilities in and around the physical school environment, but also web-based services. This corresponds with Priestley et al.'s (2013, p. 190) material aspects relating to "resources and the wider physical environment in which teachers act."

The material aspects themselves may not be adaptable by teachers, but teachers have possibilities of choosing from resources, which makes the system of material aspects to some extent adaptable.

Other aspects related to the teacher's environment are the structural aspects. Priestley et al. (2013, p. 190) describe those as relating to "relationships, roles, power and trust." For this study's model, they are interpreted to include incentives and constraints by relations with current students and colleagues, school's regulations, and national exam programs and syllabuses.

Within the dimension of structural aspects, two kinds of aspects are distinguished, to do better justice to the situation of teachers in Dutch upper secondary education. The *central-exam-system* or *CE*-system builds a resilient system of a national syllabus and a national exam, based on the CE-part of the exam program. The syllabus specifies the national exam program's attainment targets into detail. The CE-part of the exam program and the syllabus can only be adapted on a time scale of years and not by an individual teacher. At the same time, this system may enforce changes in teachers' enacted curricula by means of changes in exam program, syllabus, and national exams to which teachers need to accommodate. Because of these characteristics, the CE-system is called the *unadaptable structural system* in the model presented in Figure 2.3. Next to it, the *adaptable structural system* is distinguished, encompassing incentives and constraints in the teachers' environment that allow them more freedom to find an equilibrium with their values and beliefs. Teachers themselves can influence the adaptable structural system they are part of to a certain degree, also as an individual: their contacts with students, school leaders, colleagues from school or other schools, professional development groups, conferences. The adaptable structural system also refers to the school exam, addressing at least 40 percent of the exam program content, measured in numbers of attainment targets. The school exam (SE) part of the exam program is an important component of teachers' professional environment because it makes them responsible to enact a substantive part of the formal curriculum, including its assessment. This responsibility allows teachers a great deal of freedom in content choice and classroom activities compared to the nationally assessed 60 percent of the exam program. The attainment targets of the exam program's SE part cannot be adapted by a teacher, but for the elaboration in lessons and assessment a teacher is allowed a significantly larger variety of enactments than the high-stake CE-system with its detailed specifications of attainment targets; the SE-system can therefore be called part of the adaptable structural system.

More explanations about the Dutch upper secondary education system as a context for physics teachers and curriculum development are given in Section 4.2.

The teacher agency model also distinguishes a *projective dimension*. Priestley et al. (2013, p. 191) summarize it as the teachers' short-term and longer-term aspirations. For this study, this dimension was merged with the cultural aspects: expectations of teachers were conceptualized as being part of their beliefs and intentions of teachers as part of their values. Expectations mostly apply to learning outcomes and the appreciation of science by students. These outcomes and this appreciation were added to the model used in this study, as projected as well as experienced by the teacher.

It should be noted that the term *intentions* is used in this study to denote key ideas in a written or enacted curriculum, which are marked in terms of the set of curriculum intentions, introduced as a concept in Section 2.2, and elaborated in Chapter 3.

As for the structure of the model used in this study, the life and professional history – the *iterational dimension* in the teacher agency model – were connected to the values and beliefs of the teacher, as an influence, and not also to the material and structural dimensions because these are not influenced by the teacher's history. Together, the teacher's life and professional history are addressed as the *personal history*. The personal history is combined with the values and beliefs in the *teacher's profile*, the material and structural systems in the *teacher's environment*. Thus, the actions of teachers are influenced both by their profile and their environment.

The influence the teacher hopes or believes to have on the students is included in the model, both in learning outcomes and in appreciation of science. The experienced outcomes and appreciation of students then feed back into the teacher's professional history: today's experiences are tomorrow's history.

These modifications led to a model for the influences on a teacher's action, resulting in his/her enacted curriculum, as drawn in Figure 2.3. The model shown in the figure indicates the conceptualization that profile and environment influence a teacher in action through overlapping areas. The definitions used for the teacher's profile and environment, and their components do not overlap. But as the model does not exclude influences between those two, the areas indicating profile and environment are drawn as overlapping.

This model shows the teacher in action, her/his enacted curriculum as influencing the students, and the factors in profile and environment influencing the teacher. It pictures the factors, including teacher educators, colleagues, or students, that may directly influence the curriculum enacted by the teacher.

In Section 2.2, the terminology has been defined, including the *written curriculum* and the *enacted curriculum*. The latter is explicitly mentioned in the model of Figure 2.3, the former is included in the structural and material aspects of the teacher's environment. In the same section, the role of Goodlad's (1979) *perceived curriculum* is mentioned as a factor that influences the teacher's enacted curriculum. In Figure 2.3, the perceived curriculum, as the teachers' perception of the written curriculum, is included in the incentives and constraints perceived by the teachers from their environment. Goodlad's *experiential* and *learned curriculum* are represented in the model of Figure 2.3 as the students' learning outcomes and attitudes toward science. They are not studied as such, but may be reflected in teachers' reports of their professional histories.

Indirect influences

The factors, shown in Figure 2.3 as influencing teachers' profiles and environments, can be called *direct influences* on the teachers' enacted curriculum. If teachers' actions, profiles, and environments are regarded as a system, this may in turn be influenced by factors from outside, called *indirect influences*. An example is proposing changes of mandatory attainment targets to the Ministry of Education, but also creating provisions for professional development, or offering tools for computer modeling are indirect influences. In a model zoomed out from that of Figure 2.3, Figure 2.4 visualizes the system of direct influences, surrounded by indirect influences. Indirectly influencing factors were searched as part of this study, and the analysis of data about these factors resulted in a finer breakdown of the various factors.

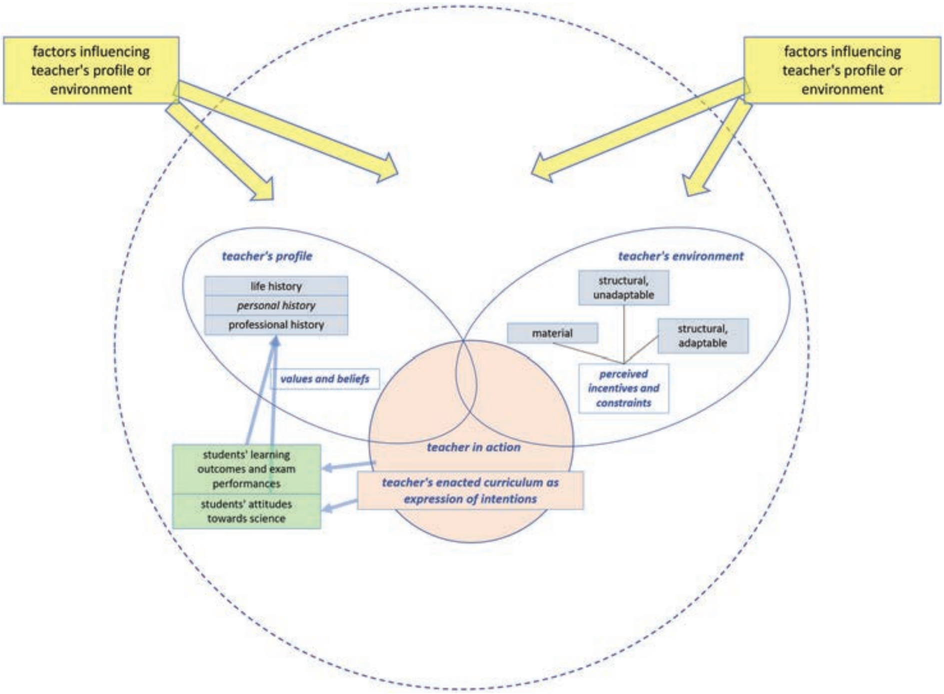

Figure 2.4 *Conceptual model for factors influencing a teacher's environment and profile, indirectly influencing teacher's actions.*

Directly and indirectly influencing factors can be seen as vehicles that more or less effectively support curriculum intentions, as memes, to travel from developers to teachers, from expressions in written and in enacted curricula. Thus, a model of factors directly and indirectly influencing teachers' actions offers a closer look at the medium between developers and teachers as shown in Figure 2.1, although only in one direction, the direction of this study, by focusing on the teacher and the enacted curriculum. The other direction, from teachers to developers, comes into play when the question is asked what sources of curriculum intentions may in turn influence developers. Indications for such influences on developers were noted as sources of curriculum intentions when they appeared in this study.

CHAPTER 3
Design of the study

3.1 Introduction

In this chapter, the research questions and methods of the four substudies are described in Section 3.2. The two sections that follow describe elements of the substudies that are not specific to any of them. The first two of the substudies aimed to identify what curriculum intentions could represent, as *memes*, the renewals' key intentions and could be used to analyze what interviewed teachers said about their practices. The initial set of curriculum intentions used as a starting point for these two substudies is described in Section 3.3. For Substudies 2 and 3, 13 teachers were interviewed. Section 3.4 describes characteristics of the selection of teachers to be interviewed and aspects of the methodology that are not specific to either of these two substudies.

3.2 Four substudies: questions and methodology

This study looks for answers to the twofold mail research question as introduced in Chapter 1:

> *To what extent do enacted curricula in upper general secondary physics education in the Netherlands reflect the intentions of renewals expressed in written curricula initiated since the 1970s and what factors may have influenced the expression of the renewals' intentions in teachers' enacted curricula?*

This question refers to the case of the study: upper general secondary physics education, at the national level, in the Netherlands since 1970. This comprises two school types: the two-year *havo* (senior general secondary education), preparing for higher professional education, and the three-year *vwo* (pre-university education).

The study had an explorative character. It started with a conceptual reflection and literature review, to identify research questions for substudies needed to answer the main research question, to clarify the perspectives and conceptual models for analyzing the data from the substudies, and to establish an appropriate terminology. The results were reported in Chapter 2.

After the conceptual reflection and literature review, the study was set up in four qualitative substudies, each guided by a subquestion and each conducted with its own method of data collection and analysis. The substudies addressed the following research questions.

1. *What curriculum intentions represent in a valid way what developers pursued in the various renewals of upper general secondary physics education in the Netherlands since 1970?*
2. *To what extent do descriptions of their practices and intentions by physics teachers in upper general secondary education in the Netherlands reflect the intentions of curriculum renewals initiated since the 1970s?*

3. *What teacher profile and environment factors, as perceived by teachers, may have influenced the expression of curriculum renewal intentions in their teaching?*
4. *What factors may have influenced profiles and environments of teachers against the background of the curriculum renewals in upper general secondary education physics education in the Netherlands since 1970?*

The third and fourth substudies, and their research questions, are closely linked and pertain to the second part of the main research question, about what factors may have influenced the expression in today's enacted curricula of curriculum renewal intentions of upper general secondary physics education in the Netherlands since 1970.

Preceding the substudies, an initial list of curriculum intentions was made, which was found plausible based on the researcher's personal knowledge of the developments in physics education. This list is described in Section 3.3. Also, 13 upper general secondary physics teachers, active in 2017 and 2018, were selected to be interviewed for Substudies 2 and 3. The procedure and outcome of this selection, as well the general structure of the interviews, is described in Section 3.4.

For Substudy 1, orientation interviews with participants and witnesses of physics education renewals were conducted along with an analysis of written curricula: exam program recommendations, publications, and other accounts by project teams or reform commissions. The sources were analyzed using the initial list of curriculum intentions to select and code relevant quotations. The analysis was then discussed in a meeting with project leaders, chairpersons, and other persons who had been active in or around those renewals. The report of this meeting was used to adjust and validate the list of curriculum intentions. The design and outcomes of this substudy will be described in Chapter 4, which includes a description of the choice of the renewals examined and a characterization of these renewals.

For Substudy 2, the 13 selected teachers were interviewed about their enacted curricula. The interviews were analyzed using ATLAS.ti. In the process of selecting and coding quotations, open coding was used next to the set of curriculum intentions and their descriptions, emerging from Substudy 1. The analysis was largely qualitative and aimed to find curriculum intentions expressed by the interviewees and to examine to what extent the reported practices and intentions reflected the renewals' curriculum intentions. The design and outcomes of this substudy will be described in Chapter 5.

For Substudy 3, the same 13 teachers were interviewed as for Substudy 2, in fact the interviews took place in one session for each teacher. The interviews were analyzed using ATLAS.ti. In the process of selecting and coding quotations, open coding was used next to a set of influencing factors based on the conceptual model of Figure 2.3. The analysis was largely qualitative and aimed to find factors mentioned by the interviewees as influencing or having influenced their enacted curriculum. Where possible, connections were made between the influencing factors and the various curriculum intentions. The design and outcomes of this substudy will be described in Chapter 6.

For Substudy 4, relevant documents produced by Dutch upper secondary education physics education renewals or reflecting on renewals were analyzed and interviews were conducted with participants and witnesses of the renewals. Part of the orientation interviews held for Substudy 1 were also used as sources for this fourth substudy. The interviews were analyzed using ATLAS.ti. The process of selecting and coding quotations started with open coding. A first analysis was used to refine the model from Figure 2.4, the refined model was then used to structure a set of codes to further analyze written sources and interviews. The analysis was qualitative and aimed to find factors that appeared to, or were meant to influence teachers' profiles and environments, and thus indirectly the enacted curricula. The design and outcomes of this substudy will be described in Chapter 7.

For Substudies 2, 3, and 4, the codes used for the analysis of the interviews and their application to a sample interview were discussed with a second coder to reach intercoder agreement. This resulted in codebooks with more detailed descriptions and more uniformity in the use of the codes to analyze interview fragments. In Substudy 4, the intercoder discussion was also used to refine the model of Figure 2.4.

The methods used to study the main research question and the subquestions are summarized in Table 3.1. The methods for each of the substudies will be described in more detail in the chapters dedicated to the substudies.

Table 3.1 *Methods used for the various parts of the study.*

Method	Used for
Conceptual reflection and literature review	Conceptual framework
Interviews with participants and witnesses, historical	Substudies 1 and 4
Document analysis, historical	Substudies 1 and 4
Meeting with participants, historical	Substudies 1 and 4
Interviews with teachers, contemporary	Substudies 2 and 3

3.3 Curriculum intentions traced and tracked in this study

Selecting curriculum intentions and making a first set of descriptions for analysis purposes in preparation of the substudies was to a great deal a joint effort with a master student working on a thesis on physics textbooks since 1980 (Ververs, 2016). We chose curriculum intentions to be traced which assumingly had been promoted by at least some of the renewals. The validity of the selection was examined in Substudy 1 and the possibility of finding other important intentions in Substudies 1 and 2 was left open. The choice was limited to intentions that were specific enough for goals and content of physics education to distinguish them from more general developments in teaching practice, such as the use of computers or the role of assessment, but it was no objection if the intentions could also apply to curricula for the other sciences. The choice of intentions was not meant to be an exhaustive representation of everything all renewals aimed at. The substudies were therefore preceded by the drawing up of a list of possible intentions that met the criteria mentioned above and that were found plausible based on personal knowledge of the researcher of the developments in physics education.

The following five categories of curriculum intentions were chosen to be tracked in both substudies:

1. Using contexts
2. Widening the scope of science education
3. Coordination with other STEM-subjects
4. Advancing concept development
5. Advancing skills development.

In the following sections, it will be elaborated how these categories have been operationalized to be validated in Substudy 1 and to be used in the analyses that were part of Substudy 2. Some of the categories needed more precise and more extensive descriptions to support intercoder agreement in analyzing the interviews for Substudy 2; those details are reported in Chapter 4. The intentions might not be described in renewal documentation or in interviews in the exact wording of the list below. What matters is that descriptions that teachers or developers give correspond with the descriptions given below, or, in Substudy 2, with the coding list that emerged from the analysis and intercoder discussion of interviews.

Using contexts

The term *context* is used in the meaning of a practice, situation, or problem that has or will have meaning for students through the learning activities to be carried out. Such a practice, situation, or problem can be taken from the world of science research, from society, or from the life world of the student in which physics knowledge can be used. This definition is borrowed from the vision document by the most recent reform commission (Commissie Vernieuwing Natuurkundeonderwijs havo/vwo, 2006, p. 36). It is consistent with more extensive descriptions used in context-based science education (Gilbert, 2006; King & Ritchie, 2017).

For the analysis of documents that describe the intentions of the renewals, two ways of using contexts were looked at:

a. as recommended or even prescribed curriculum content, to show how physicists are engaged with issues from everyday life, society, or research;
b. as a pedagogical strategy for teaching concepts or explanations, in a “light version” of this strategic function also to merely raise students’ interest in physics or the topic at hand.

Widening the scope of science education

Initially, the category *Widening the scope of science education* was called *Combining curriculum emphases*. But during Substudies 1 and 2 it appeared that this initial name did not speak for itself enough, which was a reason to change it.

The concept of *curriculum emphases* is key to this category. It characterizes the messages that a curriculum conveys to students about the scope of what matters in science education. Roberts (1982) described seven curriculum emphases, in which each emphasis stands for:

> . . . a coherent set of messages to the student about science (rather than within science). Such messages constitute objectives which go beyond learning the facts, principles, laws and theories of the subject matter itself — objectives which provide an answer to the student question:'Why am I learning this?' (p. 245)

These emphases have been adopted in various studies as indicators of curriculum intentions, related to the question 'Why are our students learning this?'. Van Driel et al. (2008) bundled the emphases for chemistry education into three categories and we chose to use these three categories because they are clearer and sufficiently distinctive. However, we formulated them in terms of science education instead of chemistry education or physics education because even in physics education, most of them intend to tell something about the history, nature, or use of science, rather than of physics alone. For the list of curriculum emphases to check and then use in the substudies, a fourth category was added to these three, which were assumed to be part of the intentions of some developers or teachers: emphasizing acquaintance with phenomena.

As operationalizations of curriculum emphases, it was investigated if the written or enacted curricula expressed the following intentions implicitly or explicitly:

a. Fundamental Science (FS): students learn that the natural sciences have a solid foundation and offer correct explanations;
b. Knowledge of the Development in Science (KDS): students learn that physics is an activity of people, who use characteristic ways of thinking and practices;
c. Science, Technology and Society (STS): students learn that science develops in conjunction with technology and society and that science is relevant to understand societal issues;
d. Phenomena in nature (PhN): students get acquainted with phenomena that reveal much about how nature works.

Both of Roberts's curriculum emphases *Correct Explanations* and *Solid Foundation*, which combine in Van Driel et al.'s (2008) category *Fundamental science*, are messages that are "communicated by default" (Roberts, 1982, p. 37). Therefore, *Widening the scope of science education* was regarded as elaborating one or more of the *other* curriculum emphases, next to the default FS.

Coordinating with other STEM subjects

The curriculum intention that physics education should be coordinated with other science, mathematics, and technology subjects, in Dutch combined in the term *bètavakken*, in English in STEM (Science, Technology, Engineering and Mathematics) subjects, addresses the intentions that:

a. cross-cutting STEM-contexts are used as prescribed content or as organizing principles of subject content;

b. cross-STEM competencies or subject content appear in attainment targets that are identical for all STEM-subjects.

Advancing concept development

For the operationalization of concept development for analysis purposes, we chose the indicators that have been developed by the American *Project 2061* to help analyze conceptual development contributions in teaching materials. The authors order them in the following clusters (Roseman et al., n.d.):

a. Providing a sense of purpose
b. Taking account of student ideas
c. Engaging students with phenomena
d. Developing and using scientific ideas
e. Promoting student reflection
f. Assessing progress
g. Enhancing the learning environment.

These indicators were elaborated in short descriptions, based on the source of *Project 2061* mentioned above. Table 3.2 gives the list of indicators. If a fragment from a document or an interview referred to one or more of these indicators, then that fragment was marked as an expression of this curriculum intention.

The clusters overlap with features of other intentions: *Using contexts* (cluster a), see also Gilbert (2006), *Widening the scope of science education* (c and d) and *Advancing skills development* (c and g), but we preferred to keep the list of clusters of *Project 2061* intact.

Table 3.2 *Indicators for Advancing concept development, based on Project 2061.*

Cluster	Indicators
a. Providing a sense of purpose	Are the purposes of this part of the curriculum made explicit and meaningful? • Framing. Are important focus problems, issues, or questions about phenomena offered that are interesting and/or familiar to students? • Connected sequence. Are students involved in a connected sequence of activities (versus a collection of activities) that build toward understanding of a benchmark(s)?
b. Taking account of student ideas	Are student ideas identified and related to in one or more of the following ways? • Prerequisite knowledge/skills. Are prerequisite knowledge/skills specified that are necessary to the learning of the benchmark(s)? • Alerting to commonly held ideas. Is there awareness of commonly held student ideas (both troublesome and helpful)? • Identifying students' ideas. Is there room to find out what students think about familiar phenomena related to a benchmark before the scientific ideas are introduced? • Addressing commonly held ideas. Are commonly held student ideas explicitly addressed?

Cluster	Indicators
c. Engaging students with phenomena	Are students enabled to see that phenomena are explained in terms of a small number of principles or ideas, and have a sense of the range of phenomena that science can explain? Do one or more of the following apply? • First-hand experiences. Are students offered activities that provide first-hand experiences with phenomena relevant to the benchmark when practical and when not practical, make use of videos, pictures, models, simulations, etc.? • Variety of contexts. Are experiences promoted in multiple, different contexts so as to support the formation of generalizations? • Questions before answers. Are problems or questions about phenomena linked to solutions or ideas?
d. Developing and using scientific ideas	Are links provided between phenomena and ideas and demonstrates the usefulness of the ideas in varied contexts? Do one or more of the following apply? • Building a case. Are students helped to draw from their experiences with phenomena, readings, activities, etc. to develop an evidence-based argument for benchmark ideas? (This could include reading material that develops a case.) • Introducing terms. Are technical terms introduced only in conjunction with experience with the idea or process and only as needed to facilitate thinking and promote effective communication? • Representing ideas. Are appropriate representations of scientific ideas provided? • Connecting ideas. Is attention explicitly drawn to appropriate connections among benchmark ideas (e.g., to a concrete example or instance of a principle or generalization, to an analogous idea, or to an idea that shows up in another field)? • Demonstrating/modeling skills and use of knowledge. Are skills or the use of knowledge demonstrated/modeled? • Practice. Are tasks/questions for students provided to practice skills or using knowledge in a variety of situations?
e. Promoting student reflection	Are students helped to express, think about, and reshape their ideas to make better sense of the world? One or more of the following: • Expressing ideas. Are activities provided (such as group work or journal writing) for having each student express, clarify, justify, and represent his/her ideas? Are students offered ways to get feedback from peers and the teacher? • Reflecting on activities. Are tasks and/or question sequences provided to guide student interpretation and reasoning about phenomena and activities? • Reflecting on when to use knowledge and skills. Are students helped to know when to use knowledge and skills in new situations? • Self-monitoring. Are students supported to check their own progress and consider how their ideas have changed and why?

Cluster	Indicators
f. Assessing progress	Do one or more of the following goal-relevant assessments apply? • Alignment to goals. Are assessment items provided that match the content? • Application. Are assessment tasks provided that require application of ideas and avoid allowing students a trivial way out, like using a formula or repeating a memorized term without understanding? • Embedded. Are some assessments embedded in the curriculum along the way? Are the results used to choose or modify activities?
g. Enhancing the learning environment	Do one or more of the following apply? • Classroom environment. Is a classroom environment created that welcomes student curiosity, rewards creativity, encourages a spirit of healthy questioning, and avoids dogmatism? • Welcoming all students. Is a classroom community created that encourages high expectations for all students, that enables all students to experience success, and that provides all different kinds of students a feeling of belonging into the science classroom?

Advancing skills development

A fifth aspect for scoring written and enacted curricula concerns the development of skills. For this study, the operationalization was limited to the following four groups of skills to be acquired by students, in the formulation borrowed with some rephrasing from the most recent exam program proposal (Commissie Vernieuwing Natuurkundeonderwijs havo/vwo, 2010):

a. Research skills: ability to analyze questions in contexts, to use relevant concepts and theory, to translate them into subject-specific research, to carry out that research, and to draw conclusions from the research results, using consistent reasoning and relevant arithmetic and mathematical skills.
b. Design skills: ability to prepare, execute, test, and evaluate a technical design in contexts based on a posed problem, using relevant concepts, theory and skills, and valid and consistent reasoning.
c. Modeling skills: ability to analyze a relevant problem in contexts, reduce it to a manageable problem, translate it into a model, generate and interpret model results, and test and assess the model, using consistent reasoning, and relevant arithmetic and mathematical skills.
d. Judging or decision-making skills: ability to give a reasoned opinion about a situation in nature or a technical application, distinguishing between scientific arguments, normative social considerations, and personal views.

The objects of these skills are also found in the components of the category *Widening the scope of science education*, in particular the curriculum emphases *Knowledge development in science* and *Science, technology and society*. For *Advancing skills development*, the focus was on a hands-on character, expressed for example in practical work or modeling activities, whereas with *Widening the scope of science education*, the focus was on the topics that are chosen as part of the curriculum content and on the theoretical reflection on history, nature, and social position of science and technology.

Scientific literacy not included separately

When deliberating which categories should be part of the initial list of curriculum intentions (see the list described above), we considered one other category that in the end was not chosen: scientific literacy. Scientific literacy was a good candidate because it reflects the desire of many developers and teachers to make science education relevant not only for future scientists, technologists, or technicians, but for all students, as an introduction in science content and competencies that all citizens and consumers ought to have had (Millar & Osborne, 1997; Laugksch, 2000; Osborne, 2007; OECD, 2013, 2017). We regarded the components of scientific literacy that emerged from OECD's deliberations to be included in its science framework for PISA 2015 (OECD, 2013) as a good reference to be compared with the other curriculum intentions that were considered. OECD (2013, p. 5; 2017, p. 21) defines as scientific literacy in PISA 2015 the following three competencies:

- explain phenomena scientifically;
- evaluate and design scientific enquiry;
- interpret data and evidence scientifically.

These components overlap strongly with the spectrum of curriculum emphases addressed by the category *Widening the scope of science education*, and with the skills in the category *Advancing skills development*. For that reason, it was decided not to include an extra category *Scientific literacy* but to leave the detection of its traces to the other categories of curriculum intentions.

Summary

The descriptions of curriculum intentions are summarized in Table 3.3. This table was used as the initial list of descriptions, to be validated in Substudy 1 as representing what physics education renewals since 1970 intended.

Table 3.3 *Elements of science curriculum intentions.*

Curriculum intentions	**Elements**
Using contexts	The curriculum uses contexts with one or more of the following intentions: a. contexts are used as curriculum content, aimed for or even prescribed; b. contexts are used as a pedagogical strategy, for teaching concepts or explanations, or just to raise students' interest in physics.
Widening the scope of science education	Next to the first curriculum emphasis mentioned below (FS), the curriculum also elaborates one or more of the other curriculum emphases: a. fundamental science (FS); b. knowledge of the development in science (KDS); c. science, technology and society (STS); d. phenomena in nature (PhN).

Curriculum intentions	Elements
Coordinating with other STEM subjects	The curriculum shows one or more of the following ways to coordinate physics with other STEM subjects: a. cross-cutting STEM-contexts are used as prescribed content or as organizing principles of subject content; b. cross-STEM competencies or subject content appear in attainment targets that are identical for all STEM-subjects.
Advancing concept development	The curriculum advances that students develop understanding of physics concepts by one or more of the following approaches: a. providing a sense of purpose; b. taking account of student ideas; c. engaging students with phenomena; d. developing and using scientific ideas; e. promoting student reflection; f. assessing progress; g. enhancing the learning environment.
Advancing skills development	The curriculum advances one or more of the following skills: a. research skills; b. design skills; c. modeling skills; d. judging or decision-making skills.

3.4 Teacher interviews as sources for Substudies 2 and 3

Combining interviews in one session per source

For answering both parts of the main research question, teachers were crucial sources, for the second as well as the third substudy. Between May 2017 and November 2018, 13 teachers were interviewed, each of them for both substudies, combined in one interview session. One interview part went into the teacher's enacted curriculum and underpinning motivations and expectations (Substudy 2), another part into the factors perceived by the teacher as influencing her/his practice (Substudy 3). In several interviews, cross-references could be made by the interviewer or the interviewee. In other interviews, the parts did not affect each other. For some of the interviewed, additional information or further clarification on details was asked by e-mail, to which the responses were integrated in the accorded transcript. For none of the interviews, a second session appeared necessary.

Table 3.4 *Distribution of interviewed teachers.*

years of age	<35	35-55	>55
experience in other roles	D (8)	B (12) J (15) K (13)	H (23) M (30)
no experience in other roles	E (6) L (9)	G (7) N (22)	A (27) C (15) F (24)

Selection of teachers to be interviewed

For the interviews, 13 teachers were selected from 20 teachers who had responded to a call on websites and during a conference or to a letter distributed in the networks of some teacher educators. All responding teachers were sent a form asking for data on their age, seniority as teacher, experience in other than teacher roles in physics education, classes which they were teaching physics at that moment, and any other subjects they were teaching. The selection was made in such a way that it included teachers (see Table 3.4):

- with and without experience in other roles in physics education than a teacher role, e.g., curriculum development, test development, textbook author;
- aged younger than 35 years, between 35 and 55 years, older than 55 years.

There were not enough responding teachers to allow including a distribution on seniority too, but nevertheless a certain distribution of seniority came out. During the interview, the professional biography of the teacher was discussed, which also informed us if the teacher had had a career outside education before, in other words if (s)he was a “main entry” or “lateral entry” teacher.

Among the responding teachers, only two were women; both were included in the interviewed group. None of the analyses of substudies 2 and 3 revealed any meaningful difference between the women and men interviewed that could be related to their gender. Therefore, references to gender were omitted in the designation of interviewees.

Table 3.4 shows the selection of teachers that participated in the interviews, the age groups, whether they have experience in other roles in physics education, and their seniority as a physics teacher (indicated by the numbers of years in brackets). D, G, J, and N had had a professional career outside education before.

The distribution of characteristics of the teachers interviewed was primarily meant to avoid age or professional training biases, each age or experience group now contains a few participants. The wish to have time for interviewing teachers limited the size of the sample, and thus its representativeness for the entire population of the (approximately 1500) Dutch upper general secondary education physics teachers.

Apart from the diversity in biographical features, the selected teachers also differed in characteristics that appeared from the interviews. Based on the forms they had previously completed and from the interviews, portraits under pseudonyms, approved and sometimes adapted by the participants, are brought together in Appendix 1, *Portraits of the interviewed teachers*. The portraits can be helpful in connecting references to the participating teachers in the results sections of the chapters about Substudies 2 and 3, Chapters 5 and 6, respectively. They also confirm the diversity in the selected group.

Organization of the interviews

The first two interviews were done by the researcher together with a colleague – a physics curriculum developer – two of the other interviews by that colleague and nine of the other interviews by the author. The teachers were visited in their workplace, in an office or empty classroom, without disturbance. The interviews took place in one session, usually interrupted by a coffee break. Most interviews lasted about 90 minutes, a few about 15 minutes longer. For one of the interviews, only 50 minutes were available, for one other 65 minutes.

The structures of the interview parts for the Substudies 2 and 3 differed, they will be described in Chapter 5 and 6, respectively.

Validation of the interview transcripts

The recorded interviews were transcribed into a text that was slightly edited, as close as possible to a verbatim transcript, leaving out some repetitions or detailed descriptions of events. The transcripts were sent to the participants for correction and validation. All participants agreed with the transcripts, some with minor corrections, some added comments meant as supplementary to the original interview.

CHAPTER 4

Curriculum intentions of physics renewals since the 1970s

4.1 Introduction

To determine the extent to which the curriculum intentions expressed in the curricula enacted by teachers today reflect the intentions of the developers working on curriculum renewals since the 1970s (the first part of the study's main question), it was first necessary to identify a valid set of such intentions. The question that guided this first substudy was:

> *What curriculum intentions represent in a valid way what developers pursued in the various renewals of upper general secondary physics education in the Netherlands since 1970?*

This substudy focuses on elements of written curricula from renewals since 1970, the leftmost cloud in Figure 4.1 (based on Figure 2.1). The animals in that cloud represent elements of written curricula as found in documents which in this study were viewed as expressions of curriculum intentions. In the figure, the abstract icons represent curriculum intentions.

This substudy looked at whether the initial list of assumed curriculum intentions, described in Chapter 3, could be regarded as a valid one. The validation was based on an analysis of written sources produced by six exam program reform commissions and innovation projects, and a discussion of the outcomes of the analyses with participants of five of those renewals in a participants' meeting in April 2016.

Section 4.2 gives an overview of the context of the case of this study: upper general secondary physics education in the Netherlands since the 1970s. Section 4.3 explains the choice of the selected renewals and describes each of them; it also mentions the sources of each renewal used to verify its curriculum intentions. Section 4.4 describes the design of this substudy, 4.5 its results, and 4.6 its conclusions.

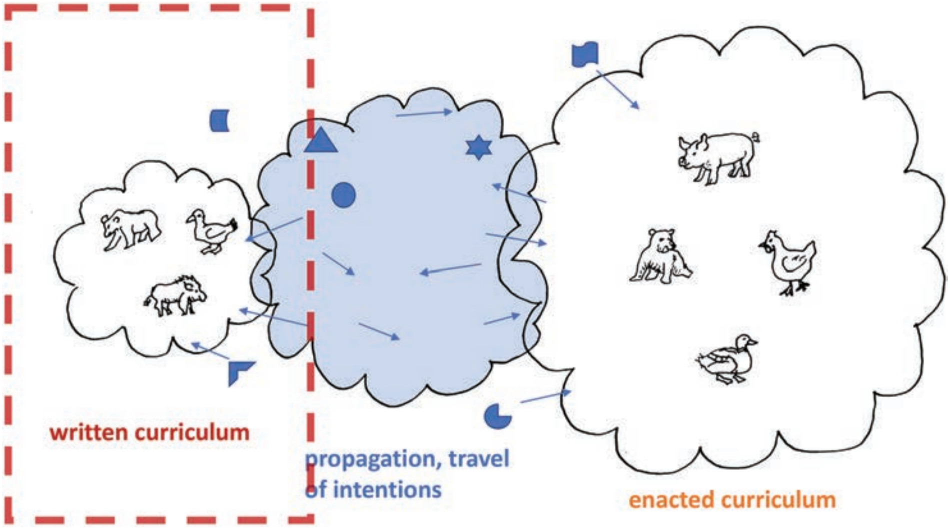

Figure 4.1 *Image of curriculum intentions traveling, as memes, between the written curriculum and the enacted curriculum.*

4.2 Context of the case

For a good understanding of this study, it is useful to know some peculiarities of the upper secondary education system and of physics education in the Netherlands.

Since 1968, the year in which the new *Law on secondary education* was implemented, there have been two student ability tracks in the upper part of general secondary education, for students from grade 10 (15 year old students): the two-year *havo* (senior general secondary education) preparing for higher professional education (today also called universities of applied science), and the three-year *vwo* (pre-university education)[1], preparing for (research) universities. All renewals in this study applied to both school types.

The *Law on secondary education* is in force to this day, with many modifications. It is also known by its nickname *Mammoth Law*, given by an MP who found the law monstrous; the minister who had proposed the law had taken it as a badge of honor because the law initiated a giant reorganization.

With that law, all subjects, except for a few compulsory subjects for all students, became optional in the upper secondary part. Physics was also optional, although it was an admission requirement for many higher studies. A 1998 reform created four so-called profiles, programs of study, each with profile-specific compulsory subjects, next to general compulsory and optional subjects. Since then, physics has been compulsory for students who choose the *Nature & Technology* profile (both at havo and at vwo), introduced in that year. Though physics is not compulsory in the *Nature & Health* profile, many students in that program take it, because in higher education many medical and other health related studies demand it as an access criterion.

1 These and other terms are listed with their explanation in Appendix 6: Glossary.

In upper general secondary physics education, students are assessed with a combination of school exams (SE) and central exams (CE). The SE tasks are constructed by teachers for their own students, the CE tasks are constructed for the national level by exam construction groups, consisting of teachers and professional test developers, working under the direction of the National Institute for Educational Measurement (Cito). The SE is meant to have an important role in the testing of skills and of some content areas, the selection of which changes over time. However, in practice today, much SE time is used to prepare CE matter.

The balance between SE and CE has changed over the decades; since 1998, the SE has been acknowledged in the regulations as an exam equivalent to the CE, with SE and CE grades for a subject each counting for 50% of the final grade for that subject. Even so, the central exam has always been the dominant part of the dual exit exam system, exerting more influence on teachers' practices than any other element in the system, in large part because teachers are evaluated based on the CE results of their students. The textbooks also follow the CE attainment targets and exam tasks closely.

Since 2007, the school exam for physics must cover at least 25 percent of the exam program content, in 2013 this SE share was increased to 40 percent (not to be confused with the 50/50 balance in the final grade). The school boards are responsible (though they delegate the implementation to the teachers) for a *Program for testing and finalizing* (Dutch acronym PTA) for each subject, and for the construction and administration of its tests, all based on the national attainment targets. Thus, teachers can decide whether to assess an attainment target in a written test, a practical test, an essay, a computer-based modeling activity, or any other format. They also have the autonomy to elaborate the content of an SE attainment target in their own preferred way, which leaves much freedom in detailing. For example, in the domain of geophysics, teachers have the freedom to focus on meteorology, climate science, seismology, or any other geophysics subdomain.

Since 1998, the exam program has been formulated in less detail than before; for the subject content assessed at CE level, the exam program's attainment targets are specified in great detail in a *syllabus*, which is a de facto legal document, formally established by the national Board of Tests and Examinations (CvTE). There is only one syllabus for each subject and school type, and only one central exam – teachers in the Netherlands do not have a choice between alternative elaborations of the exam program in central exams, as teachers in England, for example, have. The syllabus specifies attainment targets that are assessed centrally. It maximizes the content that the exam construction groups can use in exam tasks, and thereby signals to textbook authors and teachers the minimum content of the curriculum to be taught. The CE construction groups follow the syllabus, keep an eye on what the textbooks do, and respond to teachers' feedback on the annual exams. Textbook authors elaborate the syllabus, look at how the exam tasks have developed in the past years, and check what their user group wants.

In practice, the prescriptions in the syllabus for teachers and authors are extended by the content and format of what central exam papers have assessed in previous years. For new domains, the syllabus will always give sample exam questions, to let teachers and textbook authors know what to expect.

Most teachers use textbooks produced by commercial publishers, mainly written by teachers, following guidelines given by the publisher. Upper general secondary physics has always had a variety of textbooks. In 2017–2018, the years of the teacher interviews for this study, there were six series of physics textbooks, remarkably more than for other STEM subjects: three for chemistry, two for biology and two for mathematics. Many teachers also use additional sources, provided by organizations or fellow teachers over the internet or at teacher conferences.

Upper general secondary teachers are not strictly supervised by school principals. The PTA, mentioned above, is a school-related framework that binds the teacher at the process level. At the output level, the school's students' CE results may be used to judge the performance of their teachers.

Although the balance between the various components mentioned above, and sometimes their legal embedding, has changed over the decades, the dominance of the CE system is a constant, and with it the dominance of goals and content to be examined in the CE. Another constant through the decades is the fact that didactical insights can never lead to prescriptions. This goes back to the constitutional freedom of school boards, in practice largely left to the teachers, to shape the enacted curriculum (Kuiper et al., 2013). There was particular sensitivity around this issue in the years of the NiNa-project (2005-2010); in 2008, a parliamentary investigation into several system changes since the 1970s, the Inquiry Commission, chaired by then MP Jeroen Dijsselbloem, resulted in a sharp judgment about political interference in school practice (Commissie Parlementair Onderzoek Onderwijsvernieuwingen, 2008). The Inquiry Commission's report was published during the NiNa pilot and influenced the scope that the NiNa commission could include in its advice to the minister. This restricts the power of a reform commission in the Netherlands to recommendations and sample teaching materials or exam tasks. This situation affects pedagogy or school organization-related curriculum intentions like *Advancing concept development* or *STEM-coordination*.

4.3 Renewals studied

In this study, the word *renewals* will be used as a collective term for *projects* developing innovative practices and materials for teaching and assessment, and for *reforms* of the curriculum, proposed by formally established commission, eventually laid down in legal standards.

As for the renewals to examine for their curriculum intentions, this substudy was limited to the four formal reforms of the exam program after 1970 and the two innovation projects since that period that covered the entire physics curriculum. Study projects that focused on only one domain or aspect of the curriculum, such as technology education, modern physics, or attracting girls to physics, were left out. The commission responsible for the first of the formal reforms since 1970, called Commission Modernization of the Physics Curriculum (Dutch acronym CMLN) was established in 1965 by the Minister of Education with the assignment to modernize the curriculum, together with similar commissions for other subjects.

The CMLN relativized its contribution to innovation, describing it as (CMLN, 1974, p. 7) “a curriculum in which only shifting of emphases and some change of topics are proposed,” combined with stressing the need for “a fundamental research of objectives and from the didactical approach, with great attention to the choice of didactical aids to be used” and “the initiative to create the Physics Curriculum Development Project (PLON), which has received this fundamental study as its task.” For simplicity’s sake, CMLN will be addressed as one of the renewals studied, even though it played down its own renewing role. The PLON project (1970-1985), announced by the CMLN, is the earliest innovation project investigated in this study.

Table 4.1 shows the renewals that were selected and characterizes them as a development project or as a formal renewal – or, in one case, both combined. It also shows the years during which project teams or commissions were active, and for the formal exam programs, the years in which these programs were implemented nationwide.

With one exception, all these renewals had their basis in ambitions especially related to physics education. The exception is the *Second Phase* reform, the fifth renewal mentioned in Table 4.1, which covered all school subjects. That is not to say that the other renewals did not also have their roots in more general developments, as already indicated with the CMLN’s assignment.

In the following, the renewals analyzed for this study will be introduced briefly, as well as the sources used to prepare the participants’ meeting. The descriptions below also use written sources and interviews that were studied or conducted after the participants’ meeting.

Table 4.1 *Renewals studied.*

Acronym and name (Dutch / *English*) of innovation project or formal reform	**Period of development activities**	**Project, developed teaching and assessment materials[1]**	**Reform, proposed examination programs, to be legislated as input regulation. In brackets: year of nationwide implementation.**
CMLN Commissie Modernisering Leerplan Natuurkunde *Commission Modernization of the Physics Curriculum*	1965-1974		x (1976)
PLON Projekt Leerpakketontwikkeling Natuurkunde *Physics Curriculum Development Project*	1972-1985	x	

Acronym and name (Dutch / *English*) of innovation project or formal reform	**Period of development activities**	**Project, developed teaching and assessment materials[1]**	**Reform, proposed examination programs, to be legislated as input regulation. In brackets: year of nationwide implementation.**
DBK-na Differentiatie binnen Klasseverband, natuurkunde *Differentiation within Classroom, physics*	1974-1985	x	
WEN Werkgroep Examenherziening Natuurkunde *Working Group Exam Revision Physics*	1982-1987		x (1991)
Second Phase Tweede Fase *Upper Secondary Education (literally: Second Phase)*	1994-1995		x (1998)
NiNa Vernieuwing natuurkundeonderwijs havo/vwo *Renewal upper general secondary physics education*	2005-2010	x	x (2013)

[1)] PLON and its partners also produced so-called Experimental Exam Programs (EPEPs), but these were not accepted as advice to start further legislation by the Ministry of Education.

CMLN

As explained in Chapter 1, upper general secondary education physics in the Netherlands since the 1970s was selected as the case for our study. A more precise starting date than “the 1970s” could be August 6, 1976, because on that day, the Minister of Education and Sciences published the last of the pre-renewal exam programs for upper secondary physics education (Minister van O&W, 1976). This program was based on the advice of the CMLN, the 1976 program is therefore referred to as the CMLN-program. Still, the program was not so modern as the commission bearing the word *modernization* in its name would regard as ideal. In its advice (CMLN, 1974, p. 7), it stated:

> Modernization of the curriculum can hardly be more than a content innovation . . . Real renewal of education cannot be expected from a curriculum in which only a shift of emphases and some changes of topics are proposed. This will have to come from a fundamental research of objectives and from the didactical approach, with great attention to the choice of didactical aids to be used.

> With these thoughts as a starting point, the commission has taken the initiative to create the Physics Curriculum Development Project (PLON), which has received this fundamental study as its task.
>
> Because it is unacceptable to have the teachers wait until a fundamental study of objectives and resources has been completed and an attempted design can be offered, the commission decided to draw up a content list on the basis of the starting points outlined in the interim reports.

In this preamble, the CMLN made it clear that its proposed content list has a provisional status, and that “the real renewal” had to wait for the results of PLON, the *Physics Curriculum Development Project*, initiated by the same CMLN. The CMLN in its turn had been installed in 1965 by the Minister of Education, Arts and Sciences. The assignment and the terms of reference that the CMLN quoted in its advice (CMLN, 1974, p. 1) explained that the Ministry wanted the CMLN to study the possibilities of distinguishing two physics curricula, one for a *limited mathematics and physics program*, another for an *extensive program*. Additionally, the Ministry stressed that more experimentation with curricula and examinations was needed before new subject matter would be introduced, and that professional development was needed to prepare teachers for new content and new resources. All this was also inspired by a desire to strengthen the international position of the Netherlands.

The CMLN concluded its work in 1974 (see quotation above) with an advice that offered a provisional list of content, while denying that this list constituted a “real renewal”, for which more fundamental study would be needed, which it mandated to PLON, which CMLN “has taken the initiative to create” (CMLN, 1974, p. 7).

In 1976, the Dutch Ministry of Education published examination programs for the two upper secondary school types, based on CMLN’s content list.

PLON

The PLON project was funded by the Dutch Ministry of Education and ran from 1972 to 1986. It started with a 5-member project team and about 25 teachers. Over the course of its existence, the project addressed all secondary school types, in its first years focusing on lower secondary classes, mainly by producing sample teaching materials and offering guidance to the teachers. The teachers tested the materials and gave their feedback, which was used to review the materials. During the relatively long time of 14 years that the project was active, there were several changes in staff, scope and organization of the project, shifting from lower to upper secondary education.

In 1979, the PLON team formulated the *havo-bovenbouwproject* (HBB, for senior general secondary education) as a coordinated set of activities for developing teaching materials as well as an *experimental exam program*, acronym *EPEP-havo* (PLON, 1983). This exam program could serve both as an organizer for the teaching materials and as a basis for recommendations to the Ministry of Education or a future formal reform commission. Also in 1979, employees of PLON and the physics education department of the University of Amsterdam (UvA) took the initiative to set up a *vwo-bovenbouwproject* (VBB, for pre-university education). In the VBB, once started, the PLON team cooperated with the physics education departments of the UvA and the University of Groningen and with a group of teachers who had committed to the project. VBB also developed teaching materials and an *experimental exam program*, *EPEP-vwo* (PLON-UvA-RUG,1983). The leader of the UvA group had previously been the initiator of DBK-physics (see below) and can also be seen as a linking pin between PLON and DBK in VBB.

In the rest of this thesis, the VBB cooperative project is included in references to PLON's work for upper secondary education, parallel to PLON's own HBB project.

PLON's ambitions regarding upper secondary curricula were eventually reflected in the way each of the sample teaching materials was organized and in the contents of the experimental exam programs for havo and vwo, the *EPEPs*.

DBK

In 1974, researchers at the Vrije Universiteit Amsterdam (VU) initiated the development project DBK-na (Differentiation within Classroom – physics), in short: DBK. The aim was to develop teaching materials for classes with a mixed population of students. One of the interviewed participants involved in DBK said that the social aspiration for equal opportunities in education supported developments of differentiation in physics classes as a good starting case, physics being a exemplary subject for differentiation, with its mix of theoretical and practical teaching methods.

The project initially focused on lower secondary education, but many of the teachers involved extended it to upper secondary physics. In this approach, students always started with experiencing phenomena before they were introduced to the theory. As a consequence, practical work played a major role. The upper secondary materials were developed chapter by chapter in an interplay between VU-physicists and teachers into a complete set for upper secondary classes. After the end of the project, the upper secondary teaching materials were published for a few years by a commercial publisher.

WEN

In 1982, the Ministry of Education installed the *WEN*-commission (Werkgroep Examenherziening Natuurkunde, *Working Group Exam Revision Physics*). Its task was to design new exam programs for upper secondary physics education, thus going to be the first renewal of the formal programs which could benefit from the results of PLON and DBK. The influence of these projects and of their international sources of inspiration was clearly visible in the *WEN*-proposal (WEN, 1988), and was confirmed in an interview, as part of this study, prior to the participants' meeting with its then chairman. The proposal was accepted by the Ministry of Education and, after textbooks had been developed, implemented unchanged with legal status in 1991.

Second Phase

After only seven years, in 1998, WEN was replaced by a new program. The government had decided on a complete system change for upper general secondary education, and the exam programs for all subjects were rewritten. From then on, the renewed part of the education system was called *Second Phase* (*Tweede Fase*), to distinguish it from lower secondary and preparatory vocational education, the first phase. Thus, this physics program has also been addressed as *Second Phase*, the name used in this study too, since then. Initially, two physics subjects were created, Physics-1 for students in the *Science & Health* profile and Physics-1,2 for the *Science & Technology* profile. In 2007, a single exam program was created from these two for all students who had physics in their profile, whether *Science & Health* or *Science & Technology*. The *Second Phase* physics program was designed by a joint commission, with sub-commissions for biology, chemistry, and physics. One of the commission's tasks was to strengthen interdisciplinary coordination (Stuurgroep Profiel Tweede Fase, 1995b). As part of the attainment targets, the commission formulated a set of competencies common to the three science subjects. It also chose three common context areas to which attainment targets for each of the subjects could be connected: health, nature and environment, and technology. However, there had not been much freedom for policy-rich changes in subject content. The then chairman of the sciences commission for the *Second Phase* reform reported during this study's participants' meeting how the commission had had a major task in balancing the formulations between subjects. The balancing act was to a large extent very prosaic: minimizing the differences between the subjects in the number of attainment targets per course hour. The commission deliberately left modern physics out of the program, because of the complexity of content and pedagogy, (Stuurgroep Profiel Tweede Fase, 1995b, p. 23). It recommended a pilot project to gain experience with modern physics in the classroom.

Both WEN and *Second Phase* physics programs were implemented without classroom pilots. The *Second Phase* commission had argued for a pilot project for modern physics. This call was granted by the Ministry of Education, which financed the *Project Modern Physics* (Dutch acronym: PMN) from 1996 until 2009 (Hoekzema, n.d.). The topics were particle physics, quantum mechanics, and relativity theory. PMN's results were used as input for the next physics renewal commission: NiNa.

NiNa

Around the turn of the century, the shortage of vocational and higher education students in science and technology had started to worry education institutes, companies, and policy makers. Platforms from the world of science and technology approached policy makers with proposals to improve secondary science and mathematics curricula, in particular to show students the social relevance and professional attractiveness of science and technology. For physics, the Royal Netherlands Academy of Sciences (KNAW) and the Netherlands Platform for Physics, in which the institute of physics (NNV) and the physics section of the science teachers association (NVON) were represented, asked the Minister of Education to install a commission with the task of developing a new examination program. As a result, in 2005, the *Commission for the Renewal of Second Phase Physics Education* was installed. Also, funds were committed to enable a development project including classroom pilots. The project could pilot-test and revise draft versions of the commission's exam program and sample materials in co-operation with teachers and mid-term evaluators. The pilot was done with one complete cohort of vwo-students and two cohorts of havo-students. Previously, renewals had always involved either a development and research project based on classroom experiences, but without a resulting formal exam program, or a formal reform without classroom based pilots.

The commission, soon baptized NiNa (Dutch acronym for *New Physics*), selected as its focal points for renewal: topicality and relevance, connecting concepts to contexts, coherence with other STEM subjects, and connection to higher education. The STEM connection was expressed in a motto "The context of physics is science" and the vision that "the school subject of physics should provide a picture of the subject of physics in the whole of the natural sciences and the social applications in modern society" (CVN, 2010, p. 81). The commission stressed students' acquisition of conceptual understanding and a concept-context approach that would make concepts meaningful to students in different contexts. The commission used the premise that (CVN, 2010, p. 7) "physics is what physicists do," which underpinned the inclusion or strengthening of several topical domains of physicists' activities, like medical imaging or quantum physics and its applications. This premise also supported emphasis on the practices of physics, next to its outcomes.

As for international influences, above all, the NiNa commission took inspiration from British examples: *Advancing Physics*, by the Institute of Physics, for pre-university education, *Salters Horners Advanced Physics* for general secondary education. The first study weekend of the commission, in January 2005, was joined by *Advancing Physics* development team member Ian Lawrence, to share considerations, pitfalls and recommendations. NiNa also shared experiences with the German project *Physik im Kontext* from the *Leibniz-Institut für die Pädagogik der Naturwissenschaften* (IPN).

The commission's focal points also show connections to earlier renewals. Firstly, with its emphasis on relevance and on context-based education, the NiNa commission picked up a thread originally started by PLON in the 1970s. Secondly, together with the simultaneously launched commissions for biology, chemistry, mathematics and the new interdisciplinary elective subject *Nature, Life and Technology*, the NiNa commission tried to give a boost to the cross-curricular coherence that the *Second Phase* commission had written into its attainment targets, while at the same time acknowledging that working on discipline-crossing questions is "what many physicists do." Thirdly, the commission could harvest the fruits of the project on modern physics PMN, by embedding modern physics in the new exam program.

The commission's advice to the minister (CVN, 2010) was published unchanged as the official exam program, apart from some editorial adjustments, and was introduced nationwide in 2013.

4.4 Design of the substudy

Orientation interviews

To prepare an analysis of written curricula and a participants' meeting to validate that analysis, six people who had been active in a project team or commission of the renewals studied, or who had witnessed the renewals with responsibilities in teacher education or nation-wide implementation were interviewed; four of these interviews were held together with a master student (as part of his thesis work: Ververs, 2016). Of the people interviewed, four would also attend the participants' meeting (for attendants to that meeting see Table 4.3, all those interviewed for Substudies 1 or 4 are mentioned in Appendix 2). The interviews were held before the curriculum intentions used to analyze the written documentation had been established. The interviewees were asked to describe what they saw as key intentions about content or pedagogy of the renewals they had worked on or witnessed; how they estimated the expression of those intentions in current enacted curricula; and what written sources they recommended to know more about renewals' curriculum intentions. The interviews were not used as sources of references to discuss in the participants' meeting, but to help finding relevant written sources for that purpose and to support identifying and describing possible curriculum intentions.

Written sources and renewal participants

The sources listed in Section 4.2 (which could be regarded as written curricula of the selected physics education renewals) were examined to check the curriculum intentions they expressed. The set as described in Section 3.3, summarized in Table 3.1, was used to trace the intentions in those sources. The list of the written sources examined is shown in Table 4.2.

The outcomes of the analyses of written curricula were validated in a participants' meeting, in which project leaders, chairpersons, and other persons who had closely been involved with the renewals, discussed the analyses. The CMLN written curriculum was not part of that validation, because none of its participants were still alive.

The three-hour meeting took place on April 26, 2016. The participants in this conference are listed in Table 4.3. Several names appear in the table in more than one renewal: when non-italic letters are used for those mentioned next to a renewal, they had been invited because of their role in that renewal, italics are used for participants who had been invited primarily because of involvement in another renewal from the list, or in a role separate from any particular renewal.

Table 4.2 *List of sources used to prepare the participants' meeting.*

Renewal	Sources
CMLN	CMLN's report with recommendations (CMLN, 1974).
PLON	Lijnse (1982, 2014), the experimental exam programs (PLON, 1983, and PLON-UvA-RUG,1983), various publications in the collection by Eijkelhof et al. (1986), Eijkelhof and Kortland (1988), and Kortland (2005).
DBK	No publications were available reflecting on the project. Information to substantiate the link of curriculum intentions to DBK in the participants' meeting came from the participants in that meeting who had been involved in the project. Some newsletters for the DBK association and a teacher manual from the 1990s were used also, but indicated as sources from after the project period.
WEN	WEN's report with recommendations (WEN, 1988), background information given in an interview with the WEN-chairman prior to the participants' meeting.
Second Phase	The science exam program commission's report with recommendations for physics (Stuurgroep Profiel Tweede Fase, 1995b, pp. 127-205).
NiNa	The commission's vision document (CVN, 2006), its advice to the minister (CVN, 2010), sample teaching materials.

Table 4.3 *People attending the meeting of renewal participants of April 26, 2016.*

Renewal project or formal reform	**Participants, and their role in that renewal.** In non-italics: invited for his/her role in this particular renewal; in italics: also present
PLON	• Harrie Eijkelhof, project leader, developer • Koos Kortland, project leader, developer • Pieter Hogenbirk, teacher, developer • Paul Verhagen, teacher • Frank Seller, teacher • Ton van der Valk, developer • *Maarten Pieters, teacher* • *Bert Snater, member supervisory committee*
DBK	• Cees Mulder, teacher • Ed van den Berg, teacher • *Jos Cremers, teacher*
WEN	• Bert Snater, chairman • Joke van Dijk, member • *Jos Cremers, teacher*
Second Phase	• Jos Cremers, chairman • Twan Brouwers, member • *Chris van Weert, member*

Renewal project or formal reform	**Participants, and their role in that renewal.** In non-italics: invited for his/her role in this particular renewal; in italics: also present
NiNa	• Chris van Weert, chairman • Ineke Frederik, developer • *Ed van den Berg, developer* • *Harrie Eijkelhof, project leader* • *Elvira Folmer, external evaluator* • *Koos Kortland, developer* • *Wilmad Kuiper, external evaluator* • *Maarten Pieters, secretary, project manager* • *Wout Ottevanger, external evaluator*
facilitators (chairing, taking notes) of the conference	• Dirk Jan Boerwinkel, biology education researcher • Elvira Folmer, education researcher • Wilmad Kuiper, education researcher, supervisor of this study • Wout Ottevanger, education researcher • Maarten Pieters, organizer of the meeting, author of this study • Gjalt Prins, chemistry education researcher • Nienke Nieveen, education researcher, co-supervisor of this study • Jan Ververs, master student science education, carrying out a related study into physics textbooks

Identification of renewals' intentions in written sources

Quotations were selected that supported the attribution of the respective curriculum intentions to that renewal from the written sources mentioned in Table 4.2 to characterize the curricula of the renewals. The outcomes of the analyses were summarized for each renewal, with characterizations for each curriculum intention, according to the descriptions listed in Section 3.3. To recapitulate, the categories were:

- Using contexts
- Widening the scope of science education
- Coordinating with other STEM subjects
- Advancing concept development
- Advancing skills development.

As an example, Table 4.4 shows part of a summarizing table for the WEN reform. The codes in the rightmost column 'wen1', 'wen2' etc. refer to a list of quotations taken from the documents. The descriptions of curriculum intentions used in the leftmost column of the table have been adapted to the terminology chosen to use throughout this thesis; their meaning has remained the same. The entire table, as well as the tables for other renewals, was used for discussion during the validation conference.

Validation in participants' meeting

The tables summarizing the analysis outcomes of the written sources had been mailed to the participants (Table 4.3) in advance, as well as the sets of quotations for each renewal that were used as the basis of the summaries.

For the DBK project, no final publications from or about the project were available. As a consequence, this project could not be scored. Some of the participants' meeting's participants had been involved in DBK as a teacher or developer; their comments during the meeting have been used afterward as sources. Also, interviews after the participants' meeting with DBK's then project leader, who could not be present at the participants' meeting, and with another DBK developer have been used as sources.

After a personal introductory round and a general outline by the researcher, participants first discussed in parallel groups, each group specific for the renewal the group members had been invited for. Each parallel group was asked whether the outcomes of the analysis of the concerned renewal corresponded to their knowledge of the renewal and whether the participants had any additional references or sources.

After that, two mixed groups were formed, both containing people from all studied projects or reforms. In these groups, participants discussed whether the tables characterizing the five renewals did justice to the essences of the renewals. Corrections or additions from the previous round were shared. Next, the mixed groups were asked to comment on the sources and references used for characterizing intentions of the renewals. A concluding plenary session was used to collect remarks about the instrument, i.e., the categories of curriculum intentions. Also, suggestions were asked for the continuation of the study and for possible important developments since 1970 that may have influenced the current practice of teachers.

During the mixed groups sessions and plenary exchange, audio recordings were made and notes were taken. The transcribed recordings, the notes, some recommended publications not used so far, and the interviews with some DBK team members after the meeting, were used as additional sources to the publications that had been used in the preparation of the participants' meeting.

After the participants' meeting, some interviews were held with project leaders or other participants of renewals who had not been able to join the meeting. Also, some developers or researchers who had been active in or next to renewals were asked for written or oral comments and adjustments on sources.

Table 4.4 *Part of the table scoring the WEN reform on curriculum intentions, illustrating how to document the analysis of written curricula.*

curriculum intentions	what evidence is shown for this by WEN?	sources
Using contexts		
Contexts are used as curriculum content, aimed for or even prescribed	Contexts are prescribed in contextual concepts [*contextbegrippen*]. They are also referred to in various "shifts" [compared to the previous exam program] as an aspiration, namely "more physics knowledge in context"	wen1
Contexts are used as a didactical strategy, for teaching concepts or explanations, or just to raise students' interest in physics.	The examination program refers to subject specific didactical developments but does not explicitly advocate a certain didactical approach.	wen1, see reference to the developments in subject didactics (p.3) and the connection with cognitive development and the interest of students (p. 4).
Widening the scope of science education		
Fundamental Science (FS): students learn that the natural sciences have a solid foundation and offer correct explanations	The examination program mentions "knowledge of the results of physics: laws, concepts, reactions, quantities, models" as part of the objectives	wen2, in particular general target 1, 1st dash
Knowledge of the Development in Science (KDS): students learn that physics is an activity of people, who use particular ways of thinking and practices	The examination program mentions "knowledge of and insight into the method of physics, knowledge of the historical and philosophical aspects of the discipline" as part of the objectives.	wen2, in particular general target 1, 2nd and 3rd dash

curriculum intentions	what evidence is shown for this by WEN?	sources
Science, Technology and Society (STS): students learn that science develops in conjunction with technology and society and that science is relevant to understand societal issues.	The examination program mentions • “use of physics knowledge in technical applications, in the living environment, in society and in relation to other sciences”, • “critical attitude towards social problems with physics and technology aspects”, • “insight into the interaction between science, technology and society” • as part of the objectives of physics education From list of changes, #6 mentions many STS aspects under “Towards a more realistic picture of physics”.	wen2, in particular general target 1, 4th dash, and target 3, 3rd and 4th dash wen3
Phenomena in nature (PhN): students get acquainted with phenomena that reveal much about how nature works.	Is not explicitly mentioned, the introduction of the elective school exam assignment [*keuzeonderzoek*] does lead to it.	wen1, p.3-4 “The introduction of an elective school exam assignment [*keuzeonderzoek*]”
Coordinating with other STEM subjects		
	No indications found. It is true that the domain of biophysics was introduced, but its goal was not to connect different subjects, but to interest girls.	

4.5 Results

The results provided in this section are based on the analyses of the sources mentioned in Table 4.2 and, with the exception of the CMLN results, on the discussion and correction of the analysis outcomes in the participants' meeting. After the participants' meeting, the corrections and suggestions were used to rewrite the tables assigning curriculum intentions to the respective renewals. In the following, in a table per category of curriculum intentions, the expression of the intentions in the written curricula for each of the renewals is summarized.

For curriculum intention	see table
• Using contexts	4.5
• Widening the scope of science education	4.6
• Coordination with other STEM-subjects	4.7
• Advancing concept development	4.8
• Advancing skills development	4.9

Using contexts

Table 4.5 *Summary of evidence of the curriculum intention* Using contexts *in the studied renewals.*

Contexts are used as curriculum content, aimed for or prescribed	
CMLN	• Some contexts (e.g., the universe, structure and evolution of stars, electronics) were used as headings for prescribed physical concepts, others are optional (e.g., astrophysics, meteorology). • Some small contexts were in the explicitly mentioned applications, such as loudspeaker, glasses, binoculars, microscope, light bulb, safety in electricity use.
PLON	• Contexts were intended to be central; for that reason they were also included in suggested exam programs. • Contexts were intended as content meeting different students' interests, and to make personal and social relevance of physics visible.
DBK	• Contexts were not used as curriculum content on their own.
WEN	• Various context related concepts were prescribed in connection to physics content. • More physics knowledge in context was aimed for. • Contexts serve to connect content with the world that students experience, in particular the biophysics context for girls.
Second Phase	• Contexts and contextual concepts were mentioned in many attainment targets, in almost all domains, though only part of the contextual concepts refer to personal experiences or social situations.

NiNa	• Some context areas (e.g., functional materials, astrophysical contexts, biophysics, physics of the human body) are prescribed as domains or in attainment targets. • Attainment targets usually mention that concepts, laws, etc. should be applied "in contexts." • The use of contexts is recommended "both from the point of view of a motivating and varied range [of content] and to give an idea of the practice of physics in research, profession, and society."
Contexts are used as a didactical strategy, for teaching concepts or explanations, or just to raise students' interest in physics	
CMLN	• No reference was made to the use of contexts as a didactical strategy.
PLON	• Contexts also have a didactical function; central questions taken from personal life or society must help prevent overly abundant teaching units. • Versatility in the use of concepts was important in particular for the pre-university program, context-based units ("Themes") were combined with concept-based units ("Blocks")
DBK	• Concepts were introduced on the basis of phenomena shown, serving as context. • Contexts were used to apply concepts.
WEN	• The examination program refers to didactical developments but does not explicitly advocate a certain didactical approach.
Second Phase	• Attainment targets should be taught, applied and tested in realistic contexts; however, a didactical approach cannot be required in the attainment targets.
NiNa	• Recommendation of contexts as motivating and supporting students to learn the use and understand the nature of concepts; acknowledging that a didactical approach cannot be required in the attainment targets.

Widening the scope of science education

Table 4.6 *Summary of indications of the curriculum intention* Widening the scope of science education *in the studied renewals*.

Curriculum emphasis *Fundamental science* (FS): students learn that the natural sciences have a solid foundation and offer correct explanations	
all renewals	• Documentation made it clear that the curriculum emphasis *Fundamental science* is visible for all renewals in teaching materials and, if applicable, attainment targets. • In the participants' meeting it was stated that *Fundamental science* is a default approach, and that modernization should come from combining FS with other curriculum emphases.
Curriculum emphasis *Knowledge of the Development in Science* (KDS): students learn that physics is an activity of people, who use particular ways of thinking and practices	
CMLN	• No reference was made to *Knowledge of the Development in Science*
PLON	• Attention for the development of physics as part of the curriculum. • The proposed exam program for pre-university education mentions historical aspects of the relation between physics, society, and philosophy.
DBK	• No reference was made to *Knowledge of the Development in Science*.
WEN	• The examination program mentions "knowledge of and insight into the method of physics, knowledge of the historical and philosophical aspects of the discipline" as part of the objectives of physics education.
Second Phase	• Skills to be developed in practical work for the school exam part were linked with "the scientific method".
NiNa	• Attention for scientific literacy was recommended in the final report, the importance of knowledge about natural sciences and the methods of science was stated there. • In the exam program for vwo, a domain "Laws of physics and models" articulates attainment targets for this knowledge. • The skills domains include research, design, modeling, and judgment. • In the sample material for mechanics, developing scientific ideas was elaborated by making students model like Newton did.
Curriculum emphasis *Science, technology, and society* (STS): students learn that science develops in conjunction with technology and society and that science is relevant to understand societal issues	
CMLN	• Invitation to elaborate more elective topics than the ones listed in the report, which later led to an elective topic *Physics and society*, elaborated by some textbook publishers.
PLON	• The proposed exam program for pre-university education mentions historical aspects of the relation between physics, society, and philosophy. • Students have to be prepared for a role as critical consumer and citizen.
DBK	• STS had no emphasis for the project.

WEN	• The exam program mentions as belonging to the objectives of physics education ◦ use of physical knowledge in technical applications, in the living environment, in society and in relation to other sciences; ◦ critical attitude towards social problems with physical and technical aspects; ◦ insight into the interaction between science, technology and society. • STS aspects were supported as “Towards a more realistic picture of physics”.
Second Phase	• A reference was made in the description of cross-curricular skills: orientation on society, study, and profession.
NiNa	• The final advice refers to STS content in the descriptions of scientific literacy and technical design. • Attention for scientific literacy was recommended, the importance of contexts that clarify what natural science is about and what its social benefits are was stressed. • The design skills in the attainment targets refer to STS. • The STS-side of physics was stressed in the exam program for havo students by a new, overarching domain “Physics and technology.”
Curriculum emphasis *Phenomena in nature* (PhN): students get acquainted with phenomena that reveal much about how nature works	
	• This category was initially added to the three curriculum emphases as listed above and used by Van Driel et al. (2008). The discussion in the participants’ meeting supported the diagnosis from the documentation that all renewals give phenomena a high value, but nevertheless resulted in combining this curriculum emphasis with the emphasis *Knowledge development in science.*

In the discussion about curriculum emphases contained in the curriculum intention *Widening the scope of science education*, it was noted that the emphasis *Fundamental science* is default in all physics education. The discussion also yielded that *Phenomena in nature*, which had been added to the emphases formulated by Van Driel et al. (2008), could be regarded as part of the emphasis *Knowledge development in science*. As a consequence, it was decided that for the use of the curriculum emphasis *Widening the scope of science education* in the following substudies, it would be enough to look at the occurrence of the two other curriculum emphases, *Knowledge development in science* and *Science, technology and society*, and not to include *Fundamental science* in the set of curriculum emphases that make up this curriculum intention, nor to distinguish *Phenomena in nature* as a separate curriculum emphasis in this same set.

Coordinating with other STEM subjects

Table 4.7 *Summary of indications of the curriculum intention* Coordinating with other STEM subjects *in the studied renewals.*

Coordinating with other STEM subjects, in one or more of the following ways: • Cross-cutting STEM-contexts are used as prescribed content or as organizing principles of subject content. • Cross-STEM competencies or subject content appear in attainment targets that were identical for all STEM-subjects	
CMLN	• The commission referred to coordination with chemistry commission colleagues about planning of shared concepts and avoiding overlap. • The mathematical elements of physics appeared as independent from the mathematics curriculum; no reference was made to coordination.
PLON	• Elaborated in some teaching materials, in particular on ionizing radiation (with biology) and on meteorology (with geography).
DBK	• No effort was put into coordinating with other STEM subjects.
WEN	• The commission put some effort into coordinating with commissions for biology and chemistry, but without effects. • Coordinating with mathematics was not regarded as necessary.
Second Phase	• Visible in similar skills and in partly similar contexts for all three sciences, e.g., health. • Elaboration in the attainment targets in a few connections to healthcare. • A cross-disciplinary approach was recommended for the school research project.
NiNa	• A joint working group of the renewal commissions for all four STEM subjects produced a framework for coordination and outlines for cross-curricular teaching units. • A joint working group of the renewal commissions for mathematics and physics identified six themes in the problems of alignment between the two subjects and made recommendations for various stakeholders. • The attainment targets contain several identical skills for all STEM subjects. • The programs (havo or vwo) contain some domains that cross subject borders: medical imaging (h/v), materials (h/v), human body (h) / biophysics (v), earth and climate (h) / geophysics (v). • The development of cross-curricular STEM teaching materials was recommended.

Advancing concept development

Table 4.8 *Summary of indications of the curriculum intention* Advancing concept development *in the studied renewals.*

Advancing concept development ◦ providing a sense of purpose ◦ taking account of student ideas ◦ engaging students with phenomena ◦ developing and using scientific ideas ◦ promoting student reflection ◦ assessing progress ◦ enhancing the learning environment If a fragment from a document or an interview refers to one or more of these indicators, then that fragment was marked as an expression of this curriculum intention.	
CMLN	• No evidence found for concept development approaches
PLON	• Versatility in the use of physics concepts was regarded as important, in particular for the pre-university program; for this purpose, context-based units (“Themes”) were combined with concept-based units (“Blocks”). • The challenge for the post-1980 part of PLON, developing for upper secondary education, was to reconcile contexts and high-quality conceptual development. • In the last years of the upper secondary projects, conceptual development emerged in the rules and instruments for the development of teaching units: ◦ “theme questions” (standard part of the structure) must provide a sense of purpose in each teaching unit; ◦ practical tests were a standard part of the teaching unit structure, meant to engage students with phenomena; ◦ only in the very last PLON years: activities facilitating student reflection. • Extensive teacher manuals for the units proposed rich learning environments.
DBK	• Upper secondary materials were inspired by concept development experiences from research (including research into mechanics concepts) and from PLON teaching units. • A starting point of the upper secondary units was ‘from phenomena to concepts.’ • The unit about energy stimulated students to reflect on texts written by students. • Formative assessment was part of each DBK-unit. • As part of the learning environment, a practical setup was always available for experiments or tests related to the theory.
WEN	• A sense of purpose was particularly provided through the context related concepts and the shift to more “environmental” physics, explicitly meant to make the formal scientific concepts more meaningful for students. • Practical work and research by students supported engaging with phenomena.

Second Phase	•	No evidence was found for taking account of student ideas, on promoting student reflection, on formative assessment of progress, or on enhancing the learning environment.
	•	The healthcare related concepts from the attainment targets were meant to provide a sense of purpose.
	•	Practical work and the crucial role of the practical exam supported engaging with phenomena.
NiNa	•	Providing a sense of purpose was apparent from the context areas and in some sample teaching materials.
	•	Engaging students with phenomena was stimulated by the prescribed skills and domains for research and design.
	•	For pre-university education, developing and using scientific ideas and promoting student reflection appeared from the inclusion of the domain “Natural laws and models”.
	•	In the sample material for mechanics, developing scientific ideas was elaborated by making students model like Newton did.
	•	The need for enhancing the learning environment was stressed in the commission’s recommendations regarding a concept-context-approach to teachers and textbook authors.
	•	Formative assessment of students’ progress by student activities appeared in several sample teaching materials; summative assessment of conceptual thinking, expressed in the table of construction criteria for final exams, was meant to support a shift to more conceptual assignments in teachers’ practices.

Advancing skills development.

Table 4.9 *Summary of indications of the curriculum intention* Advancing skills development *in the studied renewals.*

Advancing research skills development		
CMLN	•	Practical work was a compulsory part of the school exam.
PLON	•	The teaching units were designed along a research learning trajectory.
	•	In the units’ structure, student experiments returned as a structural component.
	•	The traditional practical lessons with instruction changed into learning to investigate.
	•	The proposed exam programs (havo and vwo) elaborated research skills.
DBK	•	No reference about the project period was made to developing research skills.
	•	After the formal project, newsletters for the DBK Association from the 1990s and a teacher manual from 1991 show that developing research skills is to be included in the DBK teaching materials, but the authors wait for more guidance from didactical research.
WEN	•	Research skills were part of the physics education objectives and built into the attainment targets.
	•	Students’ research projects were mentioned as the core of the elective school exam assignment (Dutch: *keuzeopdracht*).

Second Phase	• In Domain A6. Scientific research, attainment targets mentioned stepwise nine research skills, from “recognize and specify a scientific problem” to “evaluate solution, research data, result and conclusions.”
NiNa	• Research skills were part of the exam program (domains A and I). Attainment targets mention carrying out research (for havo supported by instructions) based on research questions and analyzing and interpreting results (for vwo also using concepts from theory).
Advancing design skills development.	
CMLN	• No reference was made to design skills.
PLON	• No reference was made to design skills.
DBK	• No reference was made to design skills.
WEN	• No reference was made to design skills.
Second Phase	• In Domain A5, Technology, attainment targets mentioned nine stepwise research skills, from “recognize and specify a technical problem” to “make proposals for improving the design.”
NiNa	• Design skills were part of the exam program (domains A and I). Attainment target mention preparing, implementing, testing, and evaluating a design using relevant concepts, theory, skills, and reasoning.
Advancing modeling skills development	
CMLN	• No reference was made to modeling skills.
PLON	• The proposed exam programs (havo and vwo) mention the use of models for problem solving, while emphasizing the importance of modeling skills in physics education. • Attainment targets mention ability to use a model to describe reality, knowledge of most important models with respect to applicability and of conditions and presuppositions, for vwo also ability to define the limits of a model’s scope.
DBK	• Connected to concept development, models of electricity concepts were used for reflection on what a model is, no attention for dynamic modeling.
WEN	• The exam program states that attention must be given to the distinction between model and reality and the dynamic character of physical knowledge, and calls that a shift towards a more realistic image of physics. • Modeling with the computer plays a role in the domain of physical informatics.
Second Phase	• Supported by domains for Control systems and Signal processing, although modeling as such was not mentioned.
NiNa	• Modeling skills are part of the exam program (domains A and I). Attainment target mentioned analyzing (vwo also: constraining) a problem, selecting an appropriate model, and generating and interpreting model outputs (vwo also: testing and assessing the model). • The vwo-domain H (Laws of nature and Models) states that students must be able to use a model for a physical phenomenon and assess its limits of applicability and reliability; goal is that students see the coherence in the reasoning of physics.

Advancing judgment or decision-making skills development		
CMLN	•	No reference was made to judgment or decision-making skills.
PLON	•	The choice of contexts like ionizing radiation, energy issues and risks, and student activities in the teaching units contribute to preparing students for coping with their (future) life roles as consumers and as citizens in a technologically developing, democratic society.
DBK	•	No attention for decision-making skills.
WEN	•	For the school exam, attainment targets focus on situations in society with physical aspects: argumentation, critical comparison, making a considered balance.
Second Phase	•	Dealing with information for the purpose of forming an opinion was part of compulsory practical assignments.
	•	Students must learn to express reasoned opinions and to assess and weigh risks in contexts of nature and environment, elaborated in the domains Radiation and healthcare (havo) and Radioactivity (vwo).
NiNa	•	Judging or decision-making skills are stated in the skills domain. Attainment target mentions making reasoned judgments about a situation in nature or a technical application, distinguishing between scientific arguments, normative societal considerations, and personal opinions.

Other suggestions from the participants' meeting

During the participants' meeting, two more categories of intentions were suggested as sources for features, as they had played a role in the renewals. One was "make physics more attractive for girls," the other "show the topicality and relevance of physics." These intentions have not been made separate categories in this substudy. The intention to attract more girls to physics had been treated in the various renewals by bringing more realistic, especially biomedical, contexts into the curriculum, as several participants mentioned. Also, creating more differentiation in classroom approaches, by strengthening practical work, was meant to support girls' interest. Both contexts and practical work – as a support to skills development – were already part of the curriculum intentions selected as tracers between written and enacted curriculum. The intention of showing more topicality and relevance of physics is part of the curriculum intention to use contexts in physics education, again already included in our selection.

Overview

The findings from this substudy are summarized in a low-resolution yes-or-no-presentation in Table 4.10, as curriculum intentions at a glance.

4.6 Conclusions

The question that guided this substudy is: *What curriculum intentions represent in a valid way what developers pursued in the various renewals of upper general secondary physics education in the Netherlands since the 1970s*?

The analysis outcomes of the written documentation and the discussions, during and after the participants' meeting, with participants of the subsequent renewals, summarized in Tables 4.5 through 4.10, justify the conclusion that the initial set of curriculum intentions and its descriptions indeed represent what the renewals studied intended and can therefore be used as a valid basis for analyzing, in the next substudy, interviews with teachers about their enacted curricula. This conclusion is supported by the fact that the participants did not put forward other curriculum intentions as indispensable to characterize the renewals since the 1970s.

From the curriculum intentions, the CMLN-program only shows some prescribed or optional contexts, some attention for STS, and the intention to promote research skills. After CMLN, most curriculum intentions appear as fairly constantly present in the renewals. Curriculum intentions that emerge later in the period studied are sharing contexts or attainment targets with other STEM subjects, and advancing design and modeling skills. STEM coordination only really got on the agenda with the introduction of the Second Phase programs, when fixed combinations of STEM subjects were introduced in the so-called profiles: Nature & Health with biology, chemistry, mathematics, and physics programs, and Nature & Technology with chemistry, mathematics, and physics programs. The emergence of modeling skills was strengthened by the introduction of physical computing in the WEN program, following the assignment to the WEN commission that it should include attention for IT developments. The emergence of design skills may be connected to the introduction of attention for technology as part of science education.

More about these developments and what influenced them is investigated in the fourth substudy, described in Chapter 7.

Table 4.10 *Overview of curriculum intentions for the renewals selected in this study. Shaded columns indicate formal reforms.*

Intentions of science curricula[1]		**CMLN**	**PLON**	**DBK**	**WEN**	**Second Phase**	**NiNa**
Implementation year of exam program (if applicable)		**1976**			**1991**	**1998**	**2013**
Using contexts	contexts as content of education aimed for or prescribed	+	+		+	+	+
	contexts aimed for as a strategy for teaching concepts[2]		+	+	+	+	+

Intentions of science curricula[1]		**CMLN**	**PLON**	**DBK**	**WEN**	**Second Phase**	**NiNa**
Widening the scope of science education	knowledge of the development in science (KDS)		+		+	+	+
	science, technology, and society (STS)	+	+	+	+	+	+
Coordinating with other STEM subjects	attainment targets shared with other STEM subjects					+	+
	domains connected to other STEM subjects		+		+	+	+
	cross-cutting contexts as content or organizers of subject content					+	+
Advancing concept development[2]	providing a sense of purpose		+	+	+	+	+
	taking account of student ideas		+	+			+
	engaging students with phenomena		+	+	+		+
	developing and using scientific ideas		+	+	+	+	+
	promoting student reflection		+	+			+
	assessing progress			+			+
	enhancing the learning environment		+	+	+		+
Advancing the development of skills	research skills	+	+	[3]	+	+	+
	design skills					+	+
	modeling skills		+		+	+	+
	judging or decision-making skills		+		+	+	+

(1) A plus sign in a cell means that evidence was found for the operationalization for that renewal; a blank cell means a lack of evidence, or evidence of absence.
(2) In formal reforms, its didactical strategy could not be formally prescribed, a plus sign indicates that it was strongly encouraged, or that assessing conceptual thinking was included in the design rules for central exams.
(3) No reference about the DBK project period to developing research skills, but in the 1990s, newsletters and a teacher manual show that developing research skills is intended, though not yet realized in the teaching materials.

CHAPTER 5

Expressions of renewals' curriculum intentions in today's enacted curricula

5.1 Introduction

The second substudy concentrates on the first part of the main research question, about the extent to which enacted curricula reflect the intentions of renewals expressed in written curricula initiated since the 1970s. It focuses on descriptions given by teachers in interviews about their enacted curricula, the rightmost cloud in Figure 5.1 (based on Figure 2.1). The animals in that cloud represent elements of enacted curricula as teachers describe them. In the figure, the abstract icons represent curriculum intentions.

The analysis of interview data refers to intentions of curriculum renewals initiated since the 1970s that were validated in the previous substudy, about the leftmost cloud in Figure 5.1.

The research question guiding this substudy was:

> *To what extent do descriptions of their practices and intentions by physics teachers in upper general secondary education in the Netherlands reflect the intentions of curriculum renewals initiated since the 1970s?*

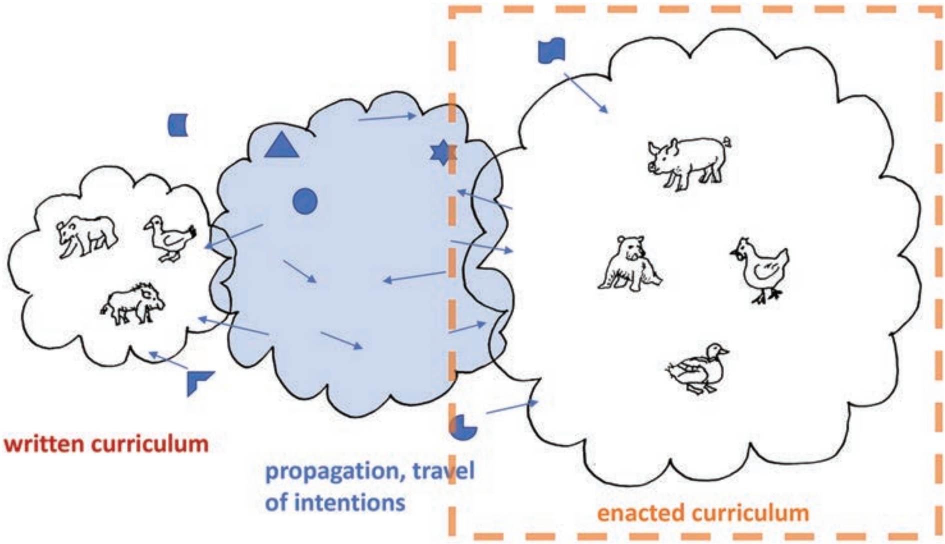

Figure 5.1 *Image of curriculum intentions traveling, as memes, between the written curriculum and the enacted curriculum.*

The data collection consisted of interviews with 13 teachers, held between May 2017 and November 2018.

Section 5.2 describes the design of the substudy, 5.3 shows its results according to the different curriculum intentions, and 5.4 presents the conclusions.

5.2 Design of the substudy

Sources

To learn about the teachers' enacted curricula, the researcher held interviews with physics teachers. Lesson observations next to interviews would have yielded additional evidence about the teachers' enacted curricula. However, in the time available, lesson observations would have restricted the number of teachers that could be studied and thus would have strongly reduced the diversity. That explains the decision to not also conduct observations. In a few cases, though, where it was possible to attend one or two of the teacher's lessons preceding the interview, some events or episodes of those lessons were incidentally referred to in some interviews, by the teacher or by the interviewer. As such, these few observed lessons were not part of the data collection. At the other end of the spectrum, nor was administering a written questionnaire for a large group of teachers chosen as a research method, because it was strongly preferred to collect in-depth answers to the questions posed in the teachers' own words.

The teachers were selected to be interviewed for this substudy as well as for Substudy 3 (Chapter 6); Section 3.4 describes how the selection was made.

Structure of interviews

The teachers were interviewed about their activities in what they see as a typical lesson and on the motives behind their choice for those activities. 'A typical lesson' means a standard lesson that runs as intended, not an exceptionally good lesson. Going back and forth between activities and motivations in the conversation usually provided more information on either of these. This combination of activities and motivations was inspired by an interview approach described by Westbroek et al. (2017, p. 1406) in their search for a teacher's goal system, "a context-dependent, within-person mental construct that consists of a hierarchy of a person's goals and means in pursuit of a task." The researcher had practiced this approach by being interviewed by one of its authors and by interviewing a few (former) teachers who were not part of the group selected to be interviewed for Substudies 2 and 3. The practice situations were discussed with the interviewees afterwards and one transcript was discussed with the supervisors in order to improve the level of detail in structuring the interview.

One great advantage of this approach is that it focuses on teachers' activities, combined with their goals, which parallels the researcher's interest in teachers' enacted curricula and their intentions. Another advantage is that the interviewed teachers describe their practices and motivations in their own words. Rather than making an entire goal system explicit by discussing as complete a map as possible, sticky notes with keywords of short quotations were used to visualize the discussion while talking. When the teachers were asked to validate their interview transcript afterwards, initially the patterns of sticky notes were also presented to them for approval. The response was always that the interview transcript sufficiently reflected what they had said, sometimes after some amendments, and that the overview from the sticky notes did not add anything. It was then decided to no longer aim for an approved goal system next to the transcript and to use the sticky notes during the interview only to keep an overview, but not as data.

The first 30 to 60 minutes of the interview were used to go through a typical lesson in an upper secondary physics class, in the teacher's own choice of words. The interview was semi-structured, built on the following elements, where references between what- and why-answers were made, as well as between lesson episodes, or to more general statements of the interviewees.

- about the first episode, e.g., 5 minutes of a typical lesson:
    - what do you do in this episode?
    - why do you do that, in that way?
    - what other or deeper motives underpin the motives you mentioned?
- about the next episode of such a lesson:
    - what do you do in this episode?
    - why do you do that, in that way?
    - etc.

In most of the interviews, the structure of the conversation per episode was left after the second section, some even after the first, and the planned elements made room for a less structured conversation going back and forth between *what* and *why* in different episodes.

Some interviewed teachers described two different typical lessons. Some teachers said that there were too many kinds of lessons to call some of them "typical." In those cases, the interview started from what first came to mind for the teacher, who was next asked about variants. Some made digressions to experiences in lower secondary education to illustrate *why*-questions. This *what*-*why* sequence was used to allow teachers to tell their stories free of structuring in terms of predefined content categories.

In the second part of the interview, the categories of analysis, as established in Substudy 1 and listed in Table 3.3, were mentioned to the interviewees. It was called "the spoiler," because now the categories of curriculum intentions used in the study were revealed. The interviewed teachers could explain to what extent their actions and intentions matched each of the categories. For this part of the interview, 5 to 15 minutes appeared enough. The curriculum emphases always needed some explanation, but contexts, coherence with other STEM-subjects, concept development (in particular taking account of student ideas) and the advancement of skills were easily understood. For most of the answers, the interviewee could refer to the first interview part. In some interviews, some of the teacher's curriculum intentions only became clear in this second part.

The third part of the interview went into factors that have influenced the teacher, the issue of the next substudy, described in Chapter 6.

In several interviews, the teacher already brought up biographical elements during the first part, and the conversation went more into that direction. In those interviews, the “spoiler” part on curriculum intentions was started after the biographical part of the interview. All interviews yielded information about all categories of curriculum intentions.

The validated texts (for the validation procedure, see Section 3.4) were analyzed according to the categories which also were used to analyze the sources describing the renewals’ written curricula (Substudy 1).

For the purpose of analyzing the interviews, it would have been easier to structure them from the start with questions around the curriculum intentions. However, great value was placed on teachers choosing their own words and associations, and so preference was given to asking questions in a way that was inspired by the goal-system approach mentioned above, by going back and forth between *what* and *why* questions. This interview part, about the teacher’s enacted curriculum and underpinning motivations and expectations (Substudy 2) was combined with a part about the factors perceived by the teacher as influencing their practice (Substudy 3), in one interview session. In several interviews, it appeared to work out well when cross-references could be made by the interviewer or the interviewee. In other interviews, the parts did not affect each other. Combining the two kinds of questions limited the time needed for each of the parts. For some of the interviews, additional information or further clarification was asked on details by e-mail. The responses were integrated in the transcript.

Analysis of interview data

Three transcripts were coded in draft form and discussed with the supervisors in order to reach initial agreement on the interpretation and application of the codes. The interview data were then analyzed using ATLAS.ti software to code and retrieve relevant quotes by type of curriculum intention. For the analysis, a codebook was created based on the categories of curriculum intentions as validated in Substudy 1. The codes in this codebook were organized in code groups, each matching one of the curriculum intentions.

The codes were used to tag quotations from the interview transcripts that expressed the presence of a curriculum intention. If more than one code applied to a quotation, then more codes were used. A quotation was accepted as relevant if it contained at least one reference supporting at least one of the curriculum intentions. Relevant combinations of quotations that were further apart than a few sentences were made by creating separate quotations and linking them with a hyperlink.

Quotations showing significant elements of a teacher’s enacted curriculum or intentions that did not match an existing code description were tagged with new codes. If such an element did fit an existing code or curriculum intention (code group), the code description was expanded accordingly. In the end, all such quotations fitted existing codes, while some code descriptions had been expanded.

An exception to this was a possible new code, called *Exercising definitions and procedures*: quite a number of interviewed teachers argues the importance of clearly defining physics concepts and practicing stepwise solving of physics problems while systematically using concepts, formulae, and procedural checks. Quotations of this kind always showed such teacher activities as a contribution to concept development, though it was not included in the description of the curriculum intentions *Advancing concept development*, based on criteria by *Project 2061*[1]. In the interviews, *Exercising definitions and procedures* appeared a default physics teacher activity, similar to the curriculum emphasis *Fundamental science*, which, due to its default character, had been removed from the initial list of curriculum intentions to be tracked, as a result of the previous substudy. For the same reason, it was decided not to add *Exercising definitions and procedures* as an element to this list.

Another deviation from the initial list of curriculum intentions is that using contexts to select physics content, one of the ways found in the renewals' written curricula, is not an option for a teacher, as opposed to a reform commission selecting physics content or a textbook author planning chapters. This subcategory was left out of the codebook for this substudy.

As a third deviation, the category *Organization of attainment targets in shared STEM-domains*, a component of *Coordinating with other STEM subjects*, was removed from the list for this substudy, as it typically belongs to the curriculum level on which attainment targets are formulated. Where teachers addressed STEM targets at the school level, it was coded as *Work on targets regarding STEM-shared competencies or content*.

The descriptions and use of codes were discussed with a colleague, who is an experienced physics teacher and curriculum developer. On the basis of a few interviews, several code descriptions were modified to increase clarity and reduce ambiguity. With this colleague, intercoder agreement was checked for an interview that had not been used in the process of clarification and modification of the codebook. Intercoder agreement was examined at the level of the code groups, the curriculum intentions. We agreed on 37 (93%) of 40 quotations, and disagreed on three quotations.

The use and development of the code descriptions in analyzing the interviews and the procedure to obtain intercoder agreement resulted in the descriptions as listed in the table in Appendix 3. The curriculum intentions in this table do not differ from those used for the first substudy, only the descriptions resulting from the procedures in this substudy were refined further and some components were changed. The curriculum intentions and codes used are listed in Table 5.2

1 See www.project2061.org/publications/articles/roseman/roseman2.htm#AppendixA, viewed April 2016.

Table 5.2 *Codes per curriculum intention, used to analyze interview data.*

Code group / curriculum intention	Code
Using contexts	• contexts as content • contexts as a teaching strategy
Widening the scope of science education	• KDS knowledge development in science • STS science, technology, and society
Coordinating with other STEM subjects	• work on targets regarding STEM-shared competencies or content • use of cross-cutting STEM-contexts
Advancing concept development	• providing a sense of purpose • taking account of student ideas • engaging students with phenomena • developing and using scientific ideas • promoting student reflection • assessing progress • enhancing the learning environment
Advancing skills development	• research skills • design skills • modeling skills • judging or decision-making skills

The interview data were analyzed in a qualitative way, although the analysis started quantitatively. The frequencies of occurrence of codes were used to guide to teacher quotations reflecting intentions in a relatively strong or weak way. They turned out to be far less significant than the content of quotations, so they only played a subsidiary role in the analyses.

5.3 Results

The first part of this section describes what curriculum intentions were expressed by the participating teachers, sorted by intention. The second part describes the differences between interviewee subgroups.

Expression by interviewed teachers of curriculum intentions

The frequencies of the occurrence of the coded quotations are displayed in Table 5.3, which also shows the percentage of each code group frequency relative to all code group frequencies.

The table shows differences among teachers in the number of times an intention is expressed and differences in intentions for each teacher. The frequency percentages in the rightmost column in Table 5.3 suggested whether curriculum intentions were expressed to a greater or lesser extent in enacted curricula. The quantitative data only served as a starting point to more in-depth qualitative analyses of the content of what teachers express about their respective curriculum intentions (leftmost column in the table). In this section, the qualitative analyses will be discussed. The certainty and intensity of what the teachers said about each curriculum intention in the relevant quotations will be used.

Table 5.3 *The frequency of the occurrence of coded quotations for each code group and each of the interviewed teachers.*

Interviewee → / Curriculum intention ↓	A	B	C	D	E	F	G	H	J	K	L	M	N	totals	%
Using contexts	2	6	12	8	4	1	0	8	1	1	5	5	6	59	15
Widening scope of science ed.	12	14	4	6	13	1	3	4	2	3	11	4	3	80	21
STEM coherence	0	0	4	4	1	2	0	1	2	5	2	0	1	22	6
Adv. concept development	7	25	9	19	10	2	2	22	10	10	13	6	16	151	39
Adv. skills development	3	7	6	12	11	5	1	3	6	4	7	2	4	71	19
totals	24	52	35	49	39	11	6	38	21	23	38	17	30	383	100

Using contexts

Contexts appear in what almost all interviewed teachers report about their lessons. Only a few of them describe that they systematically include contexts in their lessons. Only one teacher uses a context as a *starting point for selecting physics content* for a few lessons: C uses automation as learning content and selects physics content insofar it serves the context of automation. D comes close to using a context as a starting point and organizes students to work on useful devices in a technical design practical work, as contexts in the electricity domain: “Use a temperature sensor to simulate a refrigerator or something. Use the knowledge you already have to create something that you would like to use yourself.”

All other references to contexts in the interviews are about using *contexts to serve another goal*. These variants of using contexts share the idea of connecting to students’ interests, showing relevance as elements of *Advancing concept development* with the renewal intentions.

Teachers who speak relatively much and in a positive way about using contexts are C and N. C, next to using automation as a context, often refers to what the students like. As well as for motivation, C uses contexts to explain concepts already introduced. For N, contexts are needed to stimulate students’ understanding of concepts. N wants them to be able to use concepts in a flexible way, “to make a transfer, preferably to contexts they don’t know yet.” N often refers to the goal to make students think, to promote an investigative attitude, in combination with the fact that the national exams ask for students’ ability to apply knowledge in an unknown context. But contexts get their own attention too. About medical imaging, N says: “[we rent] an ultrasound machine for a week, we stand in front of the class in our bare torso, then we try to show things to each other.”

B, L, and M bring up contexts too, though less prominently. B uses contexts in assignments, different groups of students investigate concepts in different contexts, exchange between the groups is meant to stimulate transfer. “Because everyone does something different, and they see that from each other, the transfer is almost automatic." L, when asked about the use of contexts, tells to work out contexts in test assignments and exercises, "physics is not just a concept subject." M views physics as a building structured by concepts; M considers contexts secondary, though indispensable "to give the subject a meaning and to show the possibilities of the subject." M has a caution regarding contexts and wants to treat an issue either with the full conceptual depth of physics, or rather keep hands off it.

E and H hardly use the term *context* but associate it with concept development or the nature of physics. H "strongly work[s] from the concepts", like in the concept-context approach promoted by the NiNa-commission to support concept development. But H rejects the connotation of contexts as authentic practices, "a tunnel vision", and refers to the view on learning: "The danger of focusing too much [on an authentic practice] is that you go against the idea of that full orientation base, and then you don't reach your transfer." E mentions trying to select context-rich exercises and challenging students to think: "What approaches do we do, what do I neglect? I think that's essential in physics."

Teachers who speak the least about using contexts, though they do so in a positive way, are A, F, J, and K. A only mentions medical imaging when asked about contexts, as a good context for judgment skills. For J, contexts help to show the usefulness of physics content. K leaves the use of contexts to chance: "If [the actual topic] has to do with current events or if something happens in the news, you try to deal with it. But only if it fits well with the lesson." F mentions contexts that motivate students or show the relevance of physics in connection to the curriculum emphases *Science, technology and society*. But F draws a line at context based education, concepts should be "well linked in their own subfield of physics."

G is reluctant on the use of contexts and refers to professional physicists, who "prefer to go from the ground up. The context irritates them because there are several physical phenomena in a context."

D, when asked about the use of contexts, refers to using medical imaging, radiation, radiotherapy as contexts in classes, but finds contexts sometimes "a little annoying, some contexts are a little far-fetched"; for example, D does not "take a nice context" to work with kinetic energy.

In summary, the curriculum intention *Using contexts* appears as settled firmly in the practices as told by a majority of interviewees. Like the renewals in the course of the years, the participating teachers' curricula also show a variation in *Using contexts*. Some use contexts above all to motivate students, to bring some variation in the lesson, as a contribution to more attractive education. Others use contexts to show the relevance of physics. These two ways of using contexts appear in half of the interviews. As for the importance of contexts, some interviewees connect that to the nature of physics – part of another curriculum intention too, the emphasis *Knowledge development in science* – some to the role of physics and technology in society – part of the curriculum emphasis *Science, technology and society*. Four of the interviewees explicitly mention the value of contexts for students' concept development, in particular for the transfer of concepts by having to use concepts in various contexts – evidently a contribution to the curriculum intention *Advancing* *concept development*. Some teachers who hesitate to teach in contexts fear that it may come at the cost of conceptual depth, or conflict with the way physicists think.

Widening the scope of science education

The curriculum intention *Widening the scope of science education* includes two curriculum emphases, *Knowledge development in science* (KDS) and *Science, technology and society* (STS).

Teachers who speak relatively much and positively in the sense of curriculum emphases KDS and STS are A, B, E, and L. All four of them show a personal interest in epistemological and historical matters, which influence their enacted curricula.

Teacher A values teaching about the nature of science and stresses the connection between phenomena and models. For example, A starts from phenomena that “lead to the atomic-models-way of looking at matter. I use the experiment to say something about those models.” A explains why mechanics is planned at the beginning of grade 4: “You can come to abstraction with kinematics. This is important because it allows you to distance yourself from the phenomena.” B stresses that physics makes connections between phenomena. B regards laws regularities *called* laws. B tells to make the students experience such regularities by inquiry learning, and to explain to them that “there are only a few [laws] if you really narrow it down to what the essence of that [domain of] physics is.” E mentions both history and philosophy of science, as elements of KDS, and links physics to STS via technology. E considers it a matter of citizenship education that students are aware that society strongly depends on technology and its underlying physical principles. E wants the students to realize that physicists work with models and with procedures to make reasonable predictions. This view on the nature of knowledge development is supported by history, E tells the students: “How quantum mechanics came about has been a very interesting discussion. In which Einstein was ultimately wrong, for example.” L presents physics as not self-evident, but as the result of observing and tells the students: “Physics is about the world around you, so you have to look and observe.”

Next to these four teachers, for whom key elements of their approach are related to KDS or STS, there are also interviewees who in the interview put less stress on these emphases but do mention some attention for indicators of KDS and STS: epistemology, history, societal aspects, everyday coping, or combinations of those. For C, it is the history of atomic models and quantum physics. K mentions the use of the theory of relativity in the Global positioning system (GPS) to the students, as an example of how many interesting things in society emerge as a spin-off from fundamental research. For D, most important is “that you can describe nature around you and everything you see, modeling in fact.” G teaches the students that what they learn in physics makes them better at modeling, at finding patterns, which in G’s opinion reflects the nature of physics. G also sees physics lessons as part of citizenship education: being able to read an investigation.

Teachers who expressed KDS and STS with the least emphasis in the interviews are F, H, J and N, for different reasons. F does mention KDS and says about STS: “I try to emphasize social things by showing how much physics enters the house. I try to make a link [with physics], also with the nuclear bomb, energy, new fuels.” F connects excursions to research labs like CERN to the history of physics. N is clear in the judgment that KDS-aspects should only be a limited part of physics education: “I find [the historical-philosophical side] very interesting but then I say, after talking five to ten minutes about it: This is philosophy, this is not physics.” Similarly, N states for STS that big societal issues may easily be taken too superficially.

J never mentions STS in the interview, but comes close several times for KDS, by stressing that analysis and logical thinking are what physics is in essence. Asking questions is key; J starts each lesson with a question. For J, no particular concept matters in itself. “I think that that rationale, those skills, that logic are more important [than particular concepts]. That’s why I never worry so much about the curriculum.” For H, the process side of physics education is a key element, but at the same time, H does not want to pay too much *explicit* attention to the development of science. H sometimes offers the students goal-free assignments, in contrast to the means-ends approach which is typical in a physics book, where students get data and a question to calculate or determine something with them. “With goal-free I say: ‘You have these data, what can you find with them?’” H also states: “The relationship with science development is important, but it is something that grows slowly while you are working with the subject.” H and J show what happens in more interviews: some teachers show KDS and STS intentions, but do not explicitly emphasize these for their students.

M, as explained before, views physics as a building, with its domains as rooms. When asked about KDS or STS, M answers to pay little attention to those aspects, with the exception of the history of science, because for the gymnasium (grammar school) where M teaches, M sees that as a must.

In summary: in the interviews, about half of the teachers connect KDS to their view on the nature of physics and make it a part of their curriculum; one of these also connects STS in this way. By doing so, they evidently realize this intention of the renewals. Some other teachers interviewed mention KDS aspects, not as part of the nature of physics, but as an ingredient of *Advancing concept development* or *Advancing skills development*. Students of these teachers may learn implicitly about the nature of physics or other elements of KDS, without being aware that this is one of the goals of physics education. The same goes for interviewed teachers who mention STS-like contexts mainly to raise students’ interest, like a motivating context.

During the decades, the *nature of physics*, an aspect of KDS, appeared to have kept or gained relatively much attention in written curricula. This emphasis is often mentioned by the interviewed teachers in connection with a view on physics as a modeling discipline, and a view on learning physics as learning to see the abstract in phenomena and to model it. Compared with *nature of physics*, an epistemological aspect of KDS, the historical aspects are less stressed, as are the various aspects of STS.

Coordinating with other STEM subjects

With a total percentage of 5 from all quotations, STEM coordination is mentioned the least of all renewal intentions. Positive remarks about it mostly refer to coordination of research skills development with biology and chemistry. In some schools, the science departments together have developed a research skills module, which is elaborated in each of the subjects. One school works with a learning trajectory for practical skills that runs through all years, parallel to the science courses. In another school, each science course has one extra hour per three weeks for investigative work, intended to develop a learning trajectory. The key role of the school level in STEM coordination is obvious in these cases.

Apart from skills, some of the teachers mention attention for interdisciplinary issues, like biophysics, in their physics lessons, often in connection to the prescribed domains of Medical imaging, Biophysics and Physics of the human body, but without a cooperation with biology teachers, which would indeed be difficult because not all physics students have biology courses. A degree of cooperation with a chemistry colleague is sometimes mentioned, or a teacher takes care of alignment with chemistry lessons. When asked about STEM-coordination, some teachers say that they would like it, but that it never got off the ground. Like D: “Since I have been working here, . . . I have been trying to connect with ANW [General science]: without success. Connection with biology, chemistry: failed.”

Only one of the teachers is outspoken on the view that STEM-coordination has a low priority. J: “That coherence between the different subjects. . . . You have to work with math and chemistry and biology, but it’s not an important goal.”

N is cautious about cross-disciplinary contexts, which are easily dealt with in a way that is superficial in each of the contributing subjects.

The relation between physics and mathematics is strong, but even between those subjects, teachers do not mention coordination, or mention failing coordination, or describe how they teach necessary parts of mathematics themselves. One teacher reports coordinating teaching powers of ten with a chemistry colleague. Another complains that mathematics education disturbs physics education so often with wrongly planned physics contexts that mathematics education would do better to leave out all physics contexts.

In summary, the results show that the curriculum intention *Coordinating with other STEM subjects*, though intended by all renewals since the 1990s, appears to be expressed in the enacted curricula as described by the interviewed teachers in a very limited way. It is most successful in the common activities for skills development in the schools of several interviewed teachers. When asked about STEM cooperation, none of the teachers mentioned cooperation with a biology colleague on the compulsory curriculum domain medical imaging.

Advancing concept development

More than one third of all coded quotations was about any aspect of concept development, as can be seen in Table 5.3. It should be noted that the number of indicators that was used, following the characteristics given by Project 2061, was larger than for the other curriculum intentions. The indicators are written in italics in the descriptions below. They are explained in Appendix 3, with the descriptions used for coding.

Teachers who refer most often to aspects of concept development, relative to their total number of quotations coded for curriculum intentions, are B, H, J, K, and N.

B designs course material in which concept development has a key role. B tries to *engage students with phenomena* by asking them to make predictions, e.g., about a penalty kick in football, or by checking the outcome of an exercise in a test set-up. Or the other way round, groups of students have to imagine situations in which a speed change takes place and then compare these situations, a form of *developing and using scientific ideas*. B calls the approach *inquiry-based learning*, B read about it in a professional learning community: “You teach the students some tools, but not quite how to use them. . . . formulas, connections, an image, a situation sketch, they will have to learn to apply these.” B also tells to have the students experience the regularities in physics by inquiry learning, rather than to learn physics law by law, which contributes to the aspect of *connecting ideas* in *Advancing concept development*.

In H’s curriculum, insights and ideas from learning and cognitive theory are central. For example, H refers to the “Cognitive Load Theory” and the Russian psychologist Vygotsky. “[Students] have to design practical work exercises themselves. They write the results on the whiteboard, they then have to discover regularity, conservation laws.” H also holds individual think-aloud sessions with the students to help them develop their reasoning with physics concepts; and H has groups of students look for conservation laws in lab work results. The concept development aspects *engaging students with phenomena* and *promoting student reflection* appear most frequent in H’s descriptions, aimed at *developing and using scientific ideas*.

For J, *providing a sense of purpose* and *promoting student reflection* are recurring themes. J carefully prepares a guiding question for each lesson and wants the students to find out the answer themselves. J also uses the *fast feedback* method (Van den Berg, 2017) that J learned in a workshop at the physics teachers conference from a teacher trainer. Also, practical work serves concept development, “Some students . . . learn better through practical work. They must have seen or felt something.” J’s reference to seeing and feeling expresses the value attached to *engaging students with phenomena.*

K pays much attention to discussion and reflection and organizes part of the lessons in smaller groups. “With a small group . . . it is easier for some students to ask a question and you can have more discussion about the content than that you’re just going to tell.” K also uses these group sessions to discuss matter “that is not in the textbook," for example something from a documentary. In K's approach of concept development, *promoting student reflection* dominates.

N combines *engaging students with phenomena* with *promoting student reflection*, by challenging students to explain phenomena and to connect their explanations to concepts they already learned, and by using formative evaluation. Making students think in an inquiry-like way is N's ultimate goal.

Other teachers than these five mentioned speak about concept development in terms of *taking account of students' ideas*, like C, who asks students to explain what they see in a video, evaluates that with the help of an online tool (Edpuzzle).

D is another example of a teacher who is aware of students' conceptions; D has the students experience phenomena as a start for concept development and refers to Vygotsky's *zone of proximal development* while mentioning helping students to connect their prior knowledge to scientific ideas.

L uses Eric Mazur's *concept tests* and *peer instruction approach* (Mazur, 1997), "What I aim at is that they start thinking. And can also argue why they think something. That is the misconception story." M likes discussions, tries to get students to take and argue an opinion, and to find a reason to change positions. Eventually, M tells "how it is," hopefully in an insightful way. M likes this as "a way to confront students with possible misconceptions."

F and G mention concept development the fewest times, relative to total frequencies per interview and per curriculum intention. F does not express anything that would oppose the elements of concept development that were used for coding, F just talks more about other aspects. *Developing and using scientific ideas* is most clearly supported when F praises the shift in national exams from an "exercises culture" [*sommetjescultuur*] to more conceptual questions: "In my own tests I also ask many of those other questions." G emphasizes the reasoning skills that characterize physics, G mentions using the *fast feedback* approach (Van den Berg, 2017) and inviting students to discuss concepts, for example, errors in an applet.

The strongest elaborated contributions to concept development come from teachers who give descriptions coded as *promoting student reflection*, followed by *developing and using scientific ideas* and *engaging students with phenomena*. Table 5.4 supports this in a quantitative way, shown in the rightmost column, with percentages of the contributions of each of the codes to the overall score of the code group Advancing concept development.

In summary, most of the interviewed teachers enact the intention, also expressed by the renewals, of *Advancing concept development*. The strongest expressions by the teachers were about *promoting student reflection* and *developing and using scientific ideas*. *Engaging students with phenomena* was mentioned by many teachers too; it is also an element that motivates students, and it connects demonstrations and practical work to theory. The category *taking account of student ideas* is relatively well expressed too.

Table 5.4 *The frequency of quotations for each Concept development code for each of the interviewed teachers.*

Interviewee → Code ↓	A	B	C	D	E	F	G	H	J	K	L	M	N	Totals	%
providing a sense of purpose	0	4	0	5	0	1	0	3	3	0	2	0	1	19	10
taking account of student ideas	1	0	4	3	0	0	0	5	1	0	5	2	2	23	12
engaging students with phenomena	7	7	0	7	2	0	1	4	1	0	1	1	5	36	18
developing and using scientific ideas	1	13	0	7	3	1	0	4	2	4	4	1	2	42	21
promoting student reflection	1	8	5	0	3	0	2	9	4	7	7	3	8	57	29
assessing progress	0	0	2	1	2	0	2	0	0	0	0	0	2	9	5
enhancing the learning environment	0	0	1	0	0	0	0	4	0	1	1	2	1	10	5
totals	10	32	12	23	10	2	5	29	11	12	20	9	21	10	100

Advancing skills development

As shown in Chapter 4, the renewals aimed at advancing the development of skills, at stimulating that students acquire procedural scientific knowledge, "how-knowledge," complementary to the conceptual "what-knowledge." As a criterion for skills development, at least some reference to *doing science* was used, combined with the advancement of procedural scientific knowledge. Without this criterion, it appears impossible to draw a line between *Advancing skills development* and the curriculum emphasis *Knowledge development of science*.

Research skills

The strongest foundation of skills in the interviews is the assertion by some of the teachers that research is a core activity of physics. L calls promoting research skills a mission, "physics is . . . also doing research." For training students' research skills L collaborates with all science departments. K and K's science colleagues have set up a learning trajectory of practical skills from the first grade to the exam years, for all science subjects combined. K organizes full-fledged research projects, from students proposing a research question and writing an action plan, "with as much theory behind it as possible," through carrying out experiments all the way to writing a report. J plans practical work in each chapter to train students' research skills for the higher goal of their large practical work assignment in the school exam, "no cookbook practical work." For E, practicals help students become conscious of physics' modeling nature, because "you neglect things . . . and that is very useful." E states that research should and can be connected to theory lessons, but indicates that practical work is still organized separate from those lessons. N organizes the development of practical skills and builds up different practical work over different years, which is assessed and provided with feedback. N connects research to concept development: making students think in an inquiry-like way is N's goal.

Next to these five teachers, for whom research is a core activity of physics, others also stress the importance of research, but less obviously connected to training research skills. D wants to develop students' data analysis skills in all practical work activities. D rejects any suggestion to students of the kind: "this is the practical work, you take measurements here, drawing the conclusions is something you can at home." To the transcript of the interview, D adds a comment "Wherever skills seem to be concerned, knowledge is of great importance. More knowledge leads to better execution," referring to an article on Procedural and Conceptual Knowledge (Millar et al., 1994). For B, inquiry is the typical approach of physics. B does not mention it in terms of research skills, but as inquiry-based learning, to advance concept development. As for hands-on activities, B's students do some research activities, as could be observed in a class before the interview, and there were various experimental set-ups in the room. For G, research skills should have a more prominent place in the formal curriculum: setting up own studies, analyzing, assessing the validity of other studies. G advises to "remove a few topics from the physics program and spend more time on research skills." How G advances research skills was not discussed in the interview. H combines developing design and research skills when the students design practical investigative work themselves. It can be the design of a simple assignment or critically evaluate an existing task, for instance on the reliability of measurements. H does not limit research skills to the domain of physics and also had 5th grade vwo students do "didactical research, they did for example a McDermott test with second-graders" (McDermott et al., 2014). F, when asked about the role of skills development, mentions attention for measuring, calculating, and the use of Excel as contributions to research skills. F organizes practical work in a systematic way through the years, as part of the practical school assessment. In the description of a standard lesson, this practical work does not have a place, it appears as a separate stream in F's curriculum.

In summary, all teachers appear to organize practical work activities in one way or another as *doing science*, as a contribution to research skills. About half of the interviewees stress the emphasis they put on such activities and research skills as part of what physics is. Next to these, several others refer to the practical research work they have students do to support the learning of theory. One teacher works methodically on developing students' data analysis skills.

Design skills

Closest to a systematic approach of design skills education gets E, who reports that in every grade, students get to work with a technical design project. Technical design for E is “part of what physics is, the practical interpretation of what physics is.” E notices that it still is an isolated part, difficult to integrate with the rest of physics education. Also L offers design activities systematically, though feeling “less mission for designing than for research” as part of physics. L always reminds students that a design can be the subject of practical assignments, like in the school research project.

Many other teachers bring up doing design activities with the students, but they do not mention the systematic use of design steps or a design cycle to be developed in their students’ repertoire. D does bring up a design cycle but is cautious about systematically teaching it. D stresses that technical design activities already stimulate intrinsic motivation by offering variation. In a written comment on the transcript, D states: “Direct instruction has proven to be the most efficient way to learn concepts, but in my opinion not the most effective way to understand a process (productive failure approach).” Next to motivation as a reason, D plans design activities to contribute to conceptual understanding: “During designing you will encounter those [physics] concepts.” H also mentions design activities as supporting concept development or research skills. H combines developing design and research skills when making students design practical work themselves. For C, design activities are above all motivating. “[Students] like to be busy with that, . . . how they could put a lot of things they have learned into practice.” C does not mention systematic development of design skills. N says that the students do not do many design activities; one example that they do is designing a scale model of a tv-contest to launch someone from an air cushion. For F, the school research project [*profielwerkstuk*] is the only occasion to support students in design skills, so not as a part of F’s own physics lessons.

In the other interviews, nothing was brought up about design.

In summary, two interviewees describe that their students practice design activities systematically. Only one of them values design as a part of the core of physics. More teachers see it as support for theory learning, or for developing research skills. Several teachers mention design activities as motivating for students, sometimes simply as variation.

Modeling skills

In the stricter sense of computer modeling, several interviewed teachers mention that they organize student activities dedicated specifically to modeling. E describes modeling activities as a course, which E experiences as an isolated part, like design activities. N tells about the organization of a seven-week modeling course. C calls modeling an activity that you “just have to do,” referring to the exam program. F values modeling activities as part of physics education, F is glad that the new exam program covers that.

Modeling also has a wider meaning than computer modeling, as expressed in the code description (Appendix 3), including developing students' consciousness of thinking in patterns, structures or models, or students' ability to select an adequate model to interpret data. In that wider sense, modeling overlaps with concept development and with research skills.

H connects both connotations, the stricter and the wider one. "The added value of modeling skills lies in two aspects: the skill of modeling itself, which you can use very widely, but it also strengthens the relationship between physics and reality." H also connects modeling to research and design activities, "research is not fundamentally different from modeling." E, too, connects modeling and research activities to the wider concept of modeling. In practical works, "you neglect things, but students must be conscious of the fact that they are doing that."

Some other teachers only refer to modeling in its wider meaning. The most important thing that D wants to bring to the students is that you can "describe nature around you and everything you see, so in fact modeling." J states that students do not have to learn "pure physics knowledge," they do have to learn "the way of thinking, asking questions and that kind of things." L mentions models several times, as part of L's view on physics, but not in the context of modeling as a student activity. For G, helping students find the patterns in phenomena and find the right words to tell the stories of the physics domains makes them practice the key activity of physics: making models. B puts modeling in the heart of the nature of physics: "making connections, doing research, or using a model, . . . in physics you are constantly trying to catch the world in a model." B also sometimes challenges the concept of model by having students compare an applet simulation, by definition built on a model, with the real phenomenon in an experiment.

In summary, modeling in the sense of computer modeling is mentioned only by a few teachers. Modeling in the wider sense of model building is supported by many interviewees, but only few of them report organizing activities that show *doing modeling*.

Judgmental skills

The only teacher who actively stimulates judgmental skills is A, who points out that in upper secondary education, students are in an age phase that is "also about making judgments, expressing one's own point of view and that of another. In the period when [the subject] Dutch does 'discussion and debate', I do medical imaging." When asked about attention for social applications, A also mentions nuclear energy.

Other teachers only respond about advancing judgmental skills when asked, and then only by telling that they sometimes go into an example of a social application, as a context to show the relevance of physics rather than as the start of an assignment for decision or judgment making. Indeed, the relevance issue does play an important role for many interviewees, as described in the sections about *Using contexts* and the curriculum emphasis *Science, technology and society*.

In summary, hardly any reference appears to be made in the interviews to activities that, in the description of judgmental skills as given in the current exam program, “support the development of a reasoned opinion about a situation in nature or a technical application, and a distinction in the reasoning between scientific arguments, normative social considerations and personal views”, or that use the term *judgment* or *decision making*.

Summarizing for all skills: for many teachers, practical activities, whether research or design activities, are meant for variation, to motivate students, or to offer them more than one way of theory learning. In doing so, they contribute to the wish from the renewals that students experience physics as an empirical discipline. About half of the teachers go deeper into that nature-of-physics element, and report how they ensure that students experience research and build a repertoire of research skills – this position is connected with sympathy for the curriculum emphasis *Knowledge development in science*. For design skills, there is only one interviewee who takes a similar nature-of-physics stand.

All teachers say that they organize practical activities in one way or another, but about half of the interviewees give the advancement of research skills a well articulated position in their curricula and stress research activities as part of what physics is. For the advancement of design skills, the percentage is lower.

A few teachers mention computer modeling activities by their students. Given the fact that students are tested on certain computer modeling skills in the national exams, it can be assumed that all teachers pay attention to those skills – as one of the teachers says, it is something “you just have to do” –, but it was not reported in the interviews. Few of the interviewed teachers say that they enact the advancement of modeling skills in the wider meaning of model construction.

Judgment skills, in the sense of using scientific knowledge to develop or underpin a judgment on a personal or social issue, valued highly in the 1980s, play a subordinate role in the curricula of the interviewed teachers.

Differences between subgroups of teachers

Section 3.4, under *Selection of teachers*, described the distribution of interviewed teachers over years of age, years of experience as a teacher, experience in research or development roles, whether teacher is their first job, and gender. This distribution was meant to avoid biases as much as possible, but some of the characteristics were also used to get a sense of the extent to which they were related to the curriculum intentions expressed by the interviewees.

Counts of coded quotations could be made by subgroup, but comparing counts did not indicate whether the differences were significant. Reading the quotations was needed to find meaningful differences. And even then, the number of teachers within subgroups who express themselves about a curriculum intention was often too limited to assign significance to differences between subgroups. The following are a few comparisons that are nevertheless notable.

As for research or development experience, the content of quotations about the various curriculum intentions does not show differences. Relatively extensively, interviewees speak of *Advancing concept development* and of *Advancing skills development*, but even there the subgroups with and without research or development experience are balanced in their approaches.

The influence of first or second career is somewhat visible in the attitude towards *Using contexts*. While lateral entrants are divided, with conviction, about the importance of contexts, positive views dominate among main entrants. For *Advancing concept development*, one (out of five) lateral entrants and four (out of eight) main entrants report deliberate elaborated concept development activities. For the other curriculum intentions, differences are balanced or not visible.

With subgroup sizes of two women and eleven men, it did not seem justified to suggest any gender-related difference to curriculum intentions in the group of interviewed teachers.

As for age differences: support for *Advancing concept development* is balanced in the subgroups older than 55 years and between 35 and 55 years; the three individuals younger than 35 years all use contexts consciously and often. For the other curriculum intentions, support is balanced between the three age groups.

5.4 Conclusions and discussion

The research question that guides this substudy is: *To what extent do descriptions of their practices and intentions by physics teachers in upper general secondary education in the Netherlands reflect the intentions of curriculum renewals initiated since the 1970s*?

The results of the analyses of what the 13 teachers participating in this study reported in the interviews about their enacted curricula justify the conclusion that most of the curriculum intentions expressed in the teachers' reports correspond at least to aspects of what the renewals intended. The degrees of correspondence are elaborated below. The way the teachers' intentions align with what the renewals intended may not be how the developers involved in the renewals imagined the details or depth of the way to enact these intentions, but from the perspective that curriculum intentions, as *memes*, need not be expressed in exactly the same forms or intensities in different manifestations, the correspondence can be recognized.

The exception is *Coordinating with other STEM subjects*, which is hardly ever reported to be enacted, aside from school-based common activities for skills development.

Using contexts is found in the practices as reported by almost all interviewees, with a variety that is also found in the written curricula of the renewals, as contributing to attractive education, to showing the relevance of physics, or to concept development. A few hesitate to teach in contexts, fearing that it may go at the cost of conceptual depth, or conflict with the way physicists think. *Using contexts* thus appears in connection with the *Knowledge development in science* and the *Science, technology and society* aspects of *Widening the scope of science* *education* and with *Advancing concept development*, both for those who support and for those who are cautious with the use of contexts.

Widening the scope of science education is most supported by the participating teachers because of the importance of the nature of physics as a modeling discipline. Attention for the nature of physics is an aspect of *Knowledge development in science*. Interviewees connect it to concept development and skills development.

As for *Advancing concept development*, the categories *Promoting student reflection* and *Developing and using scientific ideas* were most strongly expressed in the interviews. These elements support training for exams most directly, which may explain their strong expression. *Engaging students with phenomena* was expressed by teachers who report to show phenomena to motivate students, and to connect demonstrations and practical work to theory. The key idea of concept development: the student is the active person, seems to have a place in quite a few teachers' enacted curricula.

Many interviewed teachers say that they organize practical activities for variation, or to motivate students, or to offer them more than one way of theory learning. This contributes to the wish from the renewals that students experience physics as an empirical discipline, an element of *Knowledge development in science*, but it does not automatically contribute to *Advancing skills development*. About half of the interviewees say to deliberately organize the advancement of *research skills* in connection to practical work. For the advancement of *design skills*, the proportion is lower, which may be interpreted as less recognition for technology than for research as content of physics education. *Advancing modeling skills* is most clearly mentioned by a few teachers in connection to computer modeling, but in the wider meaning of model construction it seems less enacted, if the *doing science* criterion is applied. Modeling skills development, in a sense wider than just computer modeling, may be connected to the category *Developing and using scientific ideas* of *Advancing concept development*, an approach that is most clearly elaborated by the teacher who bases the students' activities on inquiry-based learning. *Advancing judgment skills* in a context of judgments on a personal or social issue seems to play a subordinate role in the curricula of the interviewed teachers.

Discussion: comparison with an evaluation of most recent physics curriculum renewal

The above conclusions can be compared with results from a questionnaire-based evaluation by Ottevanger et al. (2018) of the implementation of the most recent exam program, which is also in effect for the teachers participating in this study. In the study by Ottevanger et al., 90 out of the approximately 1500 upper secondary physics teachers responded to an on-line questionnaire. The respondents picked from a list as the most important aspects of the exam program: physical reasoning, new contents such as quantum physics, skills (research, design, modeling), scientific thinking, and scientific practices. This finding suggests that the respondents recognize the curriculum intentions *Widening the scope of science education*, *Advancing concept development*, and *Advancing skills development* in the written curriculum, where it is not clear from this recognition to what extent these intentions are expressed in the enacted curricula. About half of the respondents indicate *Using contexts* in more than half of the lessons. An indication for support for *Widening the scope of science education* is that, in a question about its aspects, a significant number of respondents support the curriculum emphases *Knowledge development in science* and *Science, technology and society*, as “attention to . . . how scientific knowledge is used and how scientific knowledge is created” (p. 16).

As for *Coordinating with other STEM subjects*, 10% of the respondents report that STEM-coordination has affected their way of teaching. The report does not mention how the teaching had changed, but the percentage suggests a low impact anyway of the STEM commissions’ (including the NiNa commission’s) aspiration of more cooperation between STEM teachers.

CHAPTER 6

Factors in teachers' profiles and environments that influence enacted curricula

6.1 Introduction

The third and fourth substudies, and their research questions, are closely linked and pertain to the second part of the main research question, about what factors may have influenced the expression of curriculum renewal intentions in today's enacted curricula of upper general secondary physics education in the Netherlands since 1970. This third substudy focuses on descriptions given by teachers in interviews about their profile, environment, and practice. Figure 6.1 (copy of Figure 2.3) shows the categories examined.

The research question guiding this substudy was:

> *What teacher profile and environment factors, as perceived by teachers, may have influenced the expression of curriculum renewal intentions in their teaching?*

The data collection consisted of interviews with 13 teachers, held between May 2017 and November 2018. The interviews were held in the same sessions as those for Substudy 2 into teachers' curriculum intentions.

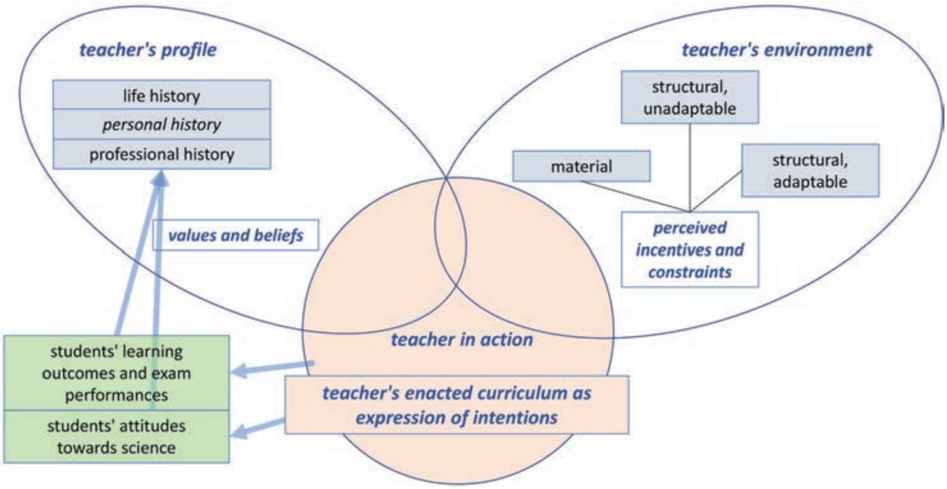

Figure 6.1 *Conceptual model for factors from a teacher's environment and profile, directly influencing a teacher's actions.*

The question how the influences examined in this substudy could relate to the various curriculum intentions as examined in Substudy 1 (Chapter 4) was answered as part of the qualitative analysis of quotations from the interviews with teachers that form the data source of this substudy. Making specific connections between influencing factors and curriculum renewal intentions was not included in the interviews as a question to the teachers; sometimes connections were made by the interviewee, in many cases the connections could be made in the analysis, in the context of interview episodes.

In addition to finding evidence for the research question, this substudy also examines whether the categories into which the influencing factors are grouped help in conceptualizing types of factors.

Section 6.2 explains the design of the substudy, 6.3 shows its results according to the different factors, and 6.4 presents its conclusions.

6.2 Design of the substudy

Sources

As part of the interviews with the 13 teachers who had been questioned about their enacted curriculum (Substudy 2), they were asked what factors have influenced their practices. Section 3.4 describes how teachers were selected.

Structure of interviews

The organization of the interviews is described in Section 3.4. The first part of the interviews, taking 30 to 60 minutes, pertained to the topic that was key to Substudy 2: the enacted curriculum. The second part focused on questions related to Substudy 3, i.e., about factors influencing the teacher's enacted curriculum. This part took between 20 and 60 minutes. In several interviews, influencing factors already emerged during the first part of the interview.

The researcher had practiced also this part of the interview by interviewing a few (former) teachers who were not part of the group selected to be interviewed for Substudies 2 and 3. The practice situations were discussed with the interviewees afterwards and one transcript was discussed with the supervisors in order to improve the level of detail in structuring the interview.

The starting question for the interview part for this substudy was: Who or what have influenced or still influence you to be the teacher you are now? In addition, the interviewees were asked to consider their own school or university time, teacher education, professional experiences in or outside education, or colleagues, in the past or today. In some interviews, references were made to the first part of the interview, to what the interviewed teacher had said about the what and why of their lessons.

Analysis of interview data

Three transcripts were coded in draft form and discussed with the supervisors in order to reach initial agreement on the interpretation and application of the codes. The interview data were then analyzed using ATLAS.ti software to code and retrieve relevant quotes by type of curriculum intention. For the analysis, the categories from the model described in Section 2.4 (also shown in Figure 6.1) were used. Based on these categories, a codebook was created. The codes were used to tag relevant quotations from the interview transcripts. Quotations that appeared relevant for the research question but did not fit in the first version of the code book could be scored with new codes and either be merged with existing codes or lead to new codes.

The description and use of codes were discussed with a colleague, an experienced educational researcher. Some code descriptions were reformulated to increase clarity and reduce ambiguity. The resulting code book is shown in a concise form in Table 6.1; its details can be found in Appendix 4. With the same colleague, intercoder agreement was checked with the detailed resulting codebook for an interview that had not been used in the process of clarification and modification of the codebook. Out of 59 quotations, there was agreement about 56 (95%) and disagreement about three quotations. Half of the total agreement stems from the agreement in the category *Cultural system: values and beliefs*.

The frequency of tagged quotations for each of the codes was established for each of the interviewed teachers. These figures were used in an indicatory way, to find out which factors were mentioned often and possibly also in relation with other factors. However, the qualitative analysis of quotations was used as the most significant method of finding answers to the substudy's research question. For that analysis, the firmness or detail with which the interviewed teachers mentioned influencing factors was used.

The qualitative analysis of quotations also considered how the various curriculum renewal intentions, as examined in Substudy 2 (Chapter 4), and the influences examined in this substudy could be connected. The reliability of this analysis, in the form of a draft version of Section 6.3 (Results), was checked with the second coder of the codebook for curriculum intentions that had been made for Substudy 2. This check resulted in a small number of corrections and some extensions of the statements linking influencing factors to curriculum intentions.

Although the possibility was left open for codes to be added or removed during the analyses and due to the discussions of the inter-coder agreement, no modifications of the structure of this list of codes were needed. Some descriptions of codes were refined or extended, resulting in the detailed list as given in Appendix 4. During the analysis, no new codes appeared to be needed that could not be merged with codes from the initial list. A code *own textbook constraints and incentives*, initially part of the group *unadaptable structural system*, appeared not to fit in that group, because teachers can adapt the choice and use of their textbooks. This code was merged with *written resources*, part of the group *material system*. That change will be discussed in Section 6.3, in the part about *written resources*.

Table 6.1 *Resulting codes for analyzing teacher interviews for experienced influencing factors. Factors used as codes are displayed in the left column, the numbered groups of influencing factors in the shaded rows.*

Influences used as codes	***Description: addressed or interpreted as a possible influence***
Teacher's profile	
Life history	
life histories general	personal biography or development
life histories school/college/ university	experiences as a student in school, college, university
Professional history	
teacher education	lessons learned; expertise acquired in teacher education
learnt from colleagues	influences from colleagues in previous teaching or previous other jobs
previous classroom experiences	teacher experiences with classrooms or students
previous school experiences	experiences with school organization from earlier teacher jobs
professional development experiences	professional development experiences in the past
curriculum development or research activities in the past	experiences as author, member of curriculum project team, science education researcher
previous professions	experiences from previous professions
curriculum renewals	experiences with one or more curriculum renewals
Cultural system: values and beliefs	
values about the goals of physics education	principles about what physics education is for
beliefs about effective education and teaching strategies	knowledge or assumptions about effective education and teaching strategies
values about the role of the teacher	principles about what a teacher is for
views on the nature of physics	epistemological beliefs of the teacher about the nature of physics
self-image	belief of teacher about who or how (s)he is or is capable of

Influences used as codes	*Description: addressed or interpreted as a possible influence*
Teacher's environment	
Material system	
written resources	all relevant textbooks available to the teacher, including the textbook chosen by the teacher as standard textbook
physical school environment	the school building, its physical facilities, including computers
digital environment	the availability of information technology, videoclips, animations, and applets
organizational environment	universities, companies, including supply of professional learning communities, conferences
other facilities & resources	other facilities and resources from material system than described above
Adaptable structural system	
classroom interaction	rules and settings in current classroom interactions that limit or stimulate forms of enactment
school organization	rules, settings, philosophies on school level
collaboration with colleagues	experiences with current colleagues
professional development provisions	sources and settings of professional development
school examination	school examination attainment targets and organization in domains
Unadaptable structural system	
national exam program	the attainment targets and their organization in the national exam program
national syllabus	the specifications of attainment targets laid down in the syllabus for the central exams
central examinations	expectations about national exam tasks from previous years

It was not always easy to choose between coding a quotation as *professional history* and coding it as a factor from a teacher's current environment, in particular the *material system* and the *adaptable structural system*. Conclusions that teachers draw from factors in the present sometimes lead to these factors also appearing as elements of professional history, even if they still apply. Still, there were enough quotations for which the distinction was clear enough to continue to distinguish codes referring to the past from codes referring to the current situation.

Where quotations tagged with codes for influencing factors, or segments of an interview containing such quotations, had also been tagged in the previous substudy for curriculum intentions, connections could be made between influencing factors and curriculum intentions. This showed what intentions from past decades, as described in Table 5.2 and more detailed in Appendix 3, are supported or hindered by the various influencing factors to be expressed in the enacted curricula of the interviewees.

6.3 Results

The first part of this section describes what influencing factors were mentioned by the interviewed teachers, presented by category of factors. A second part describes the differences between subgroups of the interviewed teachers.

Influencing factors mentioned by interviewed teachers

The frequency of occurrence of coded quotations was established for each of the codes and for each of the interviewed teachers. Table 6.2 shows the results at code group level per interviewee and for the whole group. It also shows the percentage of each code group frequency relative to all code group frequencies, in the rightmost column.

These quantitative data only served as a starting point to more in-depth qualitative analyses of the content of what teachers say about what has influenced them (leftmost column in the table). In this section, the qualitative analyses are discussed, using the certainty and intensity of what the teachers said about each factor in the relevant quotations, and limited to the influencing factors that apparently supported or hindered the expression of the curriculum renewals' intentions in the enacted curricula.

Table 6.2 *Frequency of occurrence of coded quotations for each code group and each of the interviewed teachers.*

Interviewee → Code group ↓	A	B	C	D	E	F	G	H	J	K	L	M	N	Totals	%
Life history	10	4	2	7	5	1	3	2	2	0	3	5	2	46	9
Professional history	6	6	12	14	7	11	5	23	12	4	10	4	11	125	25
Cultural	13	14	8	18	31	2	14	7	11	3	21	6	10	158	31
Material	2	2	12	2	5	7	0	4	3	8	5	2	3	55	11
Structural, adaptable	10	0	6	5	8	5	0	8	6	7	10	1	0	66	13
Structural, unadaptable	0	10	1	3	3	9	4	3	3	3	5	2	11	57	11
Totals	41	36	41	49	59	35	26	47	37	25	54	20	37	507	100

In the analysis of the interview data, connections between influencing factors and curriculum intentions were also made in conjunction with interview data from Substudy 2 (reported in Chapter 5) for the interviewed teachers. Influencing factors reported by interviewees that could not be linked to one or more of the curriculum intentions whose expression they had mentioned were not included in the results described below. For influencing factors that could be linked to other factors within the data from an interview, these links will be mentioned. Curriculum intentions and influencing factors will be written in italics. The curriculum intention *Widening the scope of science education* will often be referred to by one or both of the curriculum emphases that are part of it: *Knowledge development in science* and *Science, technology and society*.

Life history

In the category *life history*, experiences from school or university are distinguished from more personal experiences.

Personal history

Four interviewees link their personal histories to their ways of being physics teachers in a way that may support certain curriculum renewal intentions.

A has always been very consciously engaged with existential and ethical questions and connects that to A's study choices and development as a physics teacher: A describes the classroom emphasis on the different statuses of phenomena and models, an emphasis that appears, also from other interview data, as part of A's *values about the goal of physics education* and *views on the nature of physics*. Thus, A's personal history supports the chance for the curriculum emphasis *Knowledge development in science*, with its focus on the *nature of science*, to be expressed in A's enacted curriculum. This emphasis is an element of the curriculum intention *Widening the scope of science education*.

G says "I want to know the cause of the cause," to explain what is attractive in the approach of physics: "That is in physics, not in chemistry, [which only is a] phenomenological approach." It explains an emphasis in G's teaching, about the *nature of physics*, an element of *Widening the scope of science education*.

H taught chess lessons as a high school student. H mentions this to explain the eye-opener effect of Russian learning psychology theories during *teacher education*, as they helped to understand chess teaching problems. This experience may be connected to H's *beliefs about effective education*, as elaborated in descriptions of concept development activities, thus supporting the curriculum intention *Advancing concept development*.

L refers to the beauty of phenomena when explaining how and why L works to elicit the wonder of the students. "Because I personally think that nature is so ingeniously put together. . . . I can still look at the starry sky with wonder." The role of wonder in L's teaching is an element of *Widening the scope of science education*.

School history

The other life history experiences are from school or university. Several interviewees mention their high school experiences as a reason to study physics, sometimes connected to a view on physics, or on themselves as physicists.

G is an example of the latter: physics was G's best subject in high school, G became aware of the drive "to know the cause of the cause." This resonates with G's view, and is an element of *values about the goal of physics education*, that physics education must make students capable in "finding patterns, keeping larger and larger abstract wholes in your head and working with those abstractions." G says to work with the students on finding and using patterns in phenomena and their conceptualizations, which may support the curriculum intention *Advancing concept development*.

B remembers that the exam year in vwo was "the first year in which you see all the connections." With the described inquiry-based method, B would aim to bring forward that moment of seeing connections and regularities within physics, an aim that reflects B's *values about the goal of physics education*, *views on the nature of physics* and *values about the role of the teacher.* B's emphasis on connections and regularities, also shown in other data from the interview, supports the *nature of science* aspect of *Widening the scope of science education* as well as the *making connections* aspect of *Advancing concept development*.

J's own biology teacher is mentioned as a source of inspiration: "He explained very well how things were structured, and not the little facts." Together with other statements about preferring a rationale, skills, and logic over "particular concepts," this memory may explain the decisions J emphasizes for the enacted curriculum. J's *value about the goal of physics education* supports *developing and using scientific ideas*, an element of *Advancing concept development*.

M also refers to high school experiences to explain a preference for the structure of physics over contexts and cautiousness about using contexts. This element of the *views on the nature of physics* apparently *hinders* the curriculum intention *Using contexts*.

D refers to experiences with contexts in high school as "interesting, but otherwise I did nothing with it. . . . And so: I do not assume that students will read those contexts." This *belief about effective education* may *hinder* the expression of the curriculum intentions *Using contexts*, which D confirms by stating to limit the use of contexts to applications of physics like medical imaging.

University history

Influences from studying at university vary quite a bit.

E saw movies by the physicists Richard Feynman and Walter Lewin while studying philosophy of science. This experience contributes to E's *views on the nature of physics.* It struck E that "what Feynman says is all philosophy, and his outcome is all physics." E also expresses this view as part of the *values about the goal of physics education*. This is in line with other data from the interview, where E emphasizes attention for the *nature of physics* in teaching, an element of the curriculum intention *Widening the scope of science education*.

L experiences a shortcoming of high school education that became manifest at university, where L got a low grade for a lab journal. “I thought, have I been working all day on this? Then I concluded that I never learned that skill in high school.” L wants to protect students from such an experience and has made research skills into “a mission”. Thus, this experience seems to have influenced L’s *values about the goal of physics education* in a way that supports aspects of the curriculum intention *Advancing skills development.*

Professional History

Below, subcategories of *professional history* are followed as listed in Table 6.1 in order of influence, as estimated from the number of quotations referring to a certain subcategory of experiences in the past: teacher education, continued professional development, classroom experiences, development or research activities, colleagues, other professions, curriculum renewals, and school experiences.

Teacher education

With eight out of 13 interviewees positively valuing teacher education experiences for their development as a physics teacher, this subcategory is the most often reported factor of *professional history*. The nature of the influences differs from teacher to teacher.

A’s teacher educator drew attention to *Harvard Project Physics* (*The Project Physics Course*, 1970) and A consults the materials up to today because of their historical approach, which A connects with the non-self-evident character of the models used in physics. This reflects A’s *views on the nature of physics* and supports the emphasis, as part of A’s *values about the goal of physics education*, on the nature of models in physics that A describes as part of the teaching. Attention for this aspect of the *nature of physics* is an element of *Knowledge development in science* and thus of *Widening the scope of science education*.

E’s supervisor helped recognize E’s own views on the nature of physics and of philosophy in physics education, because “you felt that you were discovering things together.” E also investigated practical skills in physics as part of teacher education, and at the time of the interview, E was rewriting all practicals from the past 20 years in the department. E says the goal of this undertaking is to connect experiments to theory, which helps students to become conscious of physics’ modeling nature. These teacher education experiences may have influenced *values about the goal of physics education* and *beliefs about effective education* in a way that support the expression of *Widening the scope of science education* and of *Advancing skills development*.

G expresses appreciation for the teacher education supervisor on several occasions: “I enjoyed him. That was completely what I wanted: he works from examples, from phenomena, from interest.” This may be interpreted as connecting to *beliefs about effective education,* especially because G adopted the teacher educator’s *fast feedback* method for *Advancing concept development*.

H stresses to be indebted to the teacher education supervisor, because of this supervisor’s suggestion to study Russian learning psychology: “I came across

. . . what is needed for the development of a complete orientation base. . . . I was deeply impressed." This impression is reflected in other data from the interview, which describe the emphasis on *Advancing concept development* H has elaborated in the enacted curriculum. Apparently, this experience has influenced *beliefs about effective education* and *values about the role of the teacher*.

J tells how J's *values about the goal of physics education* were supported by the internship coach who clearly taught that learning to think is essential, rather than learning to solve exam problems. This value is reflected in several components of J's teaching, such as the use of a guiding question for each lesson, which support the curriculum intention *Advancing concept development*.

L learned to use concept questions in teacher education and says to still use them often, with the help of Eric Mazur's concept tests and peer instruction approach (Mazur, 1997). During teacher education, L also became interested in the concept-context-approach and prepared to use it as part of the upcoming exam program. L mentions to work out contexts in test assignments or exercises. Teacher education experiences seem to have affected *values about the goal of physics education* and *beliefs about effective education*, in a way that supports curriculum intentions *Using contexts* and *Advancing concept development*.

N had the opportunity to experiment with learning trajectories that differed in the order of practical and theoretical work, which N took up again when becoming a teacher. As part of a master study of science education, N did an internship in the US, developing expertise in computer supported video measurement. N says to have built up a series of practical work, which is assessed and provided with feedback, and to connect research to concept development: N's goal is making students think in an inquiry-like way. N also organizes a seven-week modeling course. The teacher education experiences N reports may have influenced *values about the goal of physics education* and *beliefs about effective education*, in a way that supports *Advancing skills development.*

Professional development experiences

In-service professional development, including development exercises and peer suggestions in PLCs (professional learning communities), is brought up as an influence by seven of the interviewees.

A started reading books about a phenomenological approach to physics education, which were suggested by colleagues. A had intense discussions with a colleague in the first year, but then "started to look what I could do with it . . . and shaped it in my lessons." A also still consults *Harvard Project Physics* (*The Project Physics Course*, 1970) every now and then, "an inspiration to approach physics along the historical line." Similar to what was described about A in the previous subsection, this influence is reflected in A's *values about the goal of physics education* and *views on the nature of physics* in a way that supports *Widening the scope of science education* in A's enacted curriculum.

B started, soon after having entered a second career as a teacher, to "develop some material and see that it works." A few years later, B received support from school to participate in a PLC. B's views on teaching were mentioned in literature used in the PLC. "It is called *inquiry learning* or *inquiry-based learning* . . . where you teach the students some tools, but not quite how to use them." This shows an influence on *beliefs about effective education* and on the enacted curriculum: B shows teaching material organized as inquiry learning, in a way that supports *Advancing concept development*.

J mentions to look for occasions to meet physics colleagues: conferences bring "new ideas for questions and demonstrations," but also the fast-feedback method J uses. A significant experience in a training session with school colleagues made J aware of the importance of asking questions and J says to start each lesson since then with a guiding question as part of the standard approach. This influence on *beliefs about effective education* supports *Advancing concept development*.

K has exchanged experiences with science education colleagues since joining in a network of teachers of the optional interdisciplinary STEM subject *Nature, Life and Technology / NLT*. K also attended a university course about guiding gifted students, and says to practice ideas from it in the classroom, in particular the method of working in a discussion group with half the class, while the other half is doing practical work. This influence on *beliefs about effective education* may support *Advancing concept development*.

L says to have extended the collection of concept questions L uses in a PLC, following up on how L learned to use these questions in teacher education. These experiences can be connected to what was described in the previous subsection about L's elaboration of the concept-context-approach; they influenced *beliefs about effective education*, which support *Advancing concept development* in L's curriculum enactment.

Previous classroom experiences

Several interviewed teachers refer in some way to how they have experienced what their students liked or were able to, or what worked in the classroom, as experiences in their professional history that apparently had changed or confirmed their activities and motivations. Seven of the interviewees go into that kind of influence.

B and H, who are engaged in research or development activities, use the feedback from classroom tests to improve teaching materials. The feedback has also influenced how they view their roles as teachers, or the best way to teach physics.

H: "You are much more aware of how students work. . . . I have changed emphases. I now do even more with meta-learning, show students there is an order in the material. . . . Experiences must arise, and different children have different experiences." H's experiences appear to have influenced *beliefs about effective education*, about the importance of building on students' experiences and of guiding students' reasoning about phenomena and activities. These beliefs and what H says about H's teaching support elements of *Advancing concept development*.

B talks about developing and using curriculum materials for inquiry-based learning to promote transfer between contexts and to support students to discover regularities as part of the physics approach, and about how B navigated on student feedback in a trial-and-error phase before starting to work more systematically: "I put something on paper myself, then [see] that it works, the students are enthusiastic." These experiences confirm and may also have developed *beliefs about effective education*, leading B to develop the inquiry-based learning approach that B says to use in teaching, and of which B shows self-developed teaching materials, supporting elements of *Advancing concept development*.

Other teachers use feedback from classroom experiences without being engaged in structured research or development work. They do not connect this to any particular curriculum intention. An exception is L, who says to use feedback from former students who said they profited from their training in the use of lab journals, to improve current students' lab work. It confirms *values about the goal of physics education* and *beliefs about effective education*, in this case supporting *Advancing skills development.*

Curriculum development or research activities in the past

In the strand *development or research activities,* four interviewed teachers mention a PhD study or a role as textbook author as an influencing factor; three teachers mention developing materials for their own or their department's use.

While participating in a PLC, B successfully applied for a scholarship for developing a textbook, which covers 25% of a full-time job. B describes in the interview how the cycle of evaluation and adjustment, comprising both development and research, supports the elaboration of an *inquiry education* view. This connects to what was described in the previous subsection about B's experiences and teaching practices: influences on *beliefs about effective education*, supporting *Advancing concept development*.

D has been active in developing practical activities for students for many years. Part of this work, aimed at design activities, was supported by an award from a development fund for teachers. D was also funded for a PhD study into students' data analysis skills. These experiences, related to the descriptions of the role that students' research and design activities play in D's teaching, appear to confirm and possibly also modify *values about the goal of physics education* and *beliefs about effective education*, in a way that supports *Advancing skills development* in D's practice.

H states that being involved as an author for the NiNa pilot helped in learning more about writing teaching material. H focuses "mainly on the learning process and on the students learning to learn and work independently. I try to give physics a reality-oriented approach." In a PhD study alongside working as a teacher, H carried out design research into modeling. This research has made H look for feedback from students more structurally; it has changed H as a teacher. H's experiences appear to have influenced *beliefs about effective education*, about the importance of building on students' experiences in a reality-oriented approach and of guiding students' reasoning about phenomena and activities. These beliefs and what H says about H's teaching support elements of *Advancing concept development*.

The three teachers described above were working on products that will eventually be publicly available. Some other interviewees have developed materials only for their own use or for immediate colleagues. Their activities can be connected to curriculum intentions that they appear to value; like E, who works on an update of practical work activities supporting *Advancing skills development*, as a follow-up of a teacher education research project. Or like L, who developed context-rich exercises for use in their own classes, supplementing the textbook, supporting *Using contexts*. For these interviewees, the developmental activities seemed more to follow from their values or beliefs rather than influence them, other than as a reinforcing influence.

Learnt from colleagues

Teacher A describes how discussions with colleagues in the past sharpened A's view of the role of phenomena and models in physics education. A describes how, in classes, the different statuses of phenomena and models are emphasized, an emphasis that appears, also from other interview data, as part of *values about the goal of physics education*. Thus, this personal history supports the chance for the curriculum emphasis *Knowledge development in science*, with its focus on the nature of science, to be expressed in A's enacted curriculum. This emphasis is an element of the curriculum intention *Widening the scope of science education*.

H mentions the senior colleague who inspired H as a starting teacher and who gave the idea to have students teach younger students. H felt supported by this colleague in the view that good physics teaching always connects to students' experiences, a *belief about effective education* that H describes putting into practice. Thus, this influence appears to contribute to student reflection on their own knowledge, and thereby supports elements of the curriculum intention *Advancing concept development*.

Previous professions

B explains the conviction that it is important for students to find out a lot themselves from an experience in the first job, for which teaching oneself computer programming was needed. B mentions it to explain a *belief about effective education*, which B elaborates in teaching, that stimulating students' first-hand experiences increases students' commitment and inquiry-based learning, an element of *Advancing concept development*.

Curriculum renewals

As mentioned in the subsection above about experiences in *Curriculum development or research*, the interviewees who had been involved in a renewal project as a pilot teacher value it as a support for their skills and for contacts with good colleagues and welcome it as a step in their professional development they had already been looking for. For the others, renewal projects and reforms they were familiar with have drawn attention to approaches that appealed to them.

A and H both are familiar with the PLON and DBK projects from their teacher education years in the 1980s, but they indicate not having used project materials directly. H links H's views on education to the renewals of the 1970s and 1980s: "Connecting with the children. PLON and DBK probably helped. Differentiation was of course of DBK. And PLON may have helped to be open to children." H connects concept development to PLON: "In my training, at the end of the 70s, I got to know PLON. In fact, I'm a child of the 80s, concept development has always been my priority." H connects this experience to *values about the goal of physics education* and *beliefs about effective education*, with an important role for *Advancing concept development*.

L became acquainted with the NiNa renewal in teacher education, and the renewal's ambitions regarding a concept-context-approach were also mentioned in the PLC that L participated in. In teaching, L says to work out contexts in test assignments and exercises to show that "physics is not just a concept subject." Thus, the renewal's intention of *Using contexts* may have been strengthened in *values and beliefs* indirectly, through education and continued professional development.

Previous school experiences

A was the only interviewed teacher who explicitly explained how the school's philosophy has challenged and influenced the interviewee's own view on education. This view focuses on awareness of the difference between phenomena and models, which A describes as a recurring element of teaching. It is a clear expression of the curriculum emphasis *Knowledge development in science*, which is an element of *Widening the scope of science education*, and apparently anchored in A's *views on the nature of physics*.

All other references that teachers make to schools where they taught, as part of their professional history, appear to refer to the influence of colleagues, which is treated as a separate category.

Cultural system: values and beliefs

The findings in the category *cultural system: values and beliefs* are described below per factor, starting with *values about the goals of physics education* and *views on the nature of physics*, which explain content preferences. Then follows *beliefs about effective education*, which is more about pedagogical preferences. Finally, *values about the role of the teacher* and *self-image* refer to both content and pedagogy. Most of the factors mentioned in this section were already brought up above, in the subsections under *life history* and *professional history*. In those cases, corresponding subsections are indicated and supporting quotations or paraphrases are not repeated.

Values about the goals of physics education

Six of the interviewees stress as their goal that students become acquainted with physical thinking and practices in a way that supports *Advancing concept development*, in particular the elements *developing and using scientific ideas* and *promoting student reflection*. Some of them legitimize this from their *views on the* *nature of physics*. None of them mention specific phenomena, domains, or concepts. All of these interviewees also mention how they contribute to that intention.

- For B and G, see subsection *school history* above.
- For L, see subsection *university history* above.
- For H and N, see subsection *teacher education* above.
- For J, see subsections *school history* and *teacher education* above.

A's *values about the goal of physics education* support attention for the *nature of physics*, an element of the curriculum intention *Widening the scope of science education*. See subsections *teacher education* and *professional development experiences* above.

L's values about the goal of physics education also support *Using contexts*. L combines a pedagogical and epistemological view and wants students to learn that physics is not just making exercises, but also to experience confusion and surprise. L relates how *contexts are used* to strengthen this experience. L also uses contexts in exercises and tests, to support *Advancing concept development*.

E wants the students to "realize, also as citizenship education, that our society and our lives depend incredibly on technology, and therefore also on the underlying physical principles." And E wants to prevent the impression that all knowledge has meanwhile been established now: "We know that there is much we don't know. It is important to convey some modesty in that regard."

Views on the nature of physics

Three teachers mention the modelling nature of physics as its essence, three (partly the same) point at the connectedness of the domains of physics, two mention the connection between concepts and contexts, one refers to the provisional nature of theories, one to physics as looking for causes. All of these teachers also describe that they express these views in their teaching. Thus, all of these teachers' views may be seen as supporting the expression of *Widening the scope of science education*. Some statements from the interviews are presented below; where data also apply to other curriculum intentions, these will be mentioned.

- For A, see subsection *personal history* and many subsections of *professional history* above.
- For B, see subsection *school history* above.
- For E, see subsection *university history* above.

L tells the students that in history "there have been paradigm shifts at quite a few moments, so that people began to think differently about certain phenomena." And L explains to them that "physics is not just a concept subject. It's about the world around you." L mentions this quote when asked about views on the use of contexts, adding that L works out contexts in test assignments and exercises, which also supports *Using contexts.*

For G, see subsection *school history*, which explains G's *views on the nature of physics* supporting *Advancing concept development.*

For G and M, see subsection *university history*, for their *views on the nature of physics* to explain their reluctance toward *Using contexts*.

Beliefs about effective education and teaching strategies

Several interviewees articulate beliefs about effective education and teaching strategies that, in connection with statements about their practices, can be interpreted as supporting the curriculum renewal intention *Advancing concept development*, and in the cases of B and N as supporting *Using contexts* also.

- For D, see subsection *curriculum research or development experiences* above.
- For G, H, J, L, and N, see subsection *teacher education* above.

In addition to what B says as described in subsection *professional development experiences*, B also thinks that students "will learn more if they don't have all the information yet, if they still have to search, puzzle, and make connections that I haven't given them yet." B explains why, in assignments, B makes students practice transferring concepts between contexts: "Making transfers, applying the same in different situations, is a condition to be able to see that larger connection."
E's beliefs about effective education, as described in subsection *teacher education*, may support *Advancing skills development* in the curriculum enactment.

L describes how all science colleagues work with a research skills module, in which students learn how to set up research. For this part of the enacted curriculum to be effective, L looks for "a good balance between steering them in the right direction but not being too cookbook-like. . . . If you give them too little, they have no idea what to do and if you give them too much, they have no idea why they should do this." This belief may support *Advancing skills development* in the enacted curriculum.

D's beliefs about effective education appear to support *Advancing skills development*, see subsection *curriculum research or development activities* above. And as described in the subsection about *school history*, D's beliefs restrict the expression of the curriculum intentions *Using contexts* in D's enacted curriculum.

Values about the role of the teacher

The three interviewees who mention values about the role of the teacher that may influence curriculum renewal intentions all refer to raising students' awareness of or interest in the *nature of science*, an element of *Widening the scope of science education*. All three also mention it with the intention to make the conceptualizing approach of physics more meaningful, thus providing a *sense of purpose*, an element of *Advancing concept development*.

- For B, see subsection *school history* above.
- For E and L, see subsection *teacher education* above.

Several teachers mention raising students' interest in physics as (part of) their role, a foundational goal of many renewals also. However, it was not used as such as a curriculum intention to be traced, but only if operationalized in, for example, *Using contexts* or *Widening the scope of science education*.

Self- image

Three of the interviewed teachers explain their choices as physics teacher also by characterizing themselves, in a way that can be connected to curriculum renewal intentions, see also subsection *personal history* above. For all three, according to their statements, this can be linked with the way they emphasize the *nature of physics* in their teaching, an element of *Widening the scope of science education*. For G, it also supports *Advancing concept development*, because of the way G guides the students in finding patterns in phenomena and building a vocabulary.

Material system

For the category *material system*, part of the teacher's environment, findings are successively described for the factors: *written resources*, *physical school environment*, *digital environment*, *organizational environment*, and *other facilities and resources*.

Written resources

All interviewed teachers refer to the textbook chosen to be used by all students, their standard textbook. All refer in one way or another to the role of their standard textbook in planning to cover subject matter. The standard book also serves as the default source for explanations, for student exercises, or for practical assignments.

Most of the interviewees collect stories, explanations, or student activities from other sources, as additions to the textbooks they use. C brings teaching materials from ASE conferences to supplement the assignments from the standard textbook with introductions for concept development. L mentions to collect concept questions or ideas for such questions from various textbooks, next to the standard textbook. With these teachers, additional written resources are used for *Advancing concept development*.

E looks for context-rich test questions from other textbooks, including foreign books. N uses newspapers and the textbook from the previous school as sources for the collection of interesting stories N was building. With these teachers, additional written resources are used for *Using contexts*.

Some say that they supplemented the standard book with self-developed materials to support their favorite intentions in their enacted curriculum: with explanations, exercises, practical work assignments, or presentations. The supported curriculum intentions vary by teacher.

Physical school environment

Several cases show how the physical school environment can influence the expression of *Advancing skills development* in enacted curricula. H works in two schools, with different facilities; the availability of a good room for research work by students makes a difference for the practical work activities planned. In the visits to both B and D, the researcher took the opportunity to attend a class and saw how parts of the classroom and an adjacent lab room were used to combine theoretical and practical parts of the lessons. D describes the use of the *Arduino* electronics platform for design activities and also mentions teaching the students to analyze videos, for which adequate hardware is needed. In the working-in-small-groups phase of J's lesson, attended by the researcher, the content of a student's tablet was sometimes projected on the whiteboard for a plenary discussion intermezzo. Several teachers refer to computer supported practical facilities, such as *Coach*, for measuring, controlling, and modeling activities.

Digital environment

In all visits that allowed attending a lesson, the researcher saw how the digital screen (part of the physical school environment) was used for more than just written notes from the teacher, but also for showing videoclips, animations, and applets. Also, several teachers whose classes were not attended mentioned their use of videoclips, animations, and applets.

B and G tell of how they discuss limitations of animated models with their students; B gives an example of checking the correspondence of animated coupled pendulums with the real pendulums. Thus, this use of the digital environment may contribute to *Advancing concept development* and to the *nature of science* aspect of *Widening the scope of science education*.

C uses the digital tool *Edpuzzle* to create interactive video lessons and describes it as an element of attention for *Advancing concept development*.

The exam program prescribes that students have to be able to use the computer in modeling. Of the interviewed teachers, C, F, H, and N mention that they teach students modeling, which from the context can be interpreted as computer modeling. The connection seems evident between the availability of modeling software and the intention *Advancing skills development,* applied to computer modelling.

K mentions to use *Coach* hardware and software for research skills development. D mentions that the students do video measurements. These two cases show the possibility to support *Advancing research skills development* with an adequate digital environment.

Organizational environment

C's students do experiments about quantum physics in a university lab room. Companies from a STEM-promotion network, *Jetnet,* came to the school with facilities for experiments or a design problem. The students took part several times in regional contests in design challenges. F mentions that scientists from a university nearby are happy to come to the school. F also visits the university with the students for excursions and sometimes there is a trip to visit the international particle accelerator CERN, as part of the time dedicated to the optional curriculum domain *particle physics*.

These examples of contacts of the interviewed teachers with universities and companies help to show students realistic social, technological, and scientific contexts in which physicists work and is further developed. Thus, they support the expression of *Widening the scope of science education* and *Using contexts*. The lab facilities and contests support *Advancing skills development*, for research and design skills, respectively.

Other facilities and resources

E uses the Physics Olympiad as a source of rich test questions. L uses SPA (Systematic Problem Analysis) material, provided by SLO, Eric Mazur's concept questions, and the Mazur-inspired Dutch book *Natuurkunde is leuker als je denkt*, composed by a PLC (Koopmans et al., 2012). N takes materials from the annual physics teachers conference (WND) as exercises, and collects newspaper clippings about phenomena and applications of physics in society.

These examples of other facilities and resources support the expression of *Using contexts* with topical examples and of *Advancing concept development* with questions for (self-)tests and exercises.

Adaptable structural system

For the category *adaptable structural system*, part of the teacher's environment, findings are successively described for the following factors: *classroom interaction*, *school organization*, *collaboration with colleagues*, *professional development*, and *school examination*.

Classroom interaction

D and N say that they are careful not to lose their students' interest, and do their best to hold that interest with a variety in work formats and with surprising examples. The use of surprising or otherwise interesting examples may support the curriculum intention *Using contexts*. And if a teacher perceives a need in students for variety in work formats, that helps creating room for practical work, which may contribute to *Advancing skills development*.

H refers to the havo-culture when describing the strong interaction with the havo-groups, "[I tell] something, explain, pepper it with little demonstrations. Then the kids get started and I walk around and coach. The fast-feedback method is my favorite there." This teacher meets the students' need for strong interaction with activities that support *Advancing concept development*.

School organization

Some schools stimulate their teachers to elaborate a pedagogical view, through organizational measures or curriculum elements.

A's school planning allows to go deeper into subject matter and problems of students during periods when A works with a class every day. The school also stimulates that teachers put observing and exploring phenomena at the start of curriculum parts. The school influence A refers to apparently supported *Advancing concept development*.

The schools of E, K, and N organize learning trajectories for the development of investigative skills, for all subjects, or for all science subjects. Some of these extend from year 1 to the final year, culminating in the school research project (*profielwerkstuk*), in other cases it concerns a one-year coordinated skill training program for the sciences. These schools contribute to *Advancing skills development* and in the latter cases also to *Coordinating with other STEM subjects*.

Also, a hindering influence from the school level is mentioned. L feels limited in the time dedicated to *Advancing investigative skills*, a typical school exam domain: "The incentives in school are such that you take care that the central exam mark is as high as possible."

Collaboration with colleagues

As for collaboration with current colleagues, several cases seemed to support, or need support for, the expression of the curriculum intention *Advancing skills development*. E mentions examples of developing, together with physics and other sciences' colleagues, practicals and tests in a module for investigative skills for the science subjects. K is involved in developing a learning trajectory for investigative skills together with colleagues from other departments. M admits not to be very skilled and active in organizing practical work, but has good hopes that a new and experienced colleague can coach M in that respect.

D is bothered by the fact that colleagues from related subjects with whom D wanted to collaborate were not forthcoming; this factor hinders *Coordinating with other STEM subjects*.

Professional development provisions

In the subsection *professional development experiences*, professional development experiences from the past were described that have influenced interviewees. Here, influences are looked for from current participation in a PLC.

C and D are active in a PLC, where they get informed about what colleagues have come up with for the new exam domains and are invited to try out ideas. And vice versa, they can present their ideas. Curriculum intentions whose expression benefits from this professional development appear predominantly related to the school exam parts of the new exam programs; the interviewees were not specific on all of them, while the examples given relate to elaborating practical work and new subject domains, which are more context based than what was previously common. This might support *Using contexts*, *Advancing skills development* and *Coordinating with other STEM subjects*.

School examination

SE domains and skills are supposed to make up 40% of the enacted curriculum. These domains and skills are in principle "protected" by the rule that they should be assessed and, by implication, be taught.

C and D mention the SE domains, in particular those connected with biomedical contexts, as fields to which they give extra attention, supported by activities in their PLC. F says to support students in design activities when they choose a physics question for their school research project (*profielwerkstuk*); F is not able to find time for these activities in the physics hours. L says to use the SE-status of investigative skills to grade students on those skills, thus adding to the importance of the skills for students. These examples show possible support for *Advancing skills development*.

In some schools, the SE-related school research project is prepared by cross-curricular courses; those cases may support *Coordinating with other STEM subjects*.

Unadaptable structural system

For the category *unadaptable structural system*, part of the teacher's environment, findings are described for the following factors successively: *national examination*, *national syllabus*, and *national examination program*. This reflects the order in which references by the interviewees dominate. The order in which the factors formally dominate each other is the reverse: the examination program forms the legal framework for the syllabus, the syllabus for the examinations.

National examinations

Three strands emerge in the interviewees' responses: loyal or pragmatic, critical, and using national exams as feedback. Each of them will be discussed below.

First strand: loyal or pragmatic

Several interviewees mention how they spend time to prepare their students for the central exam format. F uses exam tasks as examples for test questions and constructs. F agrees with the shift in CE exams, since 2013, from an "exercises culture" [*sommetjescultuur*] to more conceptual questions; this supports a shift in exam training to more conceptual questions than merely mathematical exercises would do, thus supporting *Advancing concept development*. Still, F thinks it has gone too far: "Less emphasis on arithmetic does make students somewhat insecure. To earn a point, they now must put forward arguments" – by this criticism, F confirms the contribution to *Advancing concept development*, though with the risk of making students feel insecure. F is also happy with the increased attention for modelling in the CE exams, supporting the attention F wants to pay to *Advancing modelling skills development* in teaching.

K also reports, when asked about concept development, that students have to "explain things" in the CE tasks, for which K has to prepare them and thus has to pay attention to *Advancing concept development*. K indicates the limitations too, "that you are sometimes only busy with tips, 'how to pass an exam', instead of physics and I think that's a pity."

H says to make pragmatic use of CE questions from the past for "think-aloud sessions" where H tries to find out students' reasoning steps. This use of the CE supports *Advancing concept development*.

On several occasions, N refers to the exams as a motive to "[make students] flexible to understand new contexts in the exam." Other parts of the interview also show that N values this flexibility as a contribution to *Advancing concept development* and supports also *Using contexts* for this purpose.

Second strand: critical

Several interviewees mention how they are limited in enacting their ideal teaching by pressure from CE-preparation. Some connect it to curriculum intentions examined in this study.

B says to spend a lot of time on making students see the connections and regularities in the approach of physics, contributing to the nature-of-science aspect of *Widening the scope of science education* as well as the *making connections* aspect of *Advancing concept development*. B realizes that it goes at the cost of training for the exams, but: “we’ll train, but . . . only do that in the last few months, then we will really work towards the exam.” B explains the sacrifice: “I don’t think that through exam training they learn physics better. . . . Physics is: seeing connections.” B connects it to the central exam in particular: “In the school exam I still have a higher goal, after that it’s just training for the central exam.”

L says to train the students in developing lab journals, with the purpose of teaching them to work inquiry-based, a contribution to *Advancing skills development*. However, the school is not rewarded with good CE-marks for progress that students make in inquiry-based working: “The incentives within a school are such that you prefer that the CE mark is as high as possible, . . . there should be as much work as possible in [the CE-part].”

Third strand: CE as feedback for teacher

G mentions the CE as a benchmark, and students’ good exam results as feedback for G’s own effectivity and as a support for the approach to work with the students’ emotions and to guide them in finding patterns in phenomena and building a vocabulary. G connects this approach with efforts to *Advance concept development*.

National syllabus

Several interviewed teachers mention the syllabus as the document that prescribes, but also limits attention for *Using contexts*. N uses diverse contexts to train students’ flexibility, without preferences for certain contexts, but if the syllabus explicitly mentions a context, like medical imaging or astronomy, then “of course, you will pick up those contexts, because they are mandatory.”

B criticizes the syllabus for limiting the use of some concepts to particular contexts, which hinders practicing transfer between contexts.

L would have liked to see a more contextual elaboration in the attainment targets, but recognizes that the syllabus cannot do much more than write down in a few words that students should be able to deliver a certain performance within a given context, “in practice you depend on how you handle it yourself and what your textbooks do.”

National exam program

The interviewees who talked about the constraints and incentives from the national exam program refer to the attainment targets from the CE domains of the program. They diverge in what it means for them: two mention a negative influence, one a positive, for a fourth it hardly matters.

E experiences “a certain pressure” from the exam program, which limits the time available for design work and modeling and the possibility to integrate those activities with the rest of the subject matter. L too feels pressure from the dominating role of the CE part, as interpreted by the school. Both teachers mention the pressure of CE-content of the exam program in the context of *Advancing skills development*, which is apparently limited by this pressure.

F mentions how CE topics introduced in 2013 match with expertise from previous, more physics research related, jobs: quantum physics, new parts of electromagnetism, more stress on modeling. This supports F's emphasis on *science, technology and society*, an element of *Widening the scope of science education*.

B confirms to teach part of the subject matter only because it is part of the exam program, but that the change from the previous to the new program hardly influenced foci: having students work in an inquiry-based way and having them understand connections between topics. These emphases support *Advancing concept development*.

Differences between subgroups of teachers

Section 3.4, under *Selection of teachers*, described the distribution of interviewed teachers over age, years of experience as a teacher, experience in research or development roles, whether being a teacher was their first job, and gender. This distribution was meant to avoid biases as much as possible, but some of the characteristics were also used to get a sense of the extent to which they were related to the influencing factors expressed by the participants.

Counts of coded quotations could be made by subgroup but comparing counts did not indicate whether the differences were significant. Reading the quotations was needed to find meaningful differences. And even then, the number of teachers within subgroups who express themselves about an influencing factor was often too limited to assign significance to differences between subgroups. The following are a few comparisons that are nevertheless notable.

For the factor *professional history*, in some categories differences could be seen between first-career and second-career teachers. From the eight interviewees who reported positively about their *teacher education*, seven were first-career teachers, only one was a second-career teacher. Three other second-career teachers say that teacher education has not helped them much. As for *learnt from colleagues,* four out of eight first-career teachers stress influential roles of such colleagues in their career, for second-career teachers this was one out of five. Influence from or at least familiarity with renewals in the past is brought up only by four first-career teachers. For *Professional history*, no other subgroup characteristics appeared notable than, sometimes, the first/second-career distinction.

For the factor *cultural system: values and beliefs*, a difference could be seen in the category *beliefs about effective education* between teachers with and without experiences in research or development activities: all four teachers who emphasize clarity from the start for students are from the subgroup without such experiences, the three teachers who say to start with questions, or have students puzzle a while, have experience in research or development activities. A fourth teacher, experienced in that sense, goes deeper into the question of effective education by distinguishing teaching strategies for well-defined skills from those for "swampier" content. For *cultural system: values and beliefs*, no other subgroup characteristics appeared notable than, sometimes, whether or not the teacher has research or development experience.

For the factor *organizational environment* in the *material system*, two interviewees describe co-operating with universities or companies in their environment much more extensively than the other eleven. Both are second-career teachers, both older than 55 years.

As for other factors, no notable differences between teachers' descriptions could be related to any of the subgroup characteristics.

6.4 Conclusions and discussion

The research question for this substudy is: *What teacher profile and environment factors, as perceived by the teachers, may have influenced the expression in enacted curricula of curriculum renewal intentions?*

Influencing factors summarized graphically

In Figures 6.2 and 6.3, results of the analysis as listed in Section 6.3 are summarized graphically for influences that stimulate the expression of curriculum intentions in the enacted curriculum. Hindering influences appeared much less in the interviews and are only mentioned in the descriptions of the Subsections *teacher's profile* and *teacher's environment* below. The analysis of the data showed that almost all influencing factors from *life history* and *professional history* categories led to factors categorized as *values* or *beliefs*, which together were classified as the *cultural system*. Therefore, using the categories *life history*, *professional history* and *cultural system: values & beliefs* next to each other in one figure would mean that influences on the various curriculum intentions were counted double. To avoid that, two figures show influences on curriculum intentions: Figure 6.2 with the biographical categories *life history* and *professional history*, Figure 6.3 with the categories *values and beliefs*, as main resultants from those biographical categories.

It should be noted that the category *cultural system: values & beliefs* includes everything that was reported from life or professional history, whereas not every value or belief reported could be traced back into life or professional history. The thickness of arrows is proportional to the number of interviewees who, according to the interviews, contributed to the corresponding relations. The curriculum intention *Widening the scope of science education* is presented in its two components, the curriculum emphases *Knowledge development in science* and *Science, technology and society*.

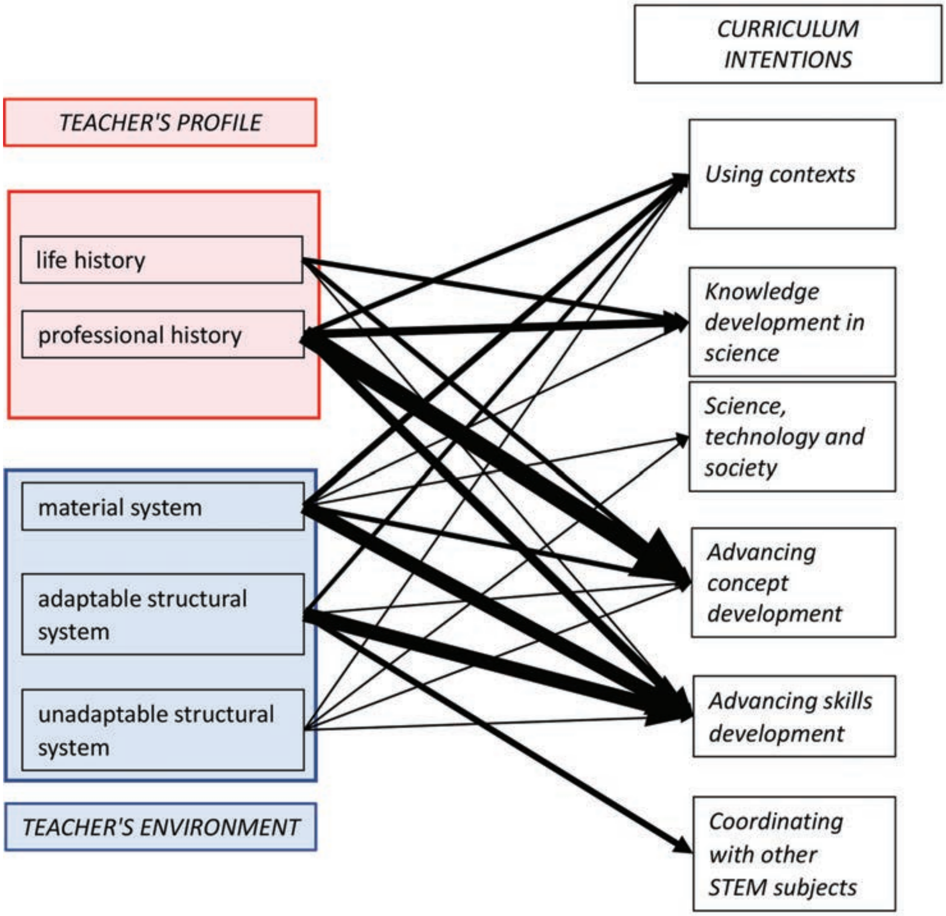

Figure 6.2 *Influences of the teacher's profile categories life history and professional history, and the teacher's environment categories on the expression of curriculum intentions.*

The analysis of the interview data show that all factors mentioned by the 13 interviewed teachers and listed in Table 6.1 have, to a greater or lesser extent, influenced the practices of the interviewed teachers. Some of the factors stand out because of the strength or detail with which the interviewees named them. Connections between influencing factors and curriculum renewal intentions were made in conjunction with interview data from Substudy 2 (reported in Chapter 5) for the interviewed teachers. The factors were found to mostly contribute to curriculum intentions being expressed in enacted curricula, but some also hindered that expression.

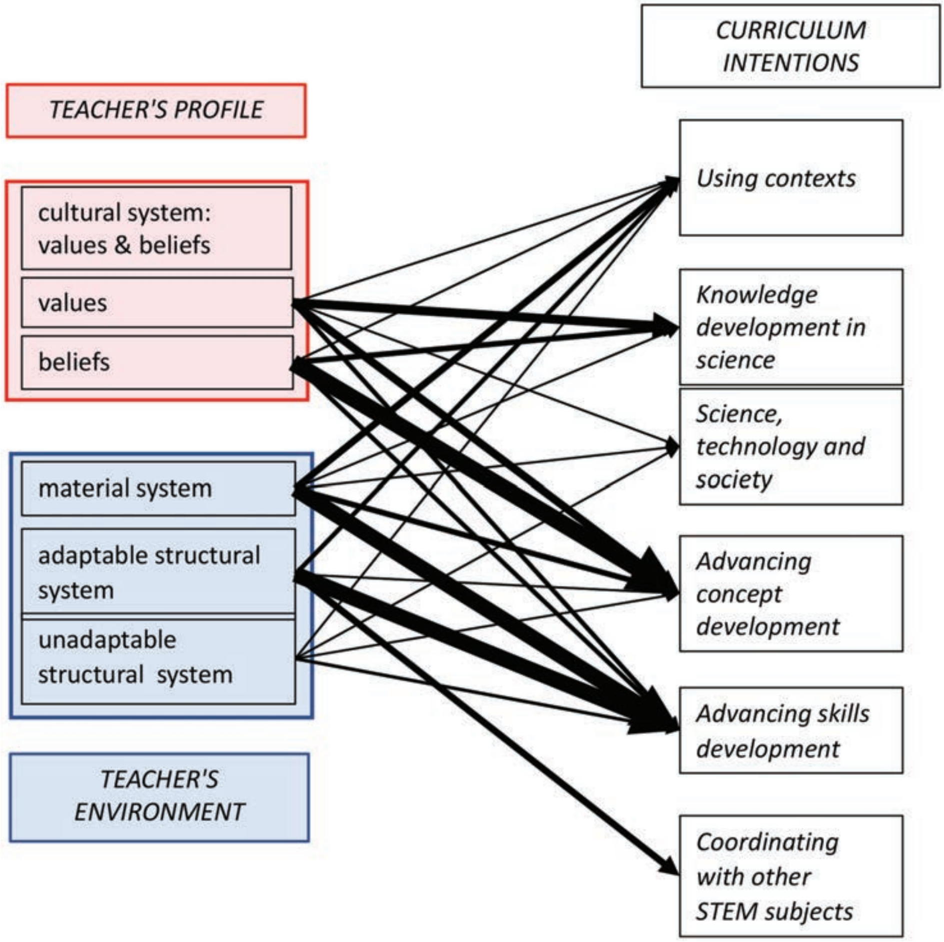

Figure 6.3 *Influences of the teacher's profile categories values and beliefs, and the teacher's environment categories on the expression of curriculum intentions.*

Teacher's profile

Nearly all statements the interviewees make about their life history and, more extensively, their professional history, describe how those factors have influenced their values or beliefs. This finding confirms that the *Cultural system: values and beliefs* can be seen as bringing together, like a funnel, the outcomes of teachers' life history and professional history. The factors from these histories mentioned as influencing teachers' actions most often or most strongly were *teacher education*, *professional development experiences*, *school or college time experiences*, *classroom experiences in the past*, and *learnt from colleagues*. The values and beliefs mentioned most often as outcome of those factors were described in terms of *values about the goals of physics education* and *beliefs about effective education and teaching strategies*.

The curriculum intention that appears most often or articulated most strongly in the *teacher's profile* factors is *Advancing concept development*, supported by tools or approaches that teachers learned to use, in particular in *teacher education* and *professional development experiences*. Various teachers mention how a scientific basis that they have become acquainted with in their *professional history* has reinforced intuitions or preferences regarding *Advancing concept development* they have acquired in their *life history*, such as Russian learning psychology or inquiry-based learning.

Another curriculum intention that stands out in the *teacher's profile* factors is *Widening the scope of science education*, most often because of references to attention for the role of the *nature of physics* in teachers' enacted curricula. This attention is seen in this study as part of the curriculum emphasis *Knowledge development in science*, which in turn is an element of *Widening the scope of science education*.

As for other curriculum intentions, in the analysis of the interview data, expression in enacted curricula of *Using contexts, Advancing skills development*, and *Science, technology and society* (an element of *Widening the scope of science education*) appear to be much less supported by factors from the teacher's profile. No mention at all was made of *Coordinating with other STEM subjects*.

Two examples could be found of factors in the *teacher's profile* that hindered the expression of a curriculum intention: the teachers who have become critical about *Using contexts*. In one case, this was due to the interviewee's experience with contexts as used by the textbook in his own school time; in another, due to the views on the nature of physics that the interviewee developed during school and university time.

Figure 6.1 shows an influence from students' learning outcomes and attitudes on teachers' *professional history*. This influence is confirmed by the interview data about the factor *classroom experiences*.

Teacher's environment

In the *teacher's environment*, no particular group of factors emerges in the analysis that appears to funnel the outcomes of other groups in this category to teachers' actions. The factors in the *material*, *adaptable structural*, and *unadaptable structural systems* all seem to have their own influence on teachers' actions, although interview quotations mentioning *professional development provisions* often refer to parts of the *school examination* program: these two factors are related in the data.

The role of central exams is less profiled in the interview data than what is obvious from the context in which upper secondary physics teachers do their job: preparing their students for the central exam goes without saying. What they say about the central exams shows that these both support and hinder the expression of curriculum intentions as investigated in this study, where the hinder arises from competition for available time.

The researcher's interpretative analysis includes a comparison with the analysis of the same interviews for Substudy 2, into curriculum intentions. The curriculum intention that thus emerges most strongly in the *teacher's environment* factors mentioned by the interviewees is *Advancing skills development*. Interviewees refer to *written materials* and *digital sources and facilities*. *Professional development provisions* appear to stimulate skills development domains from the *school examination program*. The *school organization* also plays a positive role for several teachers, with learning trajectories for research skills.

Also *Using contexts* is well articulated, supported by *written materials*, and *digital* and *organizational facilities*. This curriculum intention's expression is reinforced by what students appear to like and by the explicit place of contexts in the exam program.

In third place, *Advancing concept development* comes out as strong. Here, interviewees refer to the increasing conceptual approach of the most recent *central exams*, to clear explanations given by the standard textbooks as *written sources*, and to concept development tools provided by additional *written sources* and from the *digital environment*.

The other two curriculum intentions, *Widening the scope of science education* (through *Knowledge development in science* or *Science, technology and society*) and *Coordinating with other STEM subjects*, are less visible in the interview data as supported by factors from the teacher's environment.

Much less is said about factors that hinder the expression of curriculum intentions than about supporting factors. Most clearly, hinder is reported for *Advancing skills development* from time pressure from the *central exam program* and *central exams*; in one interview, this is increased by the pressure reported from the *school organization*, in particular the school leaders. Also *Using contexts* and *Advancing concept development* are mentioned as impeded by these factors. As for *Coordinating with other STEM subjects*, one teacher reports that the lack of *colleagues willing to collaborate* is in the way of such cooperation.

In summary, the curriculum emphasis *Knowledge development in science*, an element of *Widening the scope of science education* seems mostly supported by elements of the *teacher profiles*, anchored in the *Cultural system: values and beliefs.* On the other hand, *Using contexts* and *Advancing skills development* seem mostly supported by elements of the *teacher environments*. The curriculum intention *Advancing concept development* is supported by both categories of influencing factors.

Discussion: comparison with an evaluation of most recent physics curriculum renewal

As a secondary source, a questionnaire-based evaluation (Ottevanger et al., 2018) of the implementation, in 2013, of the most recent exam program was consulted. This is the program that also acts as the formal curriculum for the teachers participating in this study (see also Section 5.5). As part of that evaluation (conducted by SLO, surveys completed by 91 physics teachers, questioned in 2016-2017) no questions had been asked that match with the categories *life history*, *professional history*, and *cultural system: values, beliefs* from this substudy. However, some questions went into the incentives that the teachers wish and the constraints that they experience, and some of the answers could be interpreted in terms of the factors investigated in this substudy. The report shows the following results that can be linked to the research question of the substudy into influencing factors perceived by today's teachers.

As for teaching materials and school-based support with practical work (technical education assistants and lab space), the *material system* in the model used in this study, most respondents appear to feel sufficiently equipped to enact the new curriculum. Regarding computer facilities and rooms, half of the respondents is dissatisfied. These factors say little about which curriculum intentions are supported and which not, except that *advancing skills development* might be hindered by lacking computer facilities for a considerable group of respondents.

Regarding the *adaptable structural system*, the respondents do not mention obstructions from the side of the schools. As for professional development, half of them acknowledge that they need further training related to new topics, testing, and practicals, which indicates that the respondents are willing to contribute to quality or quantity of those three aspects of the enacted curriculum. Of those three, *new topics* reflect the renewal commission's intention to increase the room for topical physics, and thus the curriculum intentions *Using contexts* and *Widening the scope of science education.* And practicals are needed, though they are not enough, to facilitate the curriculum intention *Advancing skills development*.

Regarding constraints and incentives from the central exam (CE) program: the responding teachers feel overloaded. The exam program was designed following the Ministry's rule that 60% of the program *content* will be assessed in the CE and that at least the remaining 40% must be assessed in the school exam (SE). This rule does not say anything about the *time* spent on those two parts, but for a content ratio of 60/40, the time distribution also is generally seen as also 60/40. The questionnaire asked about that time distribution. Of the responding teachers, 58% think that the SE domains can be learned in 40% of the time, and only 27% think that the CE part can be done in 60% of the time. This suggests that there is an overload, which is confirmed by more than half of the teachers, who reported that they ran out of time, even in 2016-2017, three years after the examination program became effective. Teachers are looking for solutions for this by spending less time on SE components and by eliminating practicals and time-consuming teaching methods. A follow-up study by SLO (Pieters et al., 2020) confirmed that science teachers' solutions for curriculum overload may form a threat to the expression of *Advancing skills development* and *Advancing concept development*.

Results from the interviews as part of Substudy 3 suggest a few relevant connections with results from this external source. One is the interest shown in more professional development about new topics in the 2013 exam program. That would anyway support the expression of *Using contexts* and *Widening the scope of science education*. But if the interviews of this study are put next to that: these learned that several interviewees connect professional development experiences in their history with *Advancing concept development* and current membership in a PLC with *Advancing skills development*. Taken together, these results suggest that continuing professional development on new topics may support a broad spectrum of intentions.

Another connection is the role of the CE-dominated part of the structural system. The interviews indicate that *Advancing skills development* in particular is hindered by that system. The SLO-evaluation finds a curriculum overload, many teachers feel that they lack sufficient time for the CE part of the curriculum and solve that by spending less time on SE components and by eliminating practicals and time-consuming teaching. SE and practicals favor the curriculum intention *Advancing skills development*, time-consuming teaching methods favor *Using contexts* and *Advancing concept development*; the curriculum overload thus goes at the cost of those curriculum intentions.

As for the limited influence of the *unadaptable structural system* appearing from the interviews, the evaluation by Ottevanger et al. (2018) confirms the significant influence that can be expected from the national exam system, in particular the national syllabus and the central exams.

CHAPTER 7

Factors that influence teachers' profiles and environments

7.1 Introduction

Like the previous substudy, Substudy 4 investigates factors that may influence the expression of curriculum intentions in teachers' practices. But while Substudy 3 focused on factors from their profiles and environments that influence teachers' enacted curricula, this substudy focuses on factors that in turn influence these profiles and environments, thus indirectly influencing enacted curricula. For the sake of brevity, the term *direct* will be used for factors that are part of a teacher's profile or environment, and *indirect* for factors that influence that profile or environment.

The following research question guided this substudy:

> *What factors may have influenced profiles and environments of teachers against the background of the curriculum renewals in upper general secondary physics education in the Netherlands since 1970?*

Substudies 3 and 4 are closely linked and pertain to the second part of the main research question, about what factors may have influenced the expression in today's curricula of curriculum renewal intentions enacted by upper general secondary physics education in the Netherlands since 1970. They are concerned with chains of influences, inside and maybe even from outside the world of education, through which curriculum renewal intentions, seen as *memes*, may have reached the enacted curriculum of upper secondary physics teachers in the Netherlands. This substudy focuses on factors that can influence teachers' profiles and environments in such a way that they support, or hinder, the propagation of curriculum intentions between developers and teachers. Not every single one of the factors that might be identified needs to influence on its own the profile or environment of teachers; factors can also influence each other. It was not clear of all the factors examined, either from the data itself or from analysis of the data, for which curriculum intentions they might have influenced the propagation in profiles and environments of teachers, but the data sources (texts and individuals) had been selected and surveyed against the background of that question.

The factors mentioned in this research question refer to what is brought up in documents on the renewals since 1970 or by participants and other stakeholders at the time.

The question of how the influences examined in this substudy could relate to teacher profiles or environments, as examined in Substudy 3 (Chapter 6), was answered as part of the qualitative analysis of publications and interviews with participants or witnesses of the renewals that form the data source of Substudy 4.

Making connections between indirectly influencing factors and specific elements of teacher profiles, teacher environments, or teacher practices, was not included in the interviews as a question for participants or witnesses; some connections were explicitly made in the investigated sources, others result from the researcher's data analysis.

In addition to answering the research question, Substudy 4 also yielded a categorization of indirectly influencing factors, meant to organize the analysis, which was inspired by the evolution theory and ecology based models for analyzing data, as explained in Chapter 2.

Figure 7.1 (copy of Figure 2.4, explained in Section 2.4) shows the categories examined, zooming out from Figure 6.1 (copy of Figure 2.3): factors influencing a teacher's profile and environment, and indirectly their enacted curriculum.

Section 7.2 explains the design of the substudy, 7.3 shows its results according to the different factors, and 7.4 presents its conclusions.

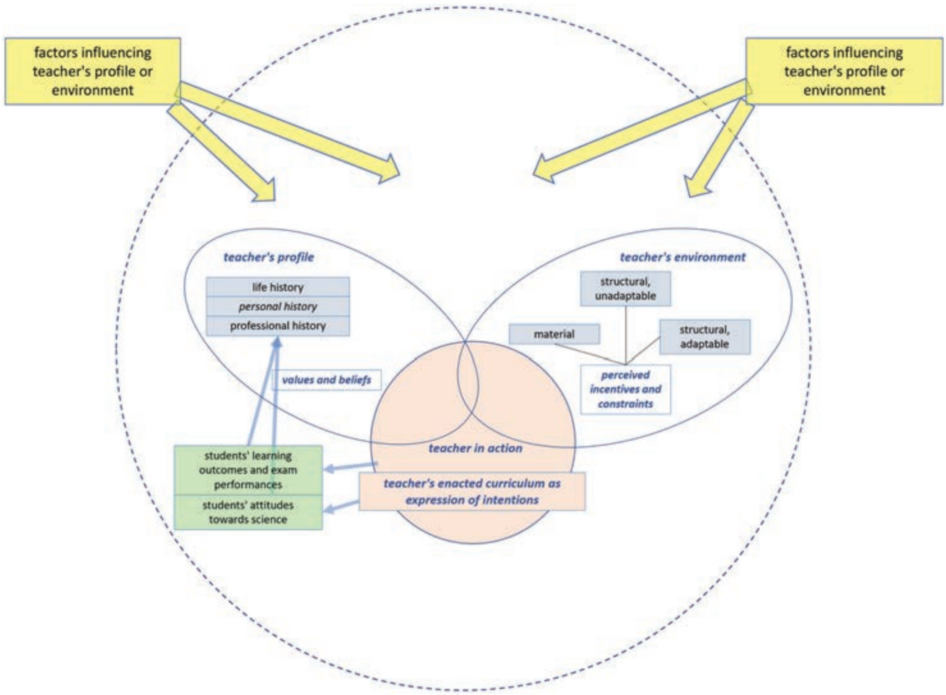

Figure 7.1 *Conceptual model for factors influencing a teacher's environment and profile, indirectly influencing teacher's actions. (Copy of Figure 2.4)*

7.2 Design of the substudy

Sources of data

Sources of data used for Substudy 4 were the following:

- documentation on implementation activities published by or around the teams responsible for the renewals investigated in this study (Table 7.1); it includes descriptions of the renewals studied in Substudy 1 (Chapter 4); Table 7.1, a copy of Table 4.1, shows the chronology of those renewals and the distinction between innovation projects and exam program reforms;
- a publication on a master study on an analysis of physics education textbooks since 1980;
- 16 interviews with project leaders and team members, teacher educators, teachers, and researchers who worked during the same periods as the projects examined and the years of implementation of these projects; seven of the interviewees would attend or had attended the participants' meeting of Substudy 1 (for attendants to that meeting see Table 4.1, all persons interviewed for Substudies 1 or 4 are mentioned in Appendix 2); the interviews were held by the researcher, those held before the participants' meeting were done together with a master student (as part of his thesis work: Ververs, 2016); 15 interviews were held with one person and one interview with two people, so in total 17 people were interviewed;
- transcriptions of the discussions in the second and third round of the participants' meeting of Substudy 1, in which participants, next to discussing the descriptions of curriculum intentions, also brought up implementation activities by the renewals.

Interview structure

The interviews mentioned above were semi-structured, as the roles, scopes, and active periods of the interviewed renewal participants differed strongly. The basic questions were about what they had noticed in the developments of physics education in the years they had been active; and about what factors influencing or intended to influence teachers' enacted curricula they had seen develop in the curriculum development and teacher support activities.

After some of the interviews, a summary was made, ordered by topics addressed during the interview, and those participants confirmed or amended the summary. For the analysis in this substudy, approved summaries were used when available; in the other cases, the transcript of the interview was used. One participant had prepared a written overview of his memories of "how the physics curriculum took shape in practice and how new ideas played a role in this" since 1970, which he used during the interview. This written overview was also used for the analysis.

Table 7.1 *Description of studied renewals (copy of Table 4.1).*

Acronym and name (Dutch / *English*) of innovation project or formal reform	Period of development activities	Project, developed teaching and assessment materials[1]	Reform, proposed exam programs, to be legislated as input regulation. In brackets: year of nation-wide implementation.
CMLN Commissie Modernisering Leerplan Natuurkunde *Commission Modernization of the Physics Curriculum*	1965-1974		x (1976)
PLON Projekt Leerpakketontwikkeling Natuurkunde *Physics Curriculum Development Projec*t	1972-1985	x	
DBK-na Differentiatie binnen Klasseverband, natuurkunde *Differentiation within Classroom, physics*	1974-1985	x	
WEN Werkgroep Examenherziening Natuurkunde *Working Group Exam Revision Physics*	1982-1987		x (1991)
Second Phase Tweede Fase *Upper General Secondary Education*	1994-1995		x (1998)
NiNa Vernieuwing natuurkundeonderwijs havo/ vwo *Renewal upper general secondary physics education*	2005-2010	x	x (2013)

1) PLON and its partners also produced so-called Experimental Exam Programs (EPEPS), in sub-projects aimed at havo and vwo, addressed as HBB and VBB, respectively. These were not accepted as advice to base further legislation on by the Ministry of Education.

Coding for analysis

Relevant passages, i.e., passages that described influences on teachers' profile or environment, whether intended or unintended, and that showed relevance for the background of the study: curriculum intentions of the renewals, were selected from the written and the transcribed oral sources.

These passages were uploaded in ATLAS.ti. Codes emerging from open coding of relevant clauses for the research question were grouped into categories that could be related to Figure 7.1.

Decisions about describing and using the codes, and organizing them in categories, were discussed with a colleague, an experienced education researcher, to increase clarity and reduce ambiguity. For the resulting codebook, inter-coder agreement was checked for three of the interviews. Out of 60 quotations, there was agreement about 57 (95%) quotations.

Two of the emerging categories of factors refer to influences within the Dutch physics education system. Their names are inspired by the image of curriculum intentions as *memes* that propagate through cultural systems and may be expressed in fitting environments (as in Figure 2.1). One of those categories of factors is *Survival and propagation of curriculum intentions*, referring to influences that are not controlled by developers or other stakeholders to promote certain curriculum intentions. These influences contribute to the survival and propagation of curriculum intentions, even if they are unintended: not applied actively and systematically as part of a physics curriculum development project or commission activities. A second, similar category is *Improving or creating circumstances favoring curriculum intentions*, referring to influences that can be exerted only intendedly, in an active and systematic way, such as recommending the minister to include a new subject domain in the prescribed exam program or providing sample teaching materials with a suggested teaching approach.

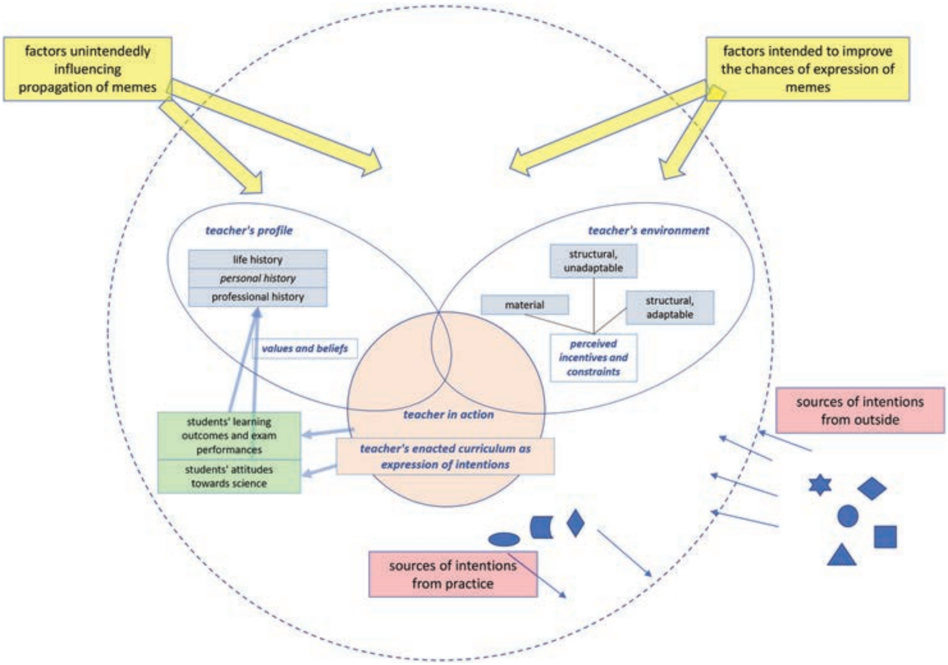

Figure 7.2 *Conceptual model for factors influencing a teacher's environment and profile, indirectly influencing teacher's actions, and for sources of curriculum intentions.*

A third category that emerged was named *Sources of curriculum intentions*. For the analysis, such sources, if they were alluded to in the data about the studied renewals, were acknowledged as indirectly influencing factors as well. Initially, this category referred to *sources from outside* the Dutch physics education system. After the intercoder agreement procedure, a code *sources from practice: teachers' reflections on their experiences* was added for references to teachers as possible sources of curriculum intentions influencing developers.

Including the categories that emerged from the analysis of data in Figure 7.1 led to Figure 7.2. Curriculum intentions that may propagate in the world of the teachers and the factors that may influence them are indicated by small abstract forms, like triangles or diamonds. The resulting code book is shown in a concise form in Table 7.2; its details can be found in Appendix 5.

The selected quotations were associated where possible with directly influencing factors, as examined in Substudy 3 (Table 6.1, Appendix 4), and with curriculum intentions as examined in Substudies 1 and 2 (Table 5.2, Appendix 3). In Section 7.3, as results of this substudy, only the indirectly influencing factors are described for which a link could be made to the directly influencing factors, arranged in the *teacher's profile* and the *teacher's environment*. The primary concern in this substudy was the connection with the direcly influencing factors. The quotations in question were selected to show relevance for the background of the study, curriculum intentions of the Dutch physics education renewals, but the quotations did not have to be able to clearly demonstrate the connection to one or more specific curriculum intentions. Where such a connection was visible, it is mentioned in section 7.3.

Of the sources used in this substudy, only one allowed to make a connection to teachers' practices: the evaluation study by SLO of the 2013 science education reforms (Ottevanger et al., 2018) questioned about 100 physics teachers about their practices, related to the most recent renewal's curriculum intentions.

Table 7.2 *Codes for analyzing documents and interviews regarding factors influencing teachers' profile and environment as observed or exerted from the outside. Codes are displayed in the left column, code groups in the shaded rows.*

Code	Description
Sources of curriculum intentions	
from outside: theories and studies about knowledge, learning and teaching	as sources, insights, models, metaphors
from outside: developments in society	general curriculum discussions technological developments advices or desires from academic research need to make students appreciate topical physics

Code	Description
from practice: teachers' reflections on their experiences	teachers' reflections on their experiences, articulated as curriculum intentions
Survival and propagation of curriculum intentions (unintended influences)	
through international project publications, sample exam programs, presentations	foreign project publications, teaching materials, exam programs workshops and presentations at teacher conferences
through persons	situations in which individuals take an idea from one job or role to another
through research projects and dissertations	research publications
through settings with a different focus	through projects or products with other focus than physics education renewal
Improving or creating circumstances favoring curriculum intentions (intended influences)	
securing in CE part	secure intentions in central examination (CE) program part, syllabus, content and format of CE assignments, parts of the textbooks about the CE content
providing clarity about curriculum intentions	create and provide clarity about curriculum intentions, e.g., in a key document describing initial intentions
designing for teachers' concerns or zone of proximal development	use knowledge about teachers' concerns or zone of proximal development use awareness of "what's in it for them?", market pull offer teasers or examples avoid curriculum overload, *replace* rather than *add*
informing and involving teachers inside and outside project	foster teachers' understanding for project ambitions and activities engage teachers in trying out their own selections prevent mistrust and immune reactions
developing or feeding infrastructure	support committees like the working group of physics teacher educators connect with partners, like institutes for teacher education professional development, textbook publishers, schools
facilitating experiences in a safe setting	facilitate teachers' experiences in an authentic and complete system environment, prevent the need to make compromises between regular demands and experiments allow teachers to experience a different approach in a normal setting provide enough resources to meet teachers' wishes and obligations

7.3 Results

This section presents the findings about factors that indirectly supported or were planned to support the enactment of curriculum renewal intentions in teachers' practices. Findings are connected, wherever possible and relevant, to the code categories of Substudies 2 and 3: curriculum intentions (Table 5.2, Appendix 3) and directly influencing factors (Table 6.1, Appendix 4), respectively. Curriculum intentions and directly influencing factors, or elements belonging to their descriptions, will be written in italics.

Sources of curriculum intentions

Described here are three categories of sources of curriculum intentions that entered the world of Dutch physics education stakeholders, which enacted curricula are part of, sources that may have influenced teachers' profiles or environments: theories and studies about knowledge, learning and teaching; developments in society, including science and technology; teachers' reflections on their experiences.

Theories and studies about knowledge, learning and teaching

The curriculum intentions most clearly inspired by theories and studies about knowledge, learning, and teaching are *Advancing concept development* and *Use of contexts*. Boersma (1987), Van Genderen (1989) and several interviewed sources mention one or more of the following as influencing Dutch innovation projects and textbooks for science education, or physics education in particular, in the 1970s and 1980s: Bruner's discovery learning, Karplus' elaboration of Piaget's phase theory for science education, Ausubel's cognitive psychology, and Vygotsky's zone of proximal development. A major influence on Dutch physics education, including its discussion of constructivist epistemology, came from the British *Children's Learning in Science Project* (Driver, 1988; Driver et al., 1994), as stated by PLON team member and later professor of Physics Education Piet Lijnse in his memoirs (Lijnse, 2014). A participant who worked as a teacher educator remembers the feeling of those years that with the help of educational science and pedagogy you could do much more in the classroom than was used at the time. Several Dutch science educators went to study in such a field, pedagogy or andragogy, next to their science background,.

The most recent reform commission, NiNa, referred to the same strand (Commissie Vernieuwing Natuurkundeonderwijs havo/vwo [CVN], 2010, pp. 11-12): "The NiNa commission therefore favors a concept-context approach, which is about making concepts meaningful to students in different contexts. Internationally, this concept-context approach is consistent with a broad understanding of context-based science education."

The data suggest that these theories and studies have influenced Dutch renewal projects or commissions and thus their written curricula, and textbook authors. These in turn may have influenced the *material* and *structural system*s of the *teacher environments*.

Developments in society

A motivation for renewals in science education that keeps coming back in the reports of reform commissions is the need for more and better trained scientists and technicians, and for a greater appreciation in society for science and technology. For developments in science education from the 1950s onward, there is a clear influence from the Cold War, which fueled the desire to be more technologically advanced than the rival countries. Lijnse (2014) describes this influence on science education projects in the United States and the United Kingdom, which in turn influenced developments in the Netherlands. The outbreak of the Korean War in 1950 and the launch of Sputnik in 1957 accelerated initiatives in the United States (Rudolph, 2006), followed by other countries, including the Netherlands. A former teacher who was interviewed had been on a study trip with physics teachers to the United States in 1976, where he saw how strongly the Sputnik effect underpinned the developments; he saw a "new kind of physics education" emerging in the United States. This inspired him to elaborate, in his later work as co-author of a textbook, increased attention for hands-on physics education in experiments by students connected to the theory. Around 1980, a study was carried out into the position of societal issues physics education (Eijkelhof et al., 1981). In a retrospective article, PLON team members Eijkelhof and Kortland (1988) associate the pressure on science education that they saw since the 1970s with a decreasing motivation among students. They also point at (p. 284) "The tension between economic and environmental considerations [which] led to: growing intensity of public debate, at first focussing on our energy future but very soon extending to more general discussion of the impact of scientific and technological developments on society." They see a shift of emphasis towards *Science, technology and society*, which is an element of this study's curriculum intention *Widening the scope of science education*, and the need for *Advancing decision making skills development*. These shifts influenced the PLON project in its aims and in the *sample teaching materials* they describe in their article. Eijkelhof and Kortland (1988) write:

> Internal and external pressures on the content of science education have led to a debate whether science education should broaden its aims and no longer concentrate mainly on the few students who will study science at university level. This debate not only takes place in the Netherlands. . . . The PLON project has been influenced by this debate, and the aims of physics education as stated within the project team have evolved over a number of years into a balance between:
>
> - *preparing students for coping with their (future) life roles as a consumer and as a citizen in a technologically developing, democratic society (emphasizing the use of physics as one of the tools for decision making at a personal and at a societal level and contributing to (more) thoughtful decision making);*
> - *preparing students for future education and for (future) employment (emphasizing an adequate mastering of scientific concepts and skills and providing an orientation on the use of scientific knowledge in different societal sectors and types of further education).* (pp. 284-285; emphasis as in original)

An interviewee who was active as a teacher educator and curriculum developer in the 1980s notes that the stress on social relevance in education was also visible in the rising popularity of cross-subject kinds of education like consumer education, traffic education, environmental education, or peace education, also calling for *Coordinating with other STEM subjects*. Elements of these *educations with other focuses than physics education* can also be seen in the *sample teaching materials* that PLON elaborated on traffic, medical diagnostics, and radiation and risks, always including the element of making informed decisions.

The need for scientists and technicians and for a broader public appreciation of science reappears in the 21st century. In the introduction to its report, the NiNa commission (CVN, 2010) refers to societal developments as driving its view of what physics education should be.

> Physics is what physicists do. From this perspective, the Commission Reforming Physics Education havo/vwo . . . has developed new exam programs. . . . Societal developments are driving the demand for broad-based physics education. Developments in research and technology, and innovations of physics education in other countries show that there are opportunities for such a renewal. (pp. 7-8)

In section 3.1 of CVN's report, it highlights the theme "Netherlands Country of Knowledge" (*Nederland Kennisland*) from government policy, in the wake of the EU's *Lisbon Agenda*, as one of the backgrounds of the renewal. The commission explains the need to educate future producers of science and technology as well as future consumers:

> In order to achieve a sustainable increase in the number of scientists and technicians, it is especially important that the appreciation for science and technology increases. Education can make an important contribution to this. Students must be aware that solutions for many social issues require scientific and technological contributions. Demonstrating the interdependence of science and technology with social domains such as health, economy, sustainable energy, climate, transport, sports, communication, is one of the ways to do this. Competences in science and technology are for everyone important. A certain amount of science knowledge and skills is necessary for all citizens to find their way in today's technological society. (p. 36)

The key idea that CVN articulates as "Physics is what physicists do" supports curriculum intentions related to physicists' practices: *Using contexts*, *Widening the scope of science education*, *Advancing skills development*, and *Coordinating with other STEM subjects*.

A more particular influence on physics education's curriculum intentions started with the government, in the 1980s (Ministerie van Onderwijs, 1985), stressing the need for IT goals in education, integrated in various subjects. One of the support activities was the PRINT-project, providing teachers of various subjects with ideas for using the computer in their lessons (e.g., a guide for physics and mathematics: Algemeen Pedagogisch Studiecentrum, 1990). For upper secondary physics education, this resulted in including physical informatics, or physical computer science (*fysische informatica*), into the *exam program* by the WEN commission. A VBB team member, who was also an adviser of both WEN and *Second Phase* commissions, describes how in the years that followed, physical informatics contributed to strengthening the role of technology in physics education, of modelling, of systems thinking, in exam programs and teaching materials, themes that support in their turn the curriculum intention *Advancing skills development* for research, design, and modeling skills.

Another line of social developments that influence curriculum intentions in physics education can be found in education policy, in the aim of equity, better access, and relevance for a more diverse population of students. Several DBK participants tell how DBK is an example for that line: an important physics innovation project, meeting the wish in society for internal differentiation in mixed classes by developing a large set of *teaching materials* and a large *professional development community* of teachers. But also, Basic Education (*Basisvorming*), a development in Dutch lower secondary education in the 1990s, aimed to promote equity, thereby exerting an influence on upper secondary education, according to an interviewed teacher educator active in that decade. It supported *Using contexts* in physics education and attention for *Advancing skills development*. Thus, it also reinforced the position of technology in physics education, part of the curriculum emphasis *Science, technology and society*.

The emphasis in the 1980s on making physics education more attractive for girls is an example of promoting equity, too (e.g., Van Aalst, 1987; Lijnse, 2014; interviewed teachers and textbook authors from that period) – this equity is also in the well-understood self-interest of the science and technology community: without girls, you would miss half of the available talent. This led to the inclusion of Biophysics in the 1991 *exam program*, the first time that a context became part of an exam program as content, rather than just a didactical suggestion, and thus entered textbooks and enacted curricula. Relevance for girls also reinforced the inclusion of concepts related to radiation effects on human tissues in the domain of Nuclear physics in the 1991 *exam program*, supporting understanding of the contexts of medical imaging and of health risks. In the 2013 *exam program*, Medical imaging became a domain in itself, a context domain. Thus, this line of social development supported the curriculum intentions of *Using contexts*, of *Science, technology and society* (an element of *Widening the scope of science education*), and of *Coordinating with other STEM subjects.*

The data suggest that these social developments have influenced Dutch renewal projects or commissions and thus their written curricula, and textbook authors. These in turn may have influenced the *material* and *structural system*s of the *teacher environments*.

Teachers' reflections on their experiences

In 1972, teachers were asked to list some key issues themselves to be addressed in the innovation project that was going to start (Hooymayers, 1986); as for the curriculum intentions examined in this study they mentioned more up to date research skills (group work, supporting theory development, quantitative reasoning) and strengthening of judgment skills, and more topical physics and philosophy in textbooks. These recommended issues reflect *Advancing skills development*, *Widening the scope of science education* (both *Knowledge development in science* and *Science, technology and society*), and *Coordinating with other STEM subjects*. In the available data on the development of physics education in the Netherlands, no other comparable open consultations of teachers could be found.

Van Aalst (1987) and several of the interviewed renewal participants or witnesses mention the WND teacher conferences in and even before the 1970s, where teachers discussed what they thought of as important elements of physics education to be included in renewal activities. In general, they responded to written and oral presentations; Van Aalst mentions presentations from *Nuffield* and *Project Physics*. In these discussions, teachers can be seen as interpreters of intentions formulated by others, like these U.K. and U.S.A. projects, rather than as sources of curriculum intentions.

All other references to teacher reflections were to consultations of renewal commissions or as feedback from pilot teachers. In those cases, the reflections informed commissions about teachers' judgments of commission plans, their concerns, or practical possibilities to express proposed curriculum intentions in their enacted curricula, but the data do not show new curriculum intentions brought forward from such reflections.

In summary, only in one occasion teachers were invited to mention curriculum intentions immediately based on their experiences; in most cases, teachers' reflections were on proposals from foreign or Dutch projects. No particular curriculum intentions stood out in the data referring to these reflections.

Unintended influences: survival and propagation of curriculum intentions

Once curriculum intentions have entered the system of physics curriculum developers, teachers, and other stakeholders, they can be promoted by active interventions that create circumstances favoring the intentions to be enacted. They can also be spread, in unintended ways, without targeted interventions, through available factors. This subsection describes the latter category; the active creation of environments is discussed in the next subsection.

Through project material

Curriculum intentions can proliferate, among other things, via project publications and sample exam programs. Many of these are included in the definition of written curricula as used in this study. Sample teaching materials and exam programs from other countries can be seen as not targeted at Dutch teachers' practices, but nevertheless influential.

Former PLON project leader Van Aalst (1987, p. 10) mentions the British *Nuffield* (Nuffield Advanced Science: Physics, 1971) and the U.S.A. *Project Physics* (*The Project Physics Course*, 1970) as projects that sparked enthusiasm at teacher conferences and formed sources of inspiration for PLON. The enthusiasm of the Dutch teachers for *Nuffield* and *Project Physics* supported CMLN's recommendation to develop a fundamental view on a new physics curriculum (CMLN, 1974), which led to the PLON project. Yet another project from the United States, by the Physical Science Study Commission at MIT (PSSC, 1960), had caught the attention of the Dutch physics education community. This project, following recommendations by Bruner (1960, see also Lijnse, 2014, Chapter 2), stressed the structure of the discipline to improve science education. According to a then PLON project team member, PLON was more attracted to *Project Physics*, as it had more attention for what would interest the student, PLON's point of view being connection to students' life world; thus, it supported the curriculum intentions *Using contexts*. Lijnse (2014, Chapter 2) explains this from the need to pay more attention to the process of physics, for which *Project Physics* developed inspiring materials, and pay less attention to the structure of the subject, for which PSSC had done high quality work. PLON also had exchanges with the Australian *ASEP* project (Australian Science Education Project [ASEP], 1974), which focused on supporting students in their personal learning routes and on students' activities and inquiry. Part of these projects was intended for junior secondary education, yet the influences occurred in the sample teaching materials and proposed exam programs of the upper secondary projects HBB and VBB (PLON, 1983; PLON-UvA-RUG, 1983), in which PLON collaborated with researchers and developers from various universities and schools (teachers as developers), including DBK experiences. The WEN commission itself, according to its then chairman in his interview, has also made direct use of materials from *Nuffield Physics* and *Project Physics*. The sample teaching materials and exam programs produced by HBB and VBB, and the WEN exam program expressed the curriculum intentions *Using contexts* and *Advancing research skills development*, and attention for history and philosophy of science, elements of the curriculum intention *Widening the scope of science education* – curriculum intentions which had initially been expressed in the publications by the foreign projects. The written curricula created by the Dutch projects and the WEN commission influenced the *material*, *adaptable*, and *unadaptable structural systems* in the *teacher environments.*

As an interviewed curriculum developer explained, several Dutch curriculum developers took ideas from projects using ICT in physics education for college students at the University of Nebraska. Bob Fuller, a strong promotor of Robert Karplus' work, in particular his *learning cycle* and promotion of hands-on science education (Fuller, 2003), was the contact person. Fuller's influence as a Karplus ambassador was mentioned several times in the interviews for this study, as one of the promoters of *Advancing concept development*. Fuller's ICT projects also inspired the physics didactics group, later the AMSTEL Institute, of the University of Amsterdam. This institute's daughter CMA developed the system board that was needed for practical work with physical informatics and has continued up to the present to provide support on the use of technology in science education in *hardware*, *software*, and *professional development*. Thus, this line of projects and scholars is relevant for the proliferation of *Advancing concept development* as well as for physical informatics in the WEN *exam program* of 1991, and its consequences for the emphasis *Science, technology and society* and *Advancing modeling skills development*. They influenced, and partly still influence, *teacher environments* through their publications, resources, and professional development provisions.

Yet another line started at the strategy of peer instruction, which was initiated and elaborated by Erik Mazur of Harvard University (Mazur, 1997). Mazur presented his work in 1996 at the Dutch WND annual teacher conference. His book became a source both for *teacher educators* and for a *professional learning community* (PLC) at the University of Groningen. In this PLC, secondary school teachers used Mazur's approach, primarily aimed at first year college students, to design questions for their own students. One of the participants in the PLC proposed to collect and publish the best questions. In collaboration with the science teachers' association NVON and Noordhoff publishers, the PLC then produced a *teacher support book* with concept questions fitting into the upper secondary physics curriculum (Koopmans et al., 2012). This line appears a strong support for the curriculum intention *Advancing concept development*: several interviewed teachers refer to Mazur's strategy and its elaborations in *teacher education* and in the book with examples by the University of Groningen PLC, see Chapters 5 and 6. The support book and PLC provisions influenced *teacher environments*.

The influences continued, not just from one Dutch project or reform to the next, but also from international sources. In 2006, the Commissie Vernieuwing Natuurkundeonderwijs havo/vwo (NiNa commission) wrote in its vision document *Physics is alive* (CVN, 2006):

> Examples of a new approach to physics education can be found in the British curricula 21st Century Science, Advancing Physics and Salters Horners Advanced Physics. . . and in the German PIKO (Physik im Kontext). We will draw on ideas and experiences from these projects when developing the sample curriculum. Existing informal contacts will be used for this. (p. 53)

Indeed, materials from those projects have been used in the NiNa commission's pilot project, to discuss the topics to be included in the exam programs and their rationale, as well as to find ideas for the elaboration in pilot teaching materials. Thus, these projects from other countries contributed to the elaboration of *Using contexts* in the NiNa *exam program* and its *sample teaching materials*, elements of *teacher environments*. The NiNa commission did not only advise contexts because they show the relevance of physics, but also because they contribute to *Advancing concept development* by making concepts meaningful (see also the quotation above, in the subsection *Theories and studies about knowledge, learning and teaching*).

Through people

Even looking at the Netherlands alone, we see a network of developers, researchers, teachers, teacher educators, and authors, where individuals get different roles over time and become involved in new projects. The list of renewal participants (Table

4.3) who took part in the participants' meeting of Substudy 1 gives an impression, but that list only represents a fragment of the entire network. If all project teachers, authors of project teaching materials, organizers of and participants in professional learning communities following the renewals were included, the list would be an order of magnitude bigger. Table 4.3 illustrates that the network also extends over time: a teacher in one project returns as developer in another, or becomes a textbook author or researcher. This connectedness between roles in the network is confirmed in a master study by Ververs (2016, Table 9), which shows that several authors of four different textbooks, in subsequent editions since 1990, had been involved as pilot teacher, developer, or adviser to renewal projects and reforms. The connections in this network may influence both the *teacher profile* and the *teacher environments,* by *teacher education*, *professional development experiences*, *textbooks*, and *exam programs*.

An example of a personal influence appears to be Dik van Genderen, a PLON team member who, towards the end of his career wrote his PhD thesis on concept development and the role of contexts (Van Genderen, 1989). Also Van Genderen's PhD supervisor Piet Lijnse had been a member of the PLON development team. His colleague and doctoral candidate Van Genderen is mentioned by several interviewed sources as the linking pin par excellence between the international literature on concept development and context based education, and the Dutch practice of curriculum development and the didactics of mechanics education. He had also contributed to the WEN *exam program*, and thus the *teacher environments*, by translating the approach of physics education through life world and social themes, as used in the PLON project, into an approach of *Using contexts* that teachers could elaborate in more ways.

Van Genderen's thesis was followed by several other theses on a variety of renewal areas (see below, in the subsection about research projects and dissertations).

Many foreign colleagues have also influenced the Dutch network involved in physics education. A glance at the reports of the annual teacher WND-conference reveals that several speakers from outside the Netherlands have contributed to the *teacher conferences* in the course of years. The following paragraphs will list some contacts that stand out in the sources.

In its later years, the PLON team, as well as the Dutch researchers after PLON, had good contacts with the researchers Joan Solomon (Chelsea College of Science and Technology, London) and Rosalind Driver (Centre for Studies in Science and Mathematics Education, University of Leeds) about the importance of students' concepts of the world as part of concept development. Solomon was a keynote speaker at the 1984 WND *teacher conference*, about types of students and how to motivate them for science (Werkgroep Natuurkunde Didactiek, 1984). Driver contributed to the same *teacher conference* in 1990, with a keynote about research into *Advancing concept development* and how to make that accessible to teachers. She also received the *Minnaert Award*, for those who have contributed to Dutch physics education in an outstanding way. In his laudatio, conference chair

Theo Wubbels added to the jury report: “Professor Driver’s influence on physics education in the Netherlands is tremendous. Many developments presented in lectures and workshops on this conference, many publications in Dutch journals, and many research projects have been inspired by her work” (Werkgroep Natuurkunde Didactiek, 1990, p. 51). The annual teacher conferences mentioned here were part of the *professional history* of hundreds of teachers.

Personal contacts existed between the British physics education researchers and developers Paul Black (Chelsea College of Science and Technology, and King’s College, London) and Jon Ogborn (Institute of Education, University of London) on the one hand, and the PLON and VBB teams, the WEN commission, and the NiNa commission on the other hand. Peter Fensham (Monash University, Melbourne) was also mentioned as a regular contact by several PLON developers, a promoter of themes that are categorized in this study under *Widening the scope of science education*. Black and Ogborn were involved in several renewals in the United Kingdom, connected to the Nuffield Foundation and to the Institute of Physics (IOP), and were involved in the innovative physics textbooks *Advancing Physics* and *Salters Horner Advanced Physics* (Science Education Group University of York, 2000). IOP staff member and *Advancing physics* author Ian Lawrence took part in a 24-hour meeting of the NiNa commission in 2005, which laid the foundation for the commission’s *vision document* (CVN havo/vwo, 2006), which would later be discussed with interested teachers (see subsection *Informing and involving teachers*). The focus in these contacts was on the conceptual side of physics education, as opposed to an overly mathematics-like approach, and on formative evaluation. In this study, these foci are collected in the curriculum intention *Advancing concept development*.

Through research projects and dissertations

Many PhD studies, some of them as part of projects focused on research questions (e.g., around concept development) or on stimulating academic research by practicing teachers, resulted not only in dissertations and presentations in teacher conferences, but also in disseminators of ideas: almost all people mentioned below became teacher educators, one became coordinator for STEM-cooperation in his school and co-author of a new physics textbook. Thus, they may have influenced teachers’ *professional development*, *textbooks*, and *collaboration with colleagues*.

The previous subsection already mentioned Van Genderen’s dissertation about concept development and the use of contexts in Mechanics education (Van Genderen, 1989). The end of the PLON project, in 1985, led to a range of PhD studies about physics education, focusing on concept development for certain domains, such as radioactivity (Eijkelhof, 1990; Klaassen, 1995), energy (Van der Valk, 1992), mechanics (Dekker, 1993), and the particle model (Vollebregt, 1998). These theses contributed to the propagation of the curriculum intention *Advancing concept development*. One former PLON team member, who became editor of a physics textbook, told us that he has always made efforts to incorporate into the *textbook* the strategies developed by these studies to meet preconceptions, a key element of *Advancing concept development*. The conceptual elaboration of risk and radiation in Eijkelhof's study (1990) also helped include in the *exam programs* from the WEN program concepts related to the interaction of radiation with living tissue. This shows the traces of *Using contexts, Science, technology and society* and *Coordinating with other STEM subjects*. Klaassen's problem posing approach (Klaassen, 1995) for concept development found its way to *sample teaching material* on mechanics for the NiNa pilot and to a chapter in the *Handbook physics didactics* for teacher students and teachers (Vollebregt & Klaassen, 2017). Pol's dissertation (2009) on computer based instructional support during physics problem solving supports the expression of *Advancing concept development*.

During the NiNa pilot, which ran parallel to similar pilots for the other STEM subjects, a program for part-time PhD studies for science or mathematics teachers started.[1] Relevant for this study are the following. De Putter-Smits (2012) studied science teachers designing context-based curriculum materials and thus developing context-based teaching competence; the study supports *Using contexts* as well as the professional development component of the infrastructure. Logman's (2014) study investigates students reinventing the general law of energy conservation; it supports the curriculum intentions *Advancing concept development*.

Koopman, who did a study on introducing the quantum mechanics formalism to bachelor students (Koopman, 2011), advised on the design of sample teaching material in the NiNa pilot. He also became an author of one of the commercially published textbooks after the implementation of the NiNa program (see previous subsection). Van Buuren (2014) developed a learning path on modeling for lower secondary education for his doctoral research; its concept of modeling was based on the formulation used by NiNa commission, and the author elaborated his findings in a professional development course and contributed to a guideline for modeling in upper secondary education.[2] More recent doctorate theses go into the teaching of quantum mechanics (Krijtenburg-Lewerissa, 2020; Stadermann, 2022) and special relativity (Kamphorst, 2021) at secondary school level, which fit in the line of didactic design research with attention for student conceptions, an element of *Advancing concept development*. Those studies benefit in their relevance from the introduction with the 2013 NiNa program of those domains and contribute to further elaborations in *textbooks*.

Through settings with a different focus

This subsection considers pathways of curriculum intentions that had taken hold in physics education and that have gained momentum in settings with a focus other than physics education.

Advancing skills development in physics education, already promoted in the 1970s-1980s renewals, shows several examples of being stimulated by more recent developments. The case of physical informatics is one of those examples, as described by two interviewed curriculum developers involved at the time in stimulating computer supported physics education. In the 1980s, it became

1 See www.nro.nl/onderzoeksprogrammas/dudoc-beta.
2 See www.slo.nl/thema/vakspecifieke-thema/natuur-techniek/modelleren.

clear that ICT should get a place in education (Volman et al., 1995). With support from several ministries, a project (NIVO) was started that provided schools with hardware, software, and professional development (Lepeltak, 1997, 2014). The Ministry of Education wanted new exam programs to connect to that development (Ministerie van Onderwijs en Wetenschappen, 1985). This led the WEN commission to include a new domain, physical informatics, in its *exam program*. Apart from the conceptualization of the basics of how a computer works, physical informatics also fostered the development of *educational software and hardware* and *professional development courses* for computer supported measuring, controlling, and dynamic modelling. These possibilities supported *Advancing skills development*, through three groups in the skills domain: research, design, and modelling skills. The resources and professional development offered have contributed to the *professional history* of the physics teachers involved. Although physical informatics was not continued as a separate domain in the 2013 program, the position of these skills remained in the exam program, and thus in the *teacher environment*.

Two interviewed curriculum developers mention the project *Technology 15+* (*Techniek 15+)* (ECENT/ELWieR, 2017), in line with the previous example. It was a national project (2000-2002), which developed various creative and design assignments for upper secondary science subjects and created a network of schools working together in regional contexts, grouped around *teacher training courses* and universities. Its results could be embedded in the science curricula and supported the design activities that the NiNa commission took into its exam program (CVN, 2010). Thus, *Technology 15+* supported the curriculum intention *Advancing design skills development*, but also the *Science, technology and society* aspect of physics education in the *teacher environment*.

The *school research project* (*profielwerkstuk*) is a good example too, brought up by several interviewees and participants of the meeting for Substudy 1. This compulsory part of the school examination for all students, regardless of their choice of profile and subjects, was introduced in the system wide *second phase* programs in 1998. It followed the example of the experimental assignment (*experimentele opdracht, EXO*) introduced in the physics exam program of 1991, for which students had to carry out an experimental study independently. The school research project appears as part of the *adaptable structural system* in the *teacher environment*, and leads in many schools to learning trajectories for *Advancing skills development* and *Coordinating with other STEM subjects*, from which physics teachers may also benefit for skills development of their students. Several interviewed teachers refer to such a *learning trajectory in their school*. Some of the interviewed researchers and teacher educators point at the fact that the school research project cannibalized the experimental assignment for physics students, resulting in a net loss for the physics curriculum.

Another example of a skill-related physics curriculum intention that continued its development in another environment is *Advancing decision-making skills development*. The PLON activities for upper secondary education in the late 1970s and early 1980s, HBB and VBB, promoted this skill. The line of *decision-making skills* in social questions, related to the *Science, technology and society* emphasis, was given a new lease of life in the project *Environmental education in secondary* *education* (NME-VO) (Pieters, 1989). The project developed elaborations of attainment targets for various subjects, with *sample teaching materials* on aspects of sustainable development as contexts, and with emphasis on judgment and decision-making skills. After its conclusion in 1992, this skills element was further investigated in a PhD study by former NME-VO-project leader Kortland (2001). The NME-VO project yielded discipline-crossing *teaching materials* and *teacher training* in cross-curricular cooperation, supporting the curriculum intentions *Coordinating with other STEM subjects*, *Using contexts*, *Science, technology and society*, and *Advancing decision making skills development.*

Several interviewees pointed out that the curriculum emphases *Knowledge development in science* and *Science, technology and society* and the curriculum intention *Coordinating with other STEM subjects* gained momentum in the new subject *General Natural Sciences* (*Algemene natuurwetenschappen, ANW*) (Stuurgroep Profiel Tweede Fase Voortgezet Onderwijs [SPTFVO], 1995a), introduced in 1998 as one of the new *second phase* exam programs, compulsory for all students, including those who chose a social studies or humanities profile. This subject offered elements of the history and philosophy of science, based on a few great stories from the sciences (Eijkelhof et al., 1997; Lijnse, 1997; Pieters, 1997). The subject was degraded in 2007 (for havo) and 2013 (for vwo) to an optional subject, but meanwhile it had been taught by many science teachers, including physics teachers, who had thus become acquainted with the KDS aspects of their subject. Since 2012, a group of ANW teachers, under the auspices of the science teachers' association NVON, in cooperation with SLO, have made an effort to save the curriculum intention of *Knowledge development in science* as part of the curriculum for all students, by collecting and elaborating *examples of teaching materials* and offering *professional development activities* and descriptions of cross-disciplinary arrangements in school curriculum (BC Wetenschapsoriëntatie, n.d.; www.wetenschapsorientatie.nl; Resink & Pieters, 2015), also for physics education (Paus & Pieters, 2015). The activities promote interdisciplinary education, resulting in support for the curriculum intention *Coordinating between STEM subjects*.

Intended influences: improving or creating circumstances favoring curriculum intentions

The previous subsection showed examples of how curriculum intentions propagate along existing paths, or along paths that happened by chance, this subsection describes examples of how curriculum developers created the opportunities – or failed to do so.

Securing in central examination system

The strongest influence of a written curriculum on enacted curricula is exercised by the central examination (CE) system. The school examination (SE) is also compulsory. Section 4.2 describes the balance between the CE and SE parts of the examination system in more detail. As mentioned in Chapter 5, a questionnaire-based evaluation of the implementation of the most recent renewal (Ottevanger et al., 2018) reports that a 60% majority of the 91 responding teachers mention that they do not have enough time for the CE part of the exam program, and that most of them compensate this by reducing time for practical work and for the school-assessment based part of the curriculum. This shows that the CE system (exam program, syllabus, exam tasks) exerts considerable pressure on teachers; in Substudy 3, it was categorized as the *Unadaptable structural system* in the *teacher's environment*.

Below, the descriptions and recommendations found in the sources about the CE system are sorted in two groups. One concerns the exam programs and syllabi that describe the content to be tested in the CE, the other concerns content and format of the CE exam papers themselves.

CE parts of exam programs, syllabuses

The first two projects from the set of renewals in this study did not have as their task (PLON) or intention (DBK) to produce new exam programs. Still, several interviewed participants involved at the time with the upper secondary education projects for havo and vwo (HBB and VBB) stated that in these final stages of the innovation projects, they made efforts to enhance their influence by developing "experimental exam programs" for havo and vwo (PLON, 1983; PLON-UvA-RUG, 1983). The WEN commission chairman confirmed that these sample exam programs were included in the discussions of the commission (1982-1987) and have influenced the WEN exam program. As a result, the influence of these two projects on the CE program became manifest, in particular regarding the curriculum intention *Using contexts*, in the WEN exam program (implemented in 1991).

The CE part of the WEN exam program contained "context concepts" (*contextbegrippen*), listed in a column next to the column "theory", which contained concepts and laws from physical theory (WEN, 1988, section 2.4). Different kinds of contexts were combined: typical physics classroom contexts (e.g., time ticker, rectangular prism) and personal, professional, or social contexts (e.g., seat belt, nuclear bomb). The classroom contexts were not meant to show the social relevance of physics and most of them were too specific to help serve the concept development goal of context based education by de- and recontextualizating concepts. But still, quite a few contexts mentioned in the exam programs, such as the energy issue, medical diagnostics, or the nuclear bomb, show that the curriculum intention *Using contexts* had reached the high-stake CE part of the 1991 programs. With the new role of contexts, as well as with the new domain Biophysics, the curriculum emphasis *Science, technology and society* was also expressed in this part of the 1991 programs, as well as *Coordinating with other STEM subjects*.

The curriculum intention *Advancing concept development* is slightly supported in the 1991 exam program. Section 2.2.1 of the commission's proposal (WEN, 1988), with content to be assessed in the CE, literally repeated in the law text, lists 23 *expectations* regarding students' abilities with physical aspects, like being able to relate phenomena to laws and concepts, or to build a simple line of reasoning in an unknown field of physics. This section of the exam program is limited to the *Advancing concept development* aspects *developing and using scientific ideas* and *promoting student reflection*. It also refers to *Advancing modeling skills development*. Likewise, *Advancing research skills development* was expressed in the 1991 exam program.

The CE part of the *Second Phase* exam program, implemented in 1998, continued the expression of all these curriculum intentions (Stuurgroep Profiel Tweede Fase Voortgezet Onderwijs [SPTVO], 1995b). At this time, contexts like recycling of materials or the dilemma between energy use and safety (o.c., p. 141) no longer appear in a separate category called "context concepts" but are included in the (compulsory) specifications of the relevant attainment targets.

As mentioned above, the 1998 exam program made an explicit distinction between CE and SE (o.c., p. 127, p. 163). It restricted opportunities for *Advancing skills development* in the CE. The curriculum intention *Coordinating with other STEM subjects* was facilitated by the skills domains, which all three science exam programs had in common, and by some attainment targets regarding the use and effects of ionizing radiation on people and the environment. But it is precisely that content that the exam program emphasizes for the SE, not the CE (o.c., p. 127, p. 163), thus excluding this STEM contribution from a strong CE position.

The aim of the NiNa exam program (CVN, 2010), implemented nationally in 2013, was that students learn to use physical concepts in contexts and as much as possible in such contexts that they become acquainted with topical working fields of physicists. Because of this attention for topical physics, the NiNa exam program forms a fruitful environment for *Using contexts* and for the curriculum emphasis *Science, technology and society*, part of *Widening the scope of science education.* Prescribed contexts or contextual domains in the CE part were Information transfer and Medical imaging (havo and vwo); Solar system & universe (havo); astrophysical contexts (vwo). For vwo, the topical character of physics was also expressed in a CE domain Quantum world. The *Science, technology and society* aspect of physics was stressed in the CE part for havo students by a new, overarching CE domain Physics and technology. For vwo students, *Knowledge development in science* and *Advancing modeling skills development* aspects were stressed in the overarching CE domain Laws of physics and models. Other contextual and topical physics domains were placed in the SE, which, since 2013, had been extended to 40% of the exam program.

Advancing skills development in general was expressed in the NiNa exam program (CVN, 2010) in domains regarding research, design, modeling, and decision-making skills, to a large extent worded identically for all science subjects. Also, several contextual and topical physics domains, supporting *Using contexts* and *Widening the scope of science education*, were assigned to the SE part. In the evaluation of the new exam programs (Ottevanger et al., 2018), as well in various discussions with teachers that the researcher was present at since 2013, teachers recognized that they spend significantly less time on these topics than on the CE topics.

The then NiNa chairman explained in the participants' meeting of Substudy 1 why recommendations relating to *Advancing concept development* could not be included in the exam program; legal curriculum documents in the Netherlands are not allowed to prescribe *how* teachers should teach. This goes back to the constitutional freedom of school boards, in practice largely left to the teachers, to shape the enacted curriculum. In the years of the NiNa project (2005-2010), this was a more sensitive issue than usually, because a parliamentary investigation into several system changes since the 1970s resulted in a sharp judgment in 2008 about the interference of politics in school practice from the Inquiry Commission, chaired by then MP Jeroen Dijsselbloem, (Commissie Parlementair Onderzoek Onderwijsvernieuwingen, 2008). The NiNa chairman explained how the publication of the Inquiry Commission's report during the NiNa pilot had influenced the scope that the NiNa commission could take on in its advice to the minister. This restricts the power of a reform commission in the Netherlands, affecting curriculum intentions like *Advancing concept development*, or *Coordinating with other STEM subjects*.

Central exams

Van Aalst (1987) reflects on CE assignments under the then current CMLN exam program and observes that "the exam makers have also been doing their best in recent years to present the problems in 'context'. However, it often remains a problem 'in situation', in which the (artificial) situation is a cover for asking systematic physics" (p. 16). By contexts, he means situations "chosen from important situations that students encounter in everyday life" (p. 14). Van Aalst's diagnosis is that, if there are any contexts elaborated in exam assignments before 1985 in such a way that they support *Using contexts*, it is only in a few cases. He recommends that on all fronts, including central exams, the benefits of ten years of physics education development are realized. The prescription in the examination program published in 1989 (Ministerie van Onderwijs en Wetenschappen, 1989), the legally introduced WEN examination program, stated that the contextual concepts in the list of subject matter were assumed to be known at the examination. This prescription meets Van Aalst's wish. In spite of the limitation of the NiNa commission's influence on the *how*-aspects of a curriculum, as mentioned in the previous subsection, there was a shift to a more conceptual approach, and to working more than before in a concept-context approach, as confirmed in Ottevanger et al. (2018).

The NiNa commission had not only exerted influence on the exams through a set of attainment targets, but also through an agreement with the Examination Board (CvTE) and the construction groups of the institute for education measurement Cito to change exam assignments to include more conceptual and fewer purely mathematical questions, supporting the commission's emphasis on conceptual thinking and thereby the curriculum intention *Advancing concept development*. This was documented in 2008 in a criterion table for exam assignments and stated in a recommendation to Cito in the NiNa commission's final advice (CVN, 2010). It was confirmed in the implementation plan written by SLO in consultation with the science commissions, CvTE, and Cito: "The innovation goals must be reflected in the assessment (school and central examination). It should be encouraged that the assessment practice acts as a lever for the innovation, rather than blocking the innovation" (Michels, 2010, p. 12).

In 2017 and 2018, SLO carried out an evaluation of central exams for physics education. Following the implementation plan (Michels, 2010), evaluators of SLO analyzed CE assignments in the first two central exams following the implementation of the 2013-exam programs for the science subjects. The NiNa-exam program was part of that. The reports, by Michels et al. (2018) for the havo-exams and by Woldhuis and Paus (2018) for the vwo-exams, tell that almost all assignments contained one or two contexts. Of these contexts, about a third addressed *Science, technology and society* issues. A considerable part of the contexts also contributed to *Advancing concept development*, by providing the purpose of a question. The questions and their contexts contribute to a lesser extent to the role of scientific practices, related to *Advancing skills development* and *Knowledge development in science*. Assessing students' reasoning competencies was assessed in about half of all questions, which contributes to the curriculum intention *Advancing concept development*, in particular *Developing and using scientific ideas* and *Promoting student reflection*. The CE exams do not (havo) or only in one question (vwo) directly express the curriculum emphases *Knowledge development in science* or *Science, technology and society*.

Providing clarity about curriculum intentions

Some sources state that an innovation can only be successful if its goals are clear to all stakeholders. Clarity about strategic intentions underpinning a project can keep inspiring developers, teachers, and other stakeholders even after the project period itself. As a former PLON project leader stated, PLON's views on physics education may not have been operationalized immediately in a formally implemented new exam program, it has nevertheless influenced the direction in which the curriculum has developed since – a claim that he feels is substantiated by the appearance of textbooks inspired by PLON's intentions and by elements of subsequent exam programs. He explained that in the final years, the PLON team wanted to offer a view of how, as a teacher, one could emphasize certain aspects of the PLON-curriculum, even if these were different from what one was doing at the time. In this way, PLON's views could remain available as a benchmark that could at some point inspire younger teachers to continue.

In 1974, the Dutch *Commission for the Modernization of the Physics Curriculum*, CMLN, stressed how important an underlying view on a new curriculum is, recommended to await the outcome of a fundamental study – for the realization of which it mentioned PLON –, and refused to consider its own task as a curriculum innovation (CMLN, 1974):

> Actual innovation in education cannot be expected of a curriculum in which only accents shift, and some changes of topics are proposed. This will have to come from a fundamental study of objectives and didactic approach. . . . With these thoughts as a starting point, the commission took the initiative to create the *Project Learning Package Development Physics* (*PLON*), which was commissioned for this fundamental study. (p. 7)

The idea that something fundamental, at the level of a vision, had to change in Dutch physics education had also been expressed by teachers. Already before 1970, the *WND* physics teacher conferences about *Nuffield* and *Project Physics* "sparked enthusiasm. . . . It was there that the idea was born in 1970 to develop a new vision of the subject in a project-based manner in the Netherlands too" (Van Aalst 1987, p. 10).

Designing for teachers' concerns or zone of proximal development

Teachers' concerns can be regarded as part of their *values and beliefs*. Some data show how developers tried to connect expressions of curriculum intentions in their written curricula, such as attainment targets or teaching materials, with teachers' concerns; and how this may have increased the likelihood that these curriculum intentions were expressed in the enacted curricula. The concept *zone of proximal development* is coined by Vygotsky (1978) for learning, with support, in a way that makes sense to learners given their actual orientation to reality and level of development and their personal interpretation of that practice (Van Oers, 2012). This concept can also be seen as guiding some of the developers' strategies to influence teachers values and beliefs, by providing them with experiences in their professional development in their environment.

In the final PLON years, in the subprojects for havo and vwo, HBB and VBB, *sample teaching materials* were developed that took into account the concern of teachers to motivate students. Two PLON team members wrote about this concern as a design element for the project (Eijkelhof & Kortland, 1988):

> A growing number of teachers adopted the idea that *relating physics to everyday life phenomena* (be they technological or natural) would make physics teaching more interesting for their students, thus countering the decreasing motivation among students. . . . Another possibility for countering decreasing motivation was seen by teachers: providing more opportunities for *individualized learning of students*, for accommodating differences and abilities among students. (pp. 283-284)

The continuation of PLON and the HBB/VBB projects in commercial textbooks, *Interactie* and *Natuurkunde overal*, allowed the respective editors, both former PLON team members, to continue in their own way in consultation with the publishers and, in the case of the book *Interactie*, with the PLON association. The two books gave rise to two expressions of the same curriculum intentions, meeting the concerns of two groups of teachers. Thus, despite differences between the books, both appeared to offer a fit for elements of the curriculum intentions *Using contexts*, *Widening the scope of science education, Advancing concept development,* and *Advancing skills development*. No records are available of the extent to which these intentions became part of the curricula enacted by teachers in those years.

DBK took a different approach from the PLON strategy. A then DBK teacher and developer explained during the witness meeting that DBK had no intention of changing the exam program, but to improve education within the framework of the program by elaborating different learning routes in *teaching materials*, in particular by practical work that fitted the theory part. Many teachers appeared to be interested in that approach to differentiation, which is also confirmed by the respondents to the study of Volman et al. (1995). The DBK approach strengthened the curriculum intention *Advancing skills development*.

The commissions that worked on the *Second Phase* exam program and the NiNa exam program, respectively, sought comments from teachers on draft exam programs prior to final revision (SPTFVO, 1995b, p. 162, pp. 204-205; CVN, 2010, pp. 75-77). The NiNa commission had also done so for a vision document (CVN, 2006). These consultations were meant to gain insight in what teachers would appreciate, what they might be opposed to, and what modifications in the proposed exam programs and what facilities might help to increase the chance of the commissions' intentions to be enacted by teachers. The *Second Phase* commission reported no specific influence on the content of the exam program to meet teacher concerns that emerged from the consultations. The NiNa commission did mention such influences. Its discussion on the vision document led to the inclusion of context areas *Life* and *Earth* in the vwo program, to greater emphasis on the practices and ways of thinking of physicists as what characterizes physics, and to a clearer role for contexts in showing how concepts are used (CVN, 2010, p. 54). Discussions with teachers in the following years uncovered a concern that context-based education would be prescribed as a didactic approach. Even though such a prescription would have conflicted with the regulations, teachers' concerns still led to a more precise indication of the role of contexts in the exam program: some prescribed as relevant practice of physics, others recommended as a contribution to concept development (CVN, 2010, pp. 75-77). Thus, the NiNa commission considering teachers' concerns may have improved the chances for the curriculum intentions *Widening the scope of science education* and *Advancing concept development* to be enacted by teachers.

From a quite different angle, we can again see the role that teachers' concerns play. One of the WEN commission's advisers said in an interview that when the first WEN proposals were presented during a WND teachers conference, many physics teachers opposed the idea of including physical informatics in the exam program. A few years later, when the WEN program had to slim down, many teachers opposed the option to take physical informatics *out* of the exam program. The reason for that: the students appreciated it so much. Apparently, students' appreciations had affected *teachers' concerns*. And it worked especially well in favor of *Advancing skills development*.

Informing and involving teachers inside and outside project

The then WEN chair confirmed in his interview the role of the WND teachers' conference. The 1970 conference "was cleverly designed: each participant was instructed to prepare and demonstrate a booklet from the Nuffield series at the conference. This way, innovation was brought from the field to the field. This resulted in the PLON project" (from his interview). Van Aalst (1987, p. 10) reports massive teacher participation in study trips that the association of science teachers organized in the 1970s to Denmark, England, Scotland, and the United States. And he mentioned the WND teacher conferences about *Nuffield* (Nuffield Advanced Science: Physics, 1971) and *Project Physics* (*The Project Physics Course*, 1970), which aroused great enthusiasm.

In its first years, PLON only developed teaching units that reflected a more revolutionary perspective (Volman et al., 1995). Several interviewed sources remember how in its first years, PLON repelled teachers who were not engaged in the project. A teacher not involved in PLON at the time explained: “You had either to go all the way for PLON, or you could not participate. . . . Not like: that part is good, I’m going to try that in practice.” A PLON team member who joined the project later felt that the negative side of the strategy was the implicit, and unintended, message to the majority of teachers that what PLON did was what all teachers were going to do later, even if they did not realize it yet. In its early years, PLON was also unwilling to supply articles to the physics teachers’ magazine *Faraday*, as a then editor mentions. PLON team members who became involved later on, from about 1980, explained that they had acknowledged that a distance had grown to teachers who did not participate in the project; they improved the communication with a wider group of teachers.

The approach of the DBK project was to involve many teachers in a role with development responsibility, even though not necessarily as authors. DBK’s work initially concerned the junior classes, but teachers asked for material for the senior years as well. A then DBK project team member who was interviewed concludes that the DBK team was above all a “professional development machine,” important in the chain of Dutch physics education renewals because of their development experience, rather than as promoters of particular curriculum intentions. Also, the follow-up activities of PLON, HBB and VBB, involved more teachers in authoring and feedback roles. Thus, DBK, HBB, and VBB, also contributed to developing the infrastructure (see next subsection).

The chairman of the WEN commission reports that external consultations focused on the textbook authors. He adds that the commission had far from the amount of contact with the field of teachers that it had wanted and that teachers complained about that.

Both the *Second Phase* commission and the NiNa commission organized field consultations about draft versions of the exam programs (SPTFVO, 1995b, p. 162, pp. 204-205; CVN, 2010, pp. 75-77). These consultations functioned as sources of feedback about the contents and the burden that the exam programs, and in the case of NiNa the syllabus, might impose on teachers. No evidence was found in the data about the effect the consultation had on the acceptance by teachers. The previous subsection reported about the feedback from about 170 teachers that the NiNa commission used to finalize its vision document (CVN, 2006) with principles for the new exam programs. During the development years, teachers were kept informed by articles on progress and experiences in the journal for science teachers (NVOX) and in workshops at the annual teacher conference (WND). It cannot be judged to what extent this involvement and information has influenced teachers’ enactment of the final exam program.

During the development and pilot years of the NiNa exam programs, almost 40 teachers were involved in a role as pilot teacher, another 10 teachers had a major role as author (CVN, 2010). After the pilot years, four of these teachers became authors in various publishers' textbook teams, and one became a teacher educator, thus influencing other teachers' *environments*. Two started a PhD study in physics education, directly influencing the *professional history* part of their own *profile*, and indirectly possibly also other teachers' *environments*.

Developing or feeding infrastructure

The infrastructure includes many possible partners for curriculum development. Particularly important for influence on or support for teachers are the following:

- external support and facilities;
- textbooks;
- facilitating schools;
- teacher education and professional development;
- infrastructure as a whole.

External support and facilities

To start with a unique example of teacher support and facilities, the mobile *Ionizing Radiation Laboratory* (Dutch acronym *ISP*) should be mentioned.[3] It started in 1972 and is still active today, with 23 experiments. The Rationale on the ISP's website gives as a motive, apart from the restrictions that schools would have on a radiation lab: "Without such a facility the teaching of the topic of ionizing radiation would be of a mainly theoretical nature, while the students' hands-on experiences could positively influence their motivation and conceptual development concerning this socially relevant topic." It shows how this mobile practicum has become a means of transport for the curriculum intentions *Widening the scope of science education* (its element *Science, technology and society*) and *Advancing concept development*. It connects to teachers' practices by adding to the *material system*, element of the *teacher environments*.

Another external source of support was the national STEM-promoting agency *Platform Bèta Techniek* (PBT). This platform was established by the Dutch government in 2004[4], with the intention of increasing the number of scientists and technicians and of fostering public appreciation of science and technology, thus supporting the intentions of *Using contexts* and *Science, technology and society*. Next to all kinds of STEM promotion projects and manifestations, it funded in-school curriculum development programs for science education, including *Coordinating with other STEM subjects*. PBT also co-funded the reform pilots for upper secondary STEM subjects in the years 2005-2010 (CVN, 2010). In the years of implementation following the formal start of the NiNa exam program and the other STEM subjects, it also supported *professional learning communities* around the country, thus contributing to renewal intentions of the new physics curriculum, as well as the

3 See https://stralenpracticum.nl/english-information.
4 nl.wikipedia.org/wiki/Platform_B%C3%A8tatechniek, viewed 28 April 2021.

other new science curricula.[5] PBT was also mentioned in this role in the accounts of some interviewed teachers, as described in Chapter 6. In the encompassing implementation plan *From pilot to practice*, written by SLO in consultation with the renewal commissions and other stakeholders, *Platform Bèta Techniek* appears with a shared responsibility for *professional development* (Michels, 2010).

The renewal commissions of 2005-2010, the science associations, most universities and many other higher education institutes, and hundreds of schools had, together with the PBT, established support centers in ten regions for the science subjects, mathematics, and informatics. These offered, and still do, *professional development* courses and PLCs about the new topics in the exam programs, and thus contribute to the *professional history* influence on teachers. Curriculum intentions that benefit from support centers for physics education are *Science, technology and society*, *Advancing skills development* and *Coordinating with other STEM subjects*.

For the *school examination* related parts of the *exam programs*, SLO provides support to teachers through web-based guidelines (*handreikingen*) for each subject.[6] A guideline offers examples of contexts and test assignments that can be used in teachers' enacted curricula, and links to more sources. Along with a guideline for physics, SLO offers one for modeling[7], developed by a group of authors who had been participants in the NiNa commission or its pilot project. This part of the infrastructure supports all curriculum intentions, most prominently *Using contexts* and *Advancing skills development*. The modeling guideline of course supports modeling skills, and by reflecting on the nature of a model and its role in physics also the curriculum emphasis *Knowledge development in science*, an element of *Widening the scope of science education.* The modeling guideline also looks at the role and examples of models in other disciplines, thus facilitating the curriculum intention *Coordinating with other subjects*, which can be STEM subjects, but also, e.g., economics.

Textbooks

As already mentioned, several PLON team members and NiNa pilot authors and teachers became authors or editors of *textbooks.* Some of these textbooks were new to the market and would capture significant market shares over time. Here this is relevant again, now as an example of how textbooks as part of the existing infrastructure were used to bring several curriculum intentions through the *material system* of the *teacher environments* closer to their practices: *Using contexts, Widening the scope of science education, Advancing concept development*, and *Advancing skills development.* In fact, this concerns all curriculum intentions tracked, except *Coordinating with other STEM subjects*. One of the then editors also mentions how he used DBK elements in his book, in the form of differentiation in the degree of difficulty of questions. More textbooks would follow, explicitly incorporating one or

5 The author witnessed the development of these activities as secretary of the NiNa commission, between 2005 and 2010, and as project leader for the implementation of the new science exam programs from 2011 on. The networks of secondary and higher education are organized nationally, see www.vohonetwerken.nl.

6 For physics in havo and vwo: www.slo.nl/handreikingen/havo-vwo/handreiking-SE natkunde-hv.

7 See www.slo.nl/thema/vakspecifieke-thema/natuur-techniek/modelleren.

more of the curriculum intentions mentioned. The researcher had correspondence by mail with current publishers about market shares of textbooks over the decades, but the available figures did not provide sufficient information to cover the period studied.

To examine more precisely how and to which extent these curriculum intentions were incorporated, Ververs (2016) carried out a Master study into curriculum intentions (largely the same as used in this study) expressed in the Mechanics sections in subsequent editions of four physics textbooks. His study did show differences between textbooks and between editions, including by curriculum intention, but most of the results were not sufficiently unambiguous to be trusted as characterizing the textbooks as a whole, or the curriculum intentions of their authors.

Facilitating schools

PLON (incl. VBB), DBK, and NiNa facilitated schools to allow teachers to get involved in their development activities, for testing and giving feedback or as co-authors of pilot material. The schools were reimbursed for the costs of part-time replacement.

Teacher education and professional development

As for *teacher education* and *professional development provisions*, contributing to the *teacher's profile* and *teacher's environment*, these were stressed by the Commission on the Modernization of the Physics Curriculum in its 1974 advice, when the PLON project had already started: "[The commission] hopes that new teaching methods and teaching materials will be introduced in the new teacher training courses, which will prepare the ground for actual educational innovation" (CMLN 1974, p. 7). Looking back at PLON twelve years after this CMLN advice, Van Aalst (1987, p. 17) recognizes that the role of teacher education had not come to much because of a variety of organizational factors, not in the least the reorganization of teacher education. Regarding professional development, he concludes that energy was put into the organization of national conferences. However, looking back at the DBK project (o.c., p. 18), Van Aalst praises its infrastructure as an example of curriculum development based on collaboration between teachers, with support from a university, which for Van Aalst partly explains the success of its rapid distribution. As for curriculum intentions, the influence of DBK was, by its focus on practical work to improve differentiation, limited to facilitating *Advancing skills development*. But the greatest effect of DBK, as pointed out by two of the then DBK team members in interviews, lay in building an extensive network of didactical researchers and teachers, including, along the way, a group of teachers with development experience. After the project period, several of these teachers were also involved as textbook authors or pilot teachers or became active as teacher educators; one of these teachers became the chairman of the *Second Phase* commission.

Another contribution to the professional development infrastructure is the *Handbook on physics didactics* (Kortland et al., 2017), supported by a website with assignments.[8] As one of its interviewed authors explains, the handbook aims to give trainee teachers and interested teachers, who do not have subscriptions to *Science education* and other relevant magazines, access to results from scientific literature. Its content supports *Advancing concept development, Advancing skills development* and *Coordinating with other STEM subjects.* Its influence is exerted on teachers mainly through their *professional history.*

Professional development activities are welcome points of leverage for external support, as described in the subsection *External support and facilities* above: PLCs are facilities for teachers that appeared to help elaborating SE domains, and thus support the use of SLO produced SE guidelines. They also appeared good platforms to support the goals of the STEM-promoting agency PBT.

Infrastructure as a whole

The previously described infrastructure of stakeholders, organizations, and individuals, already existed, and was fed, more or less successfully, by the renewal projects. Van Aalst (1987, p. 21), in evaluating the developments in physics education and the role of the infrastructure from 1975 to 1985, recommends as an agenda for the next ten years that "on all fronts - classes, courses, refresher courses, exam programs and exams" are engaged to promote "thematic education, concepts in context, rules for exams, rules for practical school research, varied teaching methods, self-motivation, stimulating differences in the classroom and more." Except for textbooks, he mentions the whole network of stakeholders. The curriculum intentions he promotes are *Using contexts* and *Advancing concept development*.

The NiNa commission (CVN 2010, chapter 4) describes how, in the pilot project already, all stakeholders had been active in their role: teachers, the Examination Board CvTE (formerly CEVO), the syllabus commission, the physics exam construction group of the Institute for Educational Measurement Cito, responsible for the national exams, the science teachers' association NVON, the professional learning communities, with support of the national STEM platform PBT and higher education institutes, and SLO. The educational publishers were kept informed and waited until the advice to the Ministry of Education had formally been accepted, in 2011, and the exam programs and syllabi had their final form and could be used as guides for author teams. After the pilot ended, a few pilot teachers became involved as authors for the publishers; in this capacity, they may have influenced the *material system* of *teacher environments*.

Referring to the implementation plan (Michels, 2010) that SLO had composed, the NiNa project, as well as the other science and mathematics renewal projects in the 2000s[9], explicitly included the existing infrastructure in its recommended development strategy after 2010, (CVN 2010):

8 www.natuurkundedidactiek.nl

9 Alongside a reform commission and project group for physics, similar groups existed for biology, chemistry, mathematics, and the new subject Nature, Life and Technology. Coordination with the Ministry and other stakeholders, as well as infrastructure development and coordinating evaluation, was a joint action of the five commissions and project groups, *Beta5*, in the period 2005-2010. SLO carried out an external evaluation of all pilots and prepared a post-2010 implementation plan in consultation with *Beta5*.

> The exam program only creates conditions for good physics education; the teacher and the way he/she is supported make all the difference. . . . From that perspective, a national implementation plan was drawn up by SLO in close collaboration with the joint renewal commissions. The plan focuses on the introduction of the new exam programs and the underlying goals, taking into account the autonomy of the schools. . . . The plan provides that the local networks between schools, higher education institutions and companies that are active in various regions play an important role in this. . . . The science associations - united in the Innovation Education in Science and Technology Foundation (IOBT) - have committed to contribute to this. (pp. 20-21)

Facilitating experiences in a safe setting

For the analysis, we interpret a safe setting as an environment offering sufficient resources in which teachers can experiment with what they consider important, without regulations that may punish them. Regulations are what has been laid down nationally in the exam program and syllabus, and at school level in the school program for testing and assessment. Regulations are *de facto* also what national exams test, as elaboration and interpretation of the syllabus. Resources are *professional development provisions*, *teaching materials*, and time.

Van Aalst (1987), at the end of the PLON and DBK project periods, as well as the commission NiNa (CVN, 2010) and SLO (Michels, 2010) at the end of the science education pilot period, based on experiences during that time, recommend that all components of the legal and support system be active in supporting teachers to enact the curriculum intentions of the renewals. Ideally, this serves all curriculum intentions.

Based on his experiences, a then DBK project leader who was interviewed, and who was also an adviser on various commissions, argues for curriculum renewal in *concerted action*: *exam programs* and *teaching materials*, *central exams* and *professional development provisions,* so that the teacher has support from all sides. A project leader for PLON, involved in several other curriculum projects, pointed at the freedom that teachers in the United Kingdom and Germany have, compared to their Dutch colleagues; e.g., in the United Kingdom, teachers are allowed to choose between examination boards, each with their own qualifications and exam papers. Thus, British and German teachers have a larger *adaptable structural system* in their *environment* than their Dutch colleagues.

A strong counterexample of a safe setting is *curriculum overload*. Van Aalst (1987, p. 13) illustrates that when he writes about the overload that characterized the 1974 CMLN *exam program*, which deprived teachers of the space necessary for the “modernization and adaptation” of the material advocated by the CMLN itself. He suspects that the physics curriculum has become even more traditional because of the 1974 exam program, “due to a necessity to focus on training issues.” According to Van Aalst, this overload made it difficult to make the knowledge and experience of PLON’s innovation experiments accessible for teachers who had not been involved in the project.

The problem of curriculum overload is reflected as an unsafe setting in the evaluation of the implementation of the 2013 exam program (Ottevanger et al., 2018), which showed that many teachers still feel a curriculum overload and solve it by "spending less time on school examination components and practicals and cutting out time-consuming methods" (p. 19). Whatever the cause of the overload, teachers do not want their students to be disadvantaged in their results in the *central exams*. Therefore, they shift the cost of the overload to the *school examination* parts and to "time consuming didactical methods." Consequently, the overload is *at the cost* of *Advancing concept development* and *Advancing skills development*.

7.4 Conclusions

The research question for this substudy is: *What factors may have influenced profiles and environments of teachers against the background of the curriculum renewals in upper general secondary education physics education in the Netherlands since 1970?*

This section presents the factors found per category that appeared to be most significant in that category. It starts with summaries of the influences on *teacher profiles* and *teacher environments* (see Table 6.1) and of the relations with renewals' curriculum intentions (see Table 5.2). These summaries are followed by more extensive conclusions per category of factors.

The discussion of this substudy's design and conclusions and examining its relation to the other substudies will be part of Chapter 8. This includes the connection between directly and indirectly influencing factors, which may help provide answers to the question of which curriculum intentions are supported by which indirectly influencing factors.

Influences on teacher's profile and environment

The descriptions of influences on teacher's profile and environment, as emerging from the analysis of the data, are summarized graphically in Figure 7.3. A grey arrow pointing at a group of teacher's profile or environment factors means that in the possible influences or relations no specific element of that group was found.

As for the *teacher's profile*, the indirect factors explored in this substudy only appear to influence teachers' *professional history*. In particular, *teacher education* and *professional development* appear as being influenced. As for the *teacher's environment*, all elements are influenced by the factors explored in this substudy: the *material system* particularly by teaching materials; the *adaptable structural system* particularly by *professional development provisions*; and the *unadaptable structural system* by *CE parts of exam programs* and *central exams*. Professional development provisions in a *teacher's environment* eventually influence the teacher's *professional history*, and thus the *teacher's profile*.

It also seems fruitful to support teachers in gaining new experiences with provisions in their *environment* from various parts of the educational infrastructure at the same time: supplying teaching materials and other resources, providing professional development, and allowing for an adapted CE setting, if only on a temporary basis, for example in a project. If a teacher's environment also includes provisions that limit the risks for the teacher, particularly with respect to students' examination results (such as a dedicated CE), then such an environment can be called a *safe setting*. Positive experiences, over several years, in such a safe setting, may become part of *professional histories*, and thus influence teachers' *values and beliefs*, the *cultural system*, which is categorized as part of the *teacher's profile*. Renewals' actions that lead to changes in the national exam program, followed by matching CE tasks, textbooks, and professional development facilities, can be seen as creating a safe setting for teachers to adopt those changes.

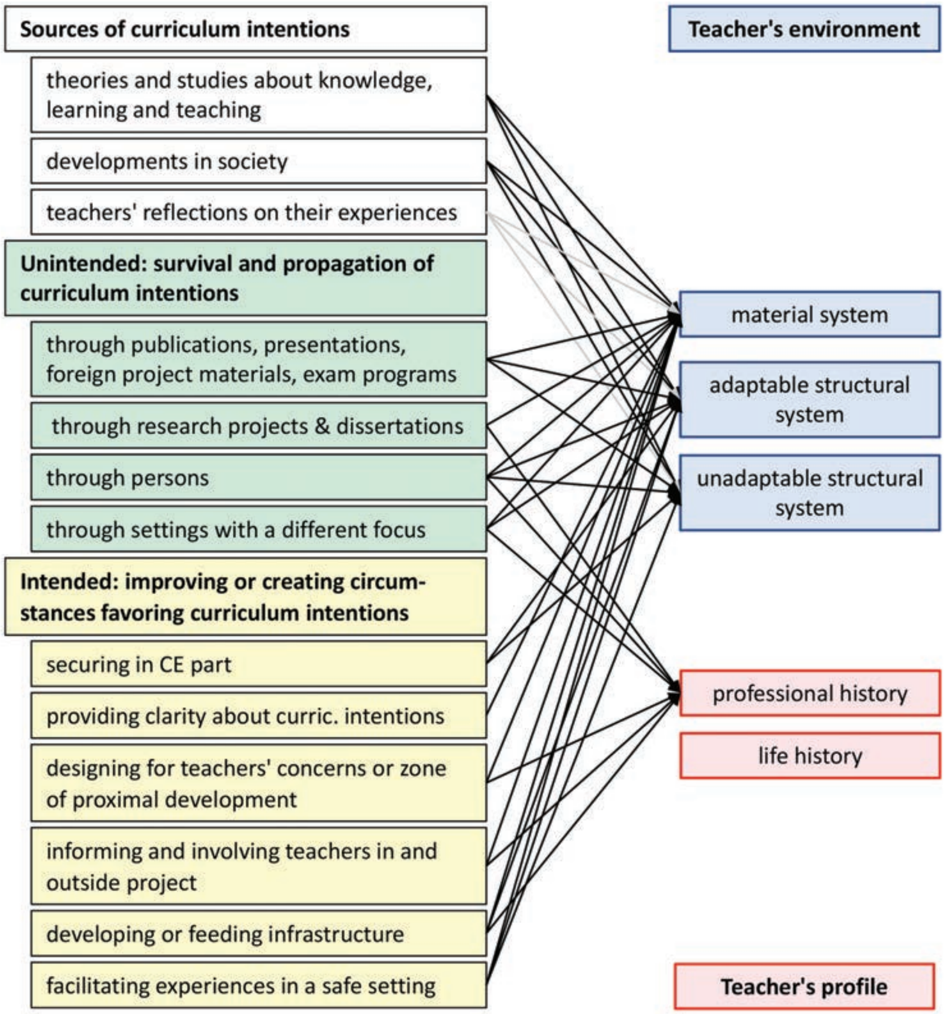

Figure 7.3 *Factors that may be influencing teacher's profile and teacher's environment categories.*

It appears from the data that the indirect factors categorized as *sources of curriculum intentions* exert their influences on teachers' profiles and environments mostly via the products and facilitating activities of renewal projects and commissions, and some teacher educators, professional development providers, and textbook authors. The factors categorized as *survival and propagation of curriculum intentions* appear to have influenced the *teacher's environment* as well as *teacher's profile*, through written texts, project teachers' practices, networks, and personal contacts. The factors categorized as *improving or creating circumstances favoring curriculum intentions* appear to have influenced all elements of the *teachers' environments,* which over time may also have influenced *teachers profiles*, in particular teachers' *professional histories*.

Connections with curriculum intentions

The analysis of indirectly influencing factors shows many connections with curriculum intentions pursued in the various renewals of upper general secondary physics education in the Netherlands since 1970.

With a few exceptions, no particular connections stand out. In those cases, the intentions, or components of intentions *Using contexts*, *Science, technology and society, Advancing concept development,* and *Advancing skills development* regularly appear in connection with the factors that were explored, of all three categories.

Coordinating with other STEM subjects has an ambiguous position. This curriculum intention hardly appears in connection with the unintended influences collected in s*urvival and propagation of curriculum intentions*; the exception is the path *through settings with a different focus,* which shows support for fostering cross-cutting STEM-intentions. However, in connection with the intended influences collected in *improving or creating circumstances favoring curriculum intentions*, it appears in several influences. Fostering STEM-co-operation can also be found in the *sources of curriculum intentions*.

The curriculum emphasis *Knowledge development in science* (an element of *Widening the scope of science education*) is relatively rarely visible in any of the categories of indirectly influencing factors, still most in the intended influences (collected in *improving or creating circumstances favoring curriculum intentions*).

The factor *securing in the central examination system* particularly affects of the renewals curriculum intentions that find a place in the CE parts of exam programs.

Conclusions per category of factors

Sources of curriculum intentions

Theories and studies on knowledge, learning, and teaching emerge from the data of this study as sources from scientific research that have influenced the Dutch physics education renewal projects and commissions, and some teacher educators, professional development providers, and textbook authors. Thus, these theories and studies may have influenced *teacher environments* through the *sample teaching materials* and *exam program proposals* produced by the renewals. The curriculum intentions most clearly inspired by theories and studies about knowledge, learning and teaching are *Advancing concept development* and *Using contexts*.

As for developments in society, a number of wishes related to science education emerge from the data as having influenced the studied renewals and the *sample teaching materials* and *exam program proposals* they produced: to attract more and better students, to show the relevance of physics, to promote equity, and to include information technology in the curriculum. In the data, these can be connected to the introduction of the following curriculum intentions in the system of Dutch physics education:

- to attract more and better students: *Using contexts* and *emphasizing Science, technology and society* (element of *Widening the scope of science education*);
- to show the relevance of physics: *Using contexts*, *emphasizing Science, technology and society* (element of *Widening the scope of science education*), *Coordinating with other STEM subjects* and *Advancing skills development*;
- to promote equity: *Using contexts*, *emphasizing Science, technology and society* (element of *Widening the scope of science education*), and *Coordinating with other STEM subjects*;
- to include information technology in the curriculum: *Advancing concept development* and *Advancing skills development*.

As for practice-based reflections by teachers as possible sources of curriculum intentions, the data only mention one open consultation of teachers, in 1992. Other reflections by teachers were reactions to ideas, proposals, or examples published by other stakeholders. Altogether, developments in science and in society seem to be the dominant sources of curriculum intentions.

Unintended influences: survival and propagation of curriculum intentions

Some factors that influence the *teacher's profile* or *teacher's environment* were not created with the purpose of having developers' curriculum intentions survive or propagate; nevertheless, that is what they helped happening too.

The curriculum intentions springing from insights, recommendations, and wishes from science and from society, as mentioned in the above subsection, appear in the exam program proposals, sample teaching materials, and other products of projects in various countries. The innovation projects in the Netherlands were initially inspired by American and British renewal projects, later also Australian and German ones.

The people involved in these projects and the written sources inspired, or (in the biological metaphors of this study) infected, the Dutch physics education community. The curriculum intentions, seen as memes, propagated in various ways: sample materials and other projects' publications were studied by Dutch researchers, project groups, and commissions, and groups of teachers. Once inside the country, all curriculum intentions had the opportunity to be further disseminated, expressed in written curricula as well as in the practices of project teachers, in the network of developers, researchers, teachers, teacher educators, and authors. Over time, people appeared in new roles: pilot teachers as textbook authors, developers in a next project, or as researchers. Developers and researchers appeared as teacher educators and professional development providers. Thus, these written texts, practices, networks and personal contacts may have affected *teacher environments* as well as *teacher profiles.*

The curriculum intentions focused on in this study also appear in settings with a different focus than physics education, inspired by similar sources and ideas, and also with the possibilities to influence the practices of physics teachers: development of ICT in education, technology education, education for sustainable development, science for public understanding (*ANW*), or the cross-cutting school research project (*profielwerkstuk*).

The data do not give indications for each of these influencing factors about specific supported curriculum intentions, but on the whole, the intentions, or components of intentions *Using contexts*, *Science, technology and society, Advancing concept development,* and *Advancing skills development* appear relatively often in connection to the factors explored, whereas *Knowledge development in science* and *Coordinating with other STEM subjects* appear more incidentally.

Intended influences: improving or creating circumstances favoring curriculum intentions

In the following, approaches are described, as found in the data, that intentionally improve or create environments in which developers' curriculum intentions may survive and propagate.

Providing clarity about curriculum intentions

Several sources state, as a recommendation or as part of their strategy, the importance of providing clarity about curriculum intentions of a renewal for stakeholders, in particular also to help future teachers, developers, and other stakeholders try small, achievable steps without losing sight of what is relevant. This factor facilitates that what is offered in *teacher environments* stays on track.

Securing in national examination system

A major factor that emerges from the analysis of the data as influencing the environment of a teacher is the national examination system, in particular the CE part of the exam program. Creating an exam program is a task mandated by the Ministry of Education to a commission. From the exam program reforms studied, only the most recent commission, NiNa, was established at the request of physics education stakeholders. Those who wanted to influence the national exam program to be developed by the NiNa commission were able to get involved in the discussions about the initial vision document and, in the pilot years, to react to the draft and sample products, informed by experiences of pilot teachers and with pilot CE exam papers. As for previous reform commissions, the CMLN and the *Second Phase* commissions were set up differently, as part of a more general education policy. Stakeholders who wanted to influence those commissions' programs had consultations as opportunities. A third way is that of the WEN commission, installed at the initiative of the Ministry with the task to harvest all experiences with renewing physics education from the preceding decade. Thus, the commission could express in an exam program curriculum intentions like those of PLON and DBK developers, and also from other, smaller projects' experiences.

Although teaching approaches cannot be prescribed in the attainment targets that constitute exam programs, reform commissions can add recommendations for such approaches, the "how" of education, to their final reports. And they can recommend criteria for the construction of central exam papers, which in the case of the NiNa commission stimulated a focus on conceptual understanding in CE papers and the curriculum intention *Advancing concept development*.

Securing (elements of) curriculum intentions in the national examination system influences the *structural systems* of the *teacher environments*, both the adaptable and the unadaptable. In their wake, offering teaching resources and professional development provisions may influence *teacher environments*, and thus, after some years of teachers' experiences, *teacher profiles.*

Informing, involving teachers and connecting to their concerns

The importance of designing for teachers' concerns or their zone of proximal development, and of informing and involving teachers, also outside a project, is clearly confirmed by negative experiences in the early PLON years. Non-project teachers at the time felt excluded and some of them turned their backs to the developers. In later PLON years, consultations about drafts and in conference workshops appeared effective to inform teachers and receive feedback about their concerns, increasing the match between written curricula and teachers' values and beliefs. Textbooks written by former project team members, expressing various curriculum intentions from those projects, appeared to gain a significant market share, and thus may have influenced teachers' *professional histories*. Involving teachers in development roles also shows to contribute to networks of researchers, developers, and teachers. Teacher education, professional development communities, and textbook authoring teams reap the benefits of such networks.

Information for teachers by a renewal team or commission can be seen as influencing *teacher environments*, involving teachers in a project can contribute to teachers' *professional histories*, and thus influence *teacher profiles*.

Developing or feeding infrastructure

All renewals also worked on feeding their curriculum intentions into teacher education and professional development, in some cases by participating in the establishment of regional support centers. "Feeding" can also be understood as "with people": after some time, developers, researchers, and teachers involved in the renewals appeared as teacher educators and professional development providers. Professional development provisions are part of *teacher environments*, teacher education and teachers' professional development experiences influence their *professional histories*, elements of their *profiles*.

In the NiNa period, regional support centers for professional development were established through concerted action by the science education commissions, the professional scientists and science teachers' associations, and the national STEM Platform PBT. These centers exist to this day.

Textbooks and the annual physics teachers conference also appear in the data frequently as significant parts of the infrastructure.

Facilitating experiences in a safe setting

Renewals sometimes developed and offered, in a concerted action of all participants, resources and professional development facilities to *teacher environments*, so that teachers could develop their own enactment of curriculum intentions. Examples from other countries show how options for teachers to choose between varieties of CE qualifications and exam papers may contribute to that safety.

When the curriculum is overloaded, teachers seem to focus on the CE, which is the strongest requirement, to reduce the risk of their students underperforming in those exams. Apparently, curriculum overload goes at the cost of the safety that teachers need to elaborate new goals or time consuming approaches in their teaching.

A project with a pilot period, its own teaching materials, its own exams, and enough time compensation offers participating teachers a safe setting for experimenting with curriculum intentions in other enactments than they may have got used to.

Like in the previous category of unintended influences (*survival and propagation of curriculum intentions*), the data from the category of intended influences (*improving or creating circumstances favoring curriculum intentions*) also do no not give indications for each of the influencing factors about particular connected curriculum intentions. Many interventions in this category may support any curriculum intention promoted by those who initiate or implement the interventions. As far as particular curriculum intentions can be traced in the data for this category, the intentions, or components of intentions *Using contexts*, *Science, technology and society, Advancing concept development,* and *Advancing skills development* appear most frequently. In addition, *Coordinating with other STEM subjects* is promoted in several interventions, significantly more often than in the previous category. The curriculum emphasis *Knowledge development in science* is more often found in this category than in the previous.

CHAPTER 8
General conclusions and discussion

8.1 Introduction

Many curriculum evaluation studies conclude that little of curriculum developers' intentions is enacted by teachers, and much slips away (for instance, Hall, 1973; Fullan & Pomfret, 1977; Cuban, 1988; Fensham, 1992; Van den Akker, 1998a; Fullan, 2007; Meltzer & Otero, 2015). In contrast to that general conclusion, based on my experiences as a student, as a teacher, and as a curriculum developer, I have seen that the development activities in the field of science curricula in the Netherlands over the decades have not left teachers' practices unaffected. Classroom visits and conference workshops have shown me that quite a few science teachers do pay attention to students' preconceptions or organize structured research activities for their students, both examples of curriculum developers' intentions. These experiences led to disbelief in the general pessimistic conclusions about the fit between developers' intentions and teachers' practices. Motivated by this disbelief, I wanted to find out through this study whether, over a period of decades, essential elements of curriculum developers' intentions might nevertheless be expressed in current teaching practices. In addition, I was curious to know what factors may have promoted or hindered the chances of such intentions to be expressed in teaching practices, and whether some intentions might need a longer period to find their way into teachers' practices.

As a case for my investigation, I chose to compare and contrast curricula enacted by current physics teachers along with curricula written by six subsequent innovation projects and reform commissions for upper general secondary physics education in the Netherlands since 1970. In this study, the term *written curriculum* covers the exam programs recommended for the national scale by reform commissions or innovation projects, as well as the mandatory exam programs following those recommendations, and sample teaching materials, publications, and other accounts by which developers expressed their intentions about what students are expected to learn and how that learning can best be organized. The term *enacted curriculum* refers to teachers' practices, in lessons and units of instruction in which teachers express their intentions about what students should learn and how that learning should be organized. In this study, I compared and contrasted the intentions expressed in the written curricula with the intentions of teachers expressed in their enacted curricula.

When analyzing the curricula written at the national level by curriculum developers (including, for instance, subject experts, teacher educators, higher and secondary education teachers involved with curriculum development, along with professional curriculum developers) and the curricula enacted at the classroom level by teachers, I used a perspective inspired by evolution theory and ecology. In this perspective, intentions expressed in written as well as in enacted curricula are regarded as *memes*, units of cultural information (Dawkins, 1976/2016), which, analogous to *genes* in a genetic-evolutionary approach, can propagate in ecosystems and can be expressed in individuals. In this study, these memes are denoted by the term *curriculum intentions*. Just as individuals with similar genes can differ in their appearance, so too curricula with similar intentions can differ in their appearance. And just as the expression of genes in individuals depends on environmental factors, so too might the expression of intentions in enacted curricula depend on environmental factors. And just as the expression of genes sometimes skips one or more generations, so too might intentions be expressed with some delay in enacted curricula.

Studying curriculum change from an ecological-evolutionary perspective requires a longer period than a few years. Where evaluation studies usually are conducted shortly after the curricula were finalized by the developers, this study considers a time span of 50 years. One assumption based on my disbelief was that looking back over a longer period might show more expression of curriculum developers' intentions in teachers' enacted curricula than what is typically found in evaluations conducted soon after the introduction of a curriculum renewal. And if the outcome of developments over a relatively long timespan was studied, then it might also make sense to explore in an open way all possible factors, including unintended influences, that might have affected teachers' practices. An exploration of this kind would perhaps yield new insights about such factors, compared to those from previous studies into the implementation of renewals.

The ecological-evolutionary perspective was applied in this study into five decades of curriculum development for upper general secondary physics education, covering the written curricula of six renewals since the 1970s and the enacted curricula of 13 current teachers interviewed about their practices.

These considerations and the choice of the case led to the following, twofold, main research question:

> *To what extent do enacted curricula in upper general secondary physics education in the Netherlands reflect the intentions of renewals expressed in written curricula initiated since the 1970s and what factors may have influenced the expression of the renewals' intentions in teachers' enacted curricula?*

To explore the twofold question, four qualitative substudies were conducted. The research questions, methods, and conclusions of these substudies have been summarized in Section 8.2, leading to conclusions about the overall research question. Section 8.3 discusses the results of the study, the conceptual framework used, and the research design applied. Section 8.4 elaborates what the study can imply for developers, facilitators, and teachers. Section 8.5 lists unanswered and new questions for future research.

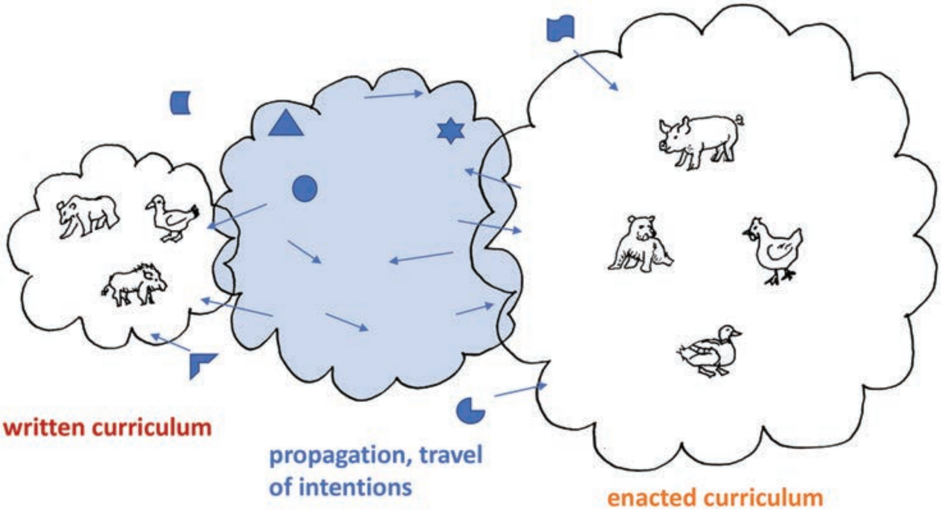

Figure 8.1 *Image of curriculum intentions traveling, as memes, between the written curriculum and the enacted curriculum (copy of Figure 2.1).*

8.2 Summary of conclusions

To explore the main research question, four qualitative substudies were conducted, informed by a conceptual reflection and literature review. The first two substudies (i.e., document analysis and analysis of reflections and discussions from a meeting with 14 participants and witnesses of the renewals since the 1970s) were strongly related and addressed the first part of the main research question. The third and fourth substudy (i.e., interviews with 13 current teachers and 18 participants and witnesses of the renewals) were also strongly related and addressed the second part of the main research question. In the following subsections, the research question, research design, and conclusions are summarized for each pair of substudies.

First part of the main research question: intentions in written and enacted curricula

The first part of the main research question is:

> *To what extent do enacted curricula in upper general secondary physics education in the Netherlands reflect the intentions of renewals expressed in written curricula initiated since the 1970s?*

This part was addressed in the first two substudies. Their research questions were, respectively:

1. *What curriculum intentions represent in a valid way what developers pursued in the various renewals of upper general secondary physics education in the Netherlands since 1970?*

2. *To what extent do descriptions of their practices and intentions by physics teachers in upper general secondary education in the Netherlands reflect the intentions of curriculum renewals initiated since the 1970s?*

These substudies were guided by an image (Figure 8.1) that shows curriculum intentions propagating as memes between written and enacted curricula. The curriculum intentions are indicated in the figure by small abstract shapes, like triangles or diamonds. Their expressions in written and enacted curricula are pictured as animals.

Design and findings of Substudy 1: intentions in written curricula

For Substudy 1, interviews with six participants of physics education renewals were conducted along with an analysis of written curricula: exam program recommendations, publications, and other accounts by project teams or reform commissions. Based on an initial list of curriculum intentions, the documents were analyzed by selecting and coding relevant quotations. The results of the analysis were then discussed in a meeting with 14 project leaders, chairpersons, and other persons who had been active in or around those renewals. The report of this meeting was used to validate the list of curriculum intentions. The findings of Substudy 1 justified the conclusion that the initially chosen set of curriculum intentions and their descriptions adequately represented what the renewals studied had intended and, as a consequence, could be used as a valid basis for analyzing interviews with teachers about their enacted curricula. This set (explained in Table 5.2, detailed in Appendix 3) contains the following curriculum intentions:

- Using contexts;
- Widening the scope of science education, further divided in curriculum emphases on
  - Knowledge development in science;
  - Science, technology and society;
- Coordination with other STEM-subjects;
- Advancing concept development;
- Advancing skills development.

Design and findings of Substudy 2: comparing intentions of written and enacted curricula

For Substudy 2, 13 teachers, selected to differ in age, seniority, and other professional experiences alongside teaching, were interviewed with a semi-structured interview guideline about their enacted curricula. The analysis of the interviews aimed to find curriculum intentions expressed by the interviewees and to examine to what extent the reported practices and intentions reflected the renewals' curriculum intentions. The interview data were analyzed in a qualitative way, although the analysis started quantitatively with the use of frequencies of the occurrence of codes for quotations reflecting intentions in a relatively strong or weak way. These frequencies of occurrence turned out to be far less meaningful than the actual substance of quotations, so the quantitative analysis only played a subsidiary role in the analyses. The results of these analyses justified the conclusion that after 50 years, significant changes have apparently taken place in enacted curricula, at least, judging from the descriptions of the interviewed teachers. Thus, the results from this case suggest that many of the negative evaluations referred to in the introduction seem to have been too pessimistic, or too general.

Overall, four out of the five curriculum intentions identified in Substudy 1 were expressed in the enacted curricula, as reported by the interviewed teachers. Only the intention *Coordinating with other STEM subjects* appeared to be enacted rarely. Whether in written curricula or in interviews about the enacted curricula, curriculum intentions were rarely expressed in a way that met *all* descriptors of these intentions (detailed in Appendix 3, summarized in Table 5.2). The correspondence of curriculum intentions between written and enacted curricula, shown in Substudies 1 and 2, is based on a sufficient fit at the level of elements from the descriptions.

To be more precise about the fit of curriculum intentions between written and enacted curricula, the following can be added.

- *Using contexts* clearly appeared in this study's data as realized in its components: connecting to relevant issues from everyday life or society and helping students apply concepts in various contexts. This spectrum of *Using contexts* could be found in the documentation of the renewals as well as in what the interviewed teachers said.
- *Widening the scope of science education* appeared as an umbrella term rather than a self-contained curriculum intention in both substudies; it was kept as the name of a category, which combined the curriculum emphases *Knowledge development in science* (KDS) and *Science, technology and society* (STS). Both KDS and STS were put into practice to a significant extent by the teachers interviewed.
- *Coordinating with other STEM subjects* appeared to be enacted only at the level of STEM-wide skills for most of the teachers interviewed. No teacher reported to have realized this intention in cross-cutting content domains.
- In most teacher interviews, *Advancing concept development* is most strongly expressed in the characteristics *promoting student reflection* and *developing and using scientific ideas*; the latter includes using concepts in various contexts. These two characteristics were seen as the basis of what written curricula expressed as ambition regarding *Advancing concept development*.
- *Advancing skills development* is expressed in both written and enacted curricula to different extents depending on the group of skills. It is kept as the name of a category. Research skills and modeling skills were found to a significant extent in the analysis of the teachers interviewed, design skills less so, and judgement skills barely.

Second part of the main research question: directly and indirectly influencing factors

The second part of the main research question is:

> *What factors may have influenced the expression of the renewals' intentions in teachers' enacted curricula?*

Pertaining to this second part were the closely linked third and fourth substudies. They had an exploratory character, expressed by 'may have' in the following research questions, which guided these substudies:

3. *What teacher profile and environment factors, as perceived by teachers, may have influenced the expression of curriculum renewal intentions in their teaching?*

4. *What factors may have influenced profiles and environments of teachers against the background of the curriculum renewals in upper general secondary physics education in the Netherlands since 1970?*

Design and findings of Substudy 3 and 4: directly and indirectly influencing factors

For Substudy 3, the same 13 teachers as for Substudy 2 were interviewed, each as part of the same session. In the process of selecting and coding quotations during the qualitative analysis of the interviews, open coding was used next to a set of influencing factors based on a conceptual model (see Figure 8.2). This model, distinguishing a *teacher's profile* and a *teacher's environment*, is imaged inside the dotted circle of Figure 8.2. Factors included in the teacher's profile and environment may influence the expression of curriculum intentions in the teacher's enacted curriculum. The analysis was largely qualitative and aimed to find factors mentioned by the interviewed teachers as influencing or having influenced their enacted curriculum. The codes for data analysis related to these influencing factors are listed in Table 8.1.

For Substudy 4, relevant documents produced by renewal teams or commissions, or reflecting on renewals, were analyzed. Also, interviews were conducted with 18 participants and witnesses of the renewals, reflecting on renewals and on what has happened in and around physics education in the Netherlands since the 1970s. The orientation interviews held for Substudy 1 were also partly used as sources for this fourth substudy. The qualitative analysis of the data started with open coding of selected quotations. From the analysis of data from some sources, codes and a categorization of codes emerged that were subsequently applied to the analysis of all written sources and interviews. These codes and their categories are listed in Table 8.2. The categories of factors are also pictured in Figure 8.2, as the two groups of factors outside the dotted circle and as the group of *sources of intentions*.

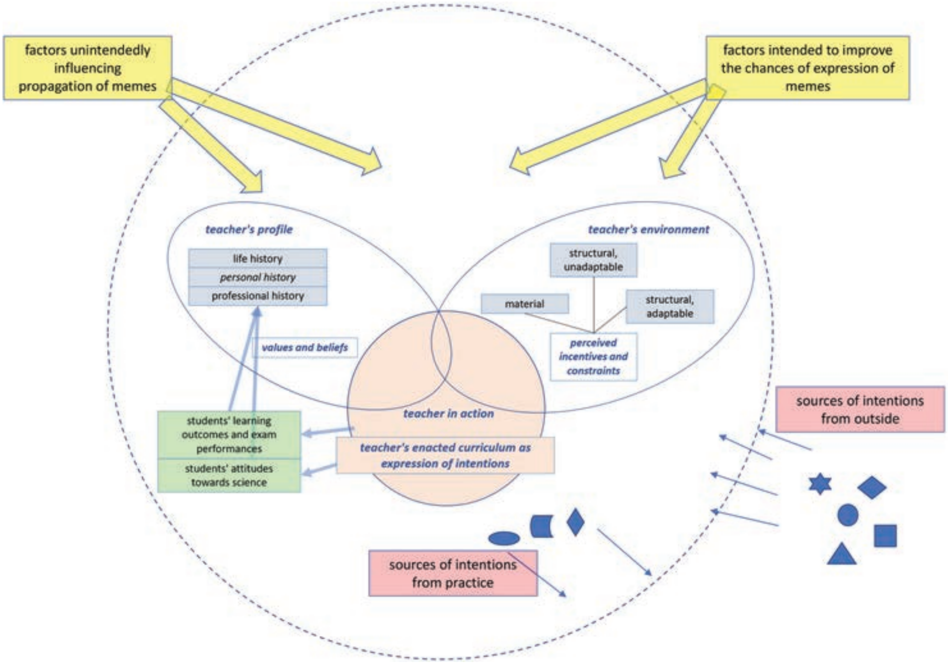

Figure 8.2 *Conceptual model for factors influencing a teacher's environment and profile, indirectly influencing teacher's actions, and for sources of curriculum intentions (copy of Figure 7.2).*

Table 8.1 *Factors that may directly influence the expression of curriculum intentions in enacted curricula, used for the analysis of teacher interviews.*

Categories of factors	Influencing factors
Teacher's profile	
Life history	life histories general life histories school/college/university
Professional history	teacher education learnt from colleagues previous classroom experiences previous school experiences professional development experiences curriculum development or research activities in the past previous professions curriculum renewals

Categories of factors	Influencing factors
Cultural system: values and beliefs	values about the goals of physics education beliefs about effective education and teaching strategies values about the role of the teacher views on the nature of physics self-image
Teacher's environment	
Material system	written resources physical school environment digital environment organizational environment other facilities & resources
Adaptable structural system	classroom interaction school organization collaboration with colleagues professional development provisions school examination
Unadaptable structural system	national exam program national syllabus central examinations

Table 8.2 *Factors that may influence teacher profiles and environments and thus possibly indirectly the expression of curriculum intentions in enacted curricula.*

Categories of factors	Influencing factors
Sources of curriculum intentions	from outside: theories and studies about knowledge, learning and teaching from outside: developments in society from practice: teachers' reflections on their experiences
Unintended influences on Dutch physics teachers: Survival and propagation of curriculum intentions	through project publications, sample exam programs, presentations through persons through research projects and dissertations through settings with a different focus
Intended influences on Dutch physics teachers: Improving or creating circumstances favoring curriculum intentions	securing in CE part providing clarity about curriculum intentions designing for teachers' concerns or zone of proximal development informing and involving teachers inside and outside project developing or feeding infrastructure facilitating experiences in a safe setting

The analysis aimed to find factors that were meant to influence Dutch upper secondary teachers' profiles and environments, or appeared to do so unintendedly, and thus indirectly may have influenced the enacted curricula. Therefore, they are addressed in the study as *indirectly influencing factors*, as opposed to the *directly influencing factors* examined in Substudy 3. Codes related to those indirectly influencing factors are listed in Table 8.2. Figure 8.2 visualizes indirectly influencing factors outside the dotted circle; these factors are distinguished in unintended and intended influences on the chances for curriculum intentions as memes to propagate in the world of teachers and to get expressed in teachers' enacted curricula. Curriculum intentions are indicated by small abstract forms, like triangles or diamonds, similar to Figure 8.1.

The codes attached to the various categories of influencing factors are listed in Tables 8.1 and 8.2. For code descriptions, see Tables 6.1 and 7.2, detailed in Appendices 4 and 5.

In the analysis of the teacher interviews for Substudy 3, connections could be made between directly influencing factors and the expressions of the various curriculum intentions in teachers' practices. The data for Substudy 4, on factors influencing teacher profiles and environments, did not show if and how such factors might indirectly influence teachers' enacted curricula. Only the evaluation study by SLO on the 2013 science education reforms (Ottevanger et al., 2018) provides some data about influences of indirect factors on enacted curricula, derived from responses from about 100 physics teachers to a questionnaire on their practices. However, what the data of Substudy 4 do show is that each indirect factor *can* support the expression of some to all curriculum intentions in teachers' practices, by influencing one or more *direct* factors in teachers' profiles or environments, whose influence on enacted curricula was shown in Substudy 3. Taken together, both substudies provide a picture of factors that may have influenced the expression of renewals' curriculum intentions in enacted curricula.

Based on the findings, Figure 8.3 combines the graphical summaries of influences from indirect on direct factors (Fig. 7.3) and from direct factors on curriculum intentions (Fig. 6.2). The *cultural system: values and beliefs* was not included in the central column of Figure 8.2. This was done because in Substudy 3 it was found that in the *teacher's profile*, the influences of the teacher's *life history* and *professional history* (mostly from *teacher education* and *professional development experiences*) translate almost entirely into the *cultural system: values and beliefs* (mostly into *values about the goal of physics education* and *beliefs about effective education and teaching*). Hence, including the factor *cultural system: values and beliefs* in Figure 8.3 would have led to double counting of influences.

In Figure 8.3, the arrows relating indirectly and directly influencing factors (the left-most group of arrows) only show that such relationships were found in the data. The arrows are all of the same thickness because in Substudy 4 no measure for the relationships was established. The arrows relating direct factors with their

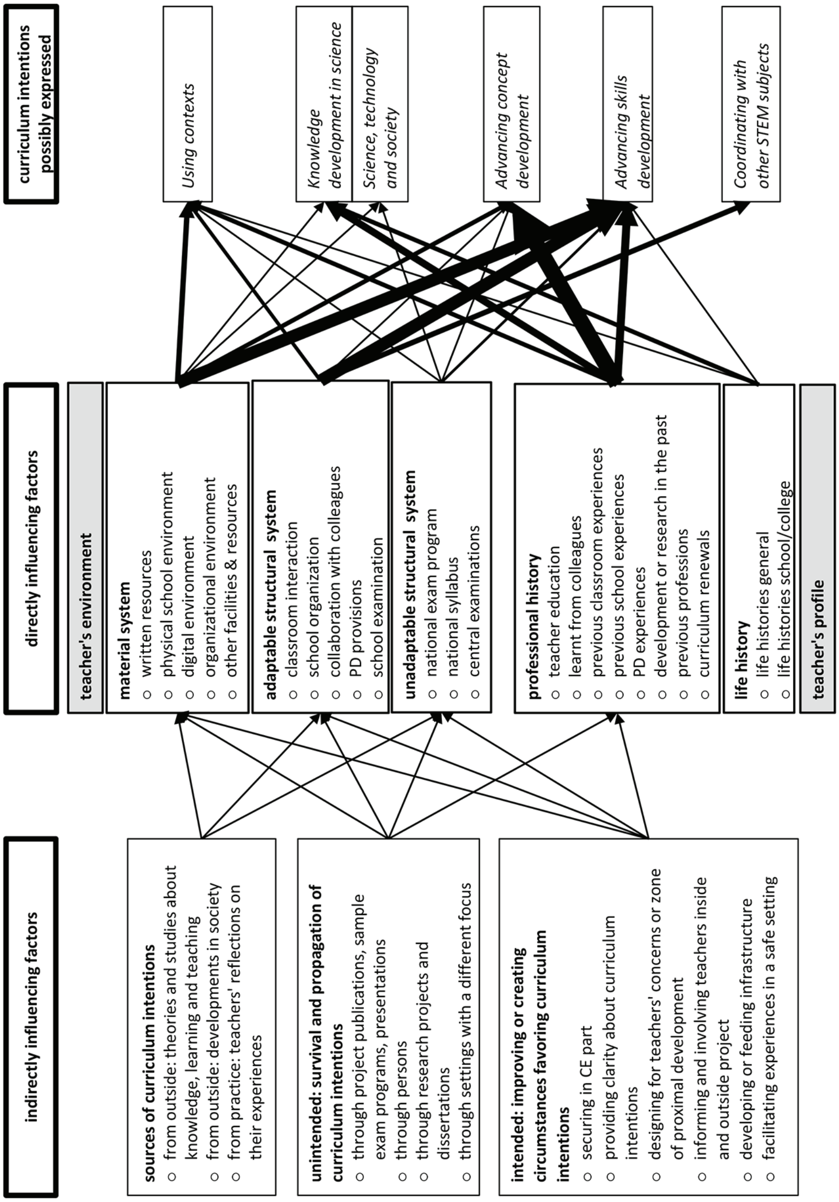

Figure 8.3 *Graphical summary combining influences from indirectly on directly influencing factors with influences from directly influencing factors on the expression of curriculum intentions in enacted curricula.*

influences on the possibility of expression of curriculum intentions in teachers' enacted curricula (the right-most group of arrows) differ in thickness, according to the extent to which the relationships were found in the data analysis of Substudy 3.

Combining direct and indirect influences leads to the following conclusions regarding the second half of the main research question.

- In the *teacher's profile*, the influences of *teacher education, professional development experiences*, and *classroom experiences* stand out in the interview data, as part of the *professional history*. These profile factors are influenced through provisions in the teacher's environment, like *professional development provisions* or opportunities to take part in pilots.
- In the *teacher's environment*, all three systems (*material*, *adaptable structural*, and *unadaptable structural*) appeared influential in supporting or hindering the expression of curriculum intentions in enacted curricula. And all three systems, in turn, appear to have been influenced by elements in the categories of unintended and intended influencing factors (*survival and propagation of curriculum intentions* and *improving or creating circumstances favoring curriculum intentions*, respectively), and by the deeper *sources of curriculum intentions*.
- The data used in this study show that the influences from unintended factors are not less significant that those from intended factors (see Table 8.2 for this distinction), the latter having been meant to influence teacher profiles and environments. It can be interpreted as a conclusion that curriculum intentions, as memes, may also propagate to teachers' enacted curricula without targeted implementation measures. These memes reach teachers through *teacher education* (*professional history*), *professional development provisions* (*adaptable structural system*), and *written resources* and *digital environments* (*material system*).

Where possible, the various factors were linked to curriculum intentions the expression of which in enacted curricula they may have influenced. Links found in this way are summarized in the following subsections.

To be more precise about directly and indirectly influencing factors, including their connection with curriculum intentions, the following can be added.

Directly influencing factors

Teacher's profile

The curriculum intentions whose enactment, from the interview data, appear most often or most strongly supported from the *teacher's profile* factors are *Advancing concept development* and *Widening the scope of science education*, the latter most often because of references to the role of the curriculum emphasis *Knowledge development in science* in teachers' enacted curricula. In contrast, in the interview data, the expression of *Using contexts* and *Advancing skills development* in enacted curricula appears to be much less related to factors from the *teacher's profile*. No mention at all was made of *Coordinating with other STEM subjects*.

The relatively rare references to the *teacher's profile* in connection to *Using contexts* and *Advancing skills development* do not necessarily mean that these are not influenced by the *teacher's profile*. Several interviewees mention *Using contexts* as part of *Advancing concept development*, but they only relate the latter curriculum intention to factors from their profile. A similar relation applies to *Advancing skills development*, mentioned by interviewees as part of emphasis on the nature of science, an element of *Widening the scope of science education*.

Teacher's environment

The curriculum intention that, in the analysis, emerges most strongly supported by *teacher's environment* factors is *Advancing skills development*. The interviewees refer to factors classified in:

- the *material system*, in particular *written materials* and *digital sources and facilities,* and
- the *adaptable structural* system, in particular professional *development provisions* connected to the *school examination program*, and *school organization*.

Also support for *Using contexts* is well articulated, due to:

- the *material system*, in particular *written materials*, *digital facilities,* and *organizational facilities*, and
- the *adaptable structural* system, in which several interviewees are reinforced by *classroom interaction* and by the explicit place of contexts in the *exam program*.

In third place, *Advancing concept development* comes out as strong, due to:

- the increasing conceptual approach of the most recent *central exams*, part of the *unadaptable structural system*, and
- clear explanations given by the standard textbooks as *written sources*, and to concept development tools provided by additional *written sources* and from the *digital environment* – all part of the *adaptable structural system*.

Apparently less supported by factors from the *teacher's environment* are *Widening the scope of science education* and *Coordinating with other STEM subjects*. The relatively rare references to the *teacher's environment* in connection to *Widening the scope of science education* may be explained by the fact that the interviewed teachers may rarely find, or look for, sources that support *Knowledge development in science* or *Science, technology and society*. The exceptions are the use of applets by one interviewee to discuss the nature of models, and excursions, brought up by two interviewees, to an academic lab, a company, or a "challenge" to show how and on what topics today's scientists work.

Much less is said about factors that hinder the expression of curriculum intentions in enacted curricula than about supporting factors. The interviewees reported more about what stimulated them to do what they do than what hindered them as an explanation for what they did not do. Still, hinder is reported: for *Advancing skills development*, *Using contexts*, and *Advancing concept development*, time pressure from the *central exam program* and *central exams* is a hindering factor, incidentally increased by the pressure reported from the *school organization*.

The role of the *unadaptable structural system*, i.e., of *national exam program*, *syllabus*, and *central exams*, is less profiled in the interview data than would seem obvious from the teachers' task to prepare their students for *school exams* (SE) and *central exams* (CE). However, a secondary source, a questionnaire-based evaluation by SLO (Ottevanger et al., 2018), carried out among upper secondary teachers of science subjects in the same period as this study, shows that for a majority of the 91 responding physics teachers, the CE part of the program plays a significant role, appearing from the respondents' reports that the CE is overloaded and that this goes at the cost of other elements of their enacted curriculum. Such other elements are, for example, lab or computer work, typically assessed in the SE, or time consuming concept development approaches. What the interviewed teachers say about the *central exams* shows that these may support as well as hinder the expression in their teaching of curriculum intentions as investigated in this study; both support and hinder count as influences, their combination does not cancel the relevance of the factor. They mention both support and hinder for *Advancing concept development* from the newest exams, and hinder for *Advancing skills development*. The SLO-evaluation referred to above strengthens this conclusion and connects it to the overload of subject matter prescribed for the central exam.

In summary, the curriculum emphasis *Knowledge development in science*, an element of *Widening the scope of science education* appears to be mostly explicitly supported by elements of the *teacher profiles*, anchored in the *Cultural system: values and beliefs.* The interviewees relatively frequently refer to the nature of physics and the goal of physics education, as factors supporting the expression of *Knowledge development in science* and *Advancing concept development*; several interviewees report that their ideas about these factors have been shaped or reinforced by their experiences in their *professional histories*. On the other hand, *Using contexts* and *Advancing skills development* appears to be mostly explicitly supported by elements of the *teacher environments*; printed and online teaching resources, and experiences (excursions) and materials offered by third parties are mentioned by many interviewees as contributing to those curriculum intentions. The curriculum intention *Advancing concept development* appears to be supported by both categories of influencing factors.

Indirectly influencing factors

Influences on teacher's profile and environment

As for the *teacher's profile*, the indirect factors explored most clearly influence teachers' *professional history*, in particular their *teacher education* and *professional development experiences*. As for the *teacher's environment*, all elements are influenced by the factors explored: the *material system* particularly through the provision of *teaching materials*; the *adaptable structural system* particularly by the *provision of professional development*; and the *unadaptable structural system* by the prescription of *exam programs* and *central exams*. *Professional development provisions* in *teacher environments* eventually influence teachers' *professional histories*, and thus *teacher profiles*.

Appearing from the data, the indirect factors categorized as *sources of curriculum intentions* exert their influences on teachers' practices mostly via curriculum renewal products, and some teacher educators, professional development providers, and textbook authors. The factors categorized as *unintended influences* (*survival and propagation of curriculum intentions*) appear to have influenced *teacher environments* as well as *teacher profiles*, through written texts, project teachers' practices, networks, and personal contacts. The factors categorized as *intended influences* (*improving or creating circumstances favoring curriculum intentions*) appear to have influenced all elements of *teacher environments,* which over time may also have influenced *teacher profiles*, in particular teachers' *professional history*.

The results also show that experimenting teachers derive safety from support from their school, and from the availability of time and of various resources. Also, for all teachers, their possibilities are strongly influenced by the limits of the CE, with the CE again providing safety by legitimizing, for example, attention to concept development. That combination, of safety (provided by the school or the examination system and by sufficient time) and the availability of material and immaterial resources, emerges as a strong facilitator for offering teachers room for innovativeness, whether they look for forms to enact elements from written curricula or experiment in their classes following their own curiosity. That innovativeness appears to work, whether intentionally or not, in favor of the expression of some renewals' curriculum intentions with the teachers interviewed.

Curriculum intentions brought up in connection with indirect factors

The curriculum intentions *Using contexts*, *Science, technology and society* (an element of *Widening the scope of science education*)*, Advancing concept development,* and *Advancing skills development*, or components of these, regularly emerged in the data for all categories of indirect influences.

The curriculum emphasis *Knowledge development in science* (an element of *Widening the scope of science education*) mostly emerged for the influences categorized as *intended influences*, also addressed as *improving or creating circumstances favoring curriculum intentions*.

The curriculum intention *Coordinating with other STEM subjects* emerged in connection with several of the influences categorized as *intended influences* (*improving or creating circumstances favoring curriculum intentions*). As for its connection with the influences categorized as *unintended influences* (*survival and propagation of curriculum intentions*), it only appears in the factor *through settings with a different focus.*

8.3 Discussion

In this section, some conclusions are reflected upon, followed by a discussion of the conceptual framework and of the research design.

Reflection on the study's conclusions

Long time spans and short term evaluations

Much of the skepsis expressed about the extent to which developers' intentions are enacted by teachers (for instance, see Chapter 1 or Section 8.1) is based on evaluations of renewals which took place in the years following a project period, or following the implementation of a reform in a whole jurisdiction. Several authors, like Snyder et al. (1992), Coburn (2003), or Penuel (2019), emphasize the importance of *time* for teachers, school teams, or educational infrastructures to become familiar with and experience the reform, to reflect on experiences and negotiate steps in curriculum change. I assumed that changes that fade out may also reappear after some time, under more favorable conditions, whether or not these conditions had been intentionally created. This assumption was inspired by evolution theory, genetics, and ecology, which allow for the idea that genetic traits can disappear from phenotypes but reappear in a later generation. I assumed that an ecological-evolutionary perspective applied to several decades of physics curriculum development might show a better match between written and enacted curricula than only immediate evaluations. This assumption stands next to, and can complement, the recommendations on changes to take time.

An outcome of Substudies 1 and 2 is that developers involved in the renewals of the 1980s could have been satisfied to a large extent about the enacted curricula of the 13 teachers interviewed in 2017 and 2018. So far, the assumption seems justified that skepsis about the pessimistic conclusions of immediate evaluations is necessary. It would be informative to also apply this assumption to the few evaluations that had been conducted shortly after the completion of the activities of the renewal included in this study. However, only one immediate and comprehensive evaluation study of this kind exists, that of the 2013 NiNa renewal. This evaluation was carried out by SLO (Ottevanger et al., 2018), based on a questionnaire to which 91 physics teachers responded. Of the 1972-1985 PLON project only the aspect of *Using contexts* was evaluated up to the level of teachers and students (Wierstra, 1990); regarding teachers in upper general secondary education, Wierstra's study was limited to one domain (mechanics) in the fourth *havo* year, for which 23 teachers completed a questionnaire. The study by Volman et al. (1995), reflecting on approximately 25 years of curriculum innovation in STEM subjects, can be considered a "semi-immediate" evaluation; for the physics education component, it used as data sources five interviews with participants and witnesses of the renewals and a number of reflective publications. No other evaluations have been carried out concerning the renewals included in this study. The evaluation by SLO of the national implementation of the NiNa renewal shows that many elements of the NiNa commission's curriculum intentions had indeed found their way into teachers' practices in about 2017.

Had my assumption that immediate evaluations cause pessimism because of a too short period between developers' activities and teachers' practices perhaps been incorrect? Or are there nevertheless possible explanations for the relative success shown by the evaluation of the NiNa renewal that followed shortly after the national implementation of its exam programs? The following are some possible answers to those questions.

One answer might be in the duration of activities of the NiNa renewal: six years (2005-2010). The time delay that may explain successes in evolutionary processes might have been offered by the length of the NiNa pilot period. However, the longer-lasting PLON project (1972-1985) had less immediate effect on a national scale than NiNa, as far as known from its limited evaluations and from the interviews and written sources contributing to Substudy 4. But as the data showed, the WEN exam program (activities in 1982-1987) met reasonably well the ambitions of PLON, DBK, and the HBB and VBB projects (for *havo* and *vwo* upper secondary physics education, respectively), which ran in the early 1980s. The whole set of those projects and the WEN commission's activities can be seen as one large renewal, which indeed satisfied quite a lot of the preceding renewals' curriculum intentions. Due to a lack of systematic evaluations of upper secondary physics education in the Netherlands in the past 50 years, this hypothesis cannot be checked, but some of the interviewees in Substudy 4 mentioned it. Only in the evaluation by Volman et al. (1995, p. 70), one of the five respondents addresses this question, stating that the WEN renewal, although not a revolution, shows changes in classroom practices that follow the ideas of the then renewals. Be that as it may, the examination programs of both WEN and NiNa were "practice-informed" and the development of the NiNa program even involved, through its included four-year pilot project, the possibility of *mutual adaptation* (Snyder et al., 1992). Other possible explanations for a relatively successful fit between written and enacted curricula after the NiNa renewals (like for the contemporaneous biology and chemistry curriculum renewals) will be discussed below.

Another answer to those questions may be in the process of the NiNa renewal. It was the only one among six renewals studied that had been able to test the practicability of intended national attainment targets in a pilot setting, which yielded, next to proposed exam programs asked for by the Ministry of Education: a group of experienced teachers, pilot teaching materials, pilot syllabus specifications, and pilot exams, which could act as samples in the phase of national implementation. It was also the only of the six renewals that had used, next to a formative evaluation by the NiNa-commission and project team themselves, an externally conducted formative evaluation by SLO (Kuiper et al., 2011). The other renewals that had taken time for pilot testing and formative evaluation had been PLON (including the HBB and VBB projects) and DBK. The latter did not yield exam program proposals; the former did, but these received no formal status other than being used as input for the WEN-commission, and an external formative evaluation had not been part of the PLON activities. Based on the available data, it is not possible to say whether the relative success of NiNa can indeed be explained by the combination of ingredients:

the invitation of the Ministry of Education to develop examination programs, pilot tests in the classroom, and internal as well as external formative evaluation.

A third answer to those questions can be found in the influences on their teaching mentioned by the teachers interviewed for Substudy 3. None of these influences refer to the NiNa exam program or sample teaching materials as a direct cause for their teaching approaches, though some say that the exam program and central exams confirm their favoured approaches. Most of the influences reported by the interviewees that support NiNa's intentions go back to experiences dating from before the changes. Only in some cases were professional development provisions that had been initiated in the pilot years mentioned as strengthening attention for *Advancing concept development* or *Advancing skills development*. In addition, the *Zero measurement* carried out by SLO in 2012 and 2013 (Michels et al., 2014), to which about 70 physics teachers responded, confirms that also before 2013 many teachers enacted curriculum intentions *Using contexts* and *Advancing research skills development* in many of their lessons, according to their responses to a questionnaire. The focuses of NiNa's written curriculum, with its emphasis on what physicists do, seems to have consolidated attention for a more concept-oriented type of physics education, using contexts in a concept-context-approach, and for modeling as a key element of physics. These focuses seemed connected to the practices of a significant number of teachers, rooted in the decades preceding 2013. All of this confirms that NiNa, too, was a next step in an evolutionary, rather than an individual revolutionary development of written and enacted curricula since the 1970s.

This discussion can also be viewed from the perspective of *sustainability* of curriculum changes. Hargreaves and Fink (2006, p. 2) write: "If the first challenge of change is to ensure that it's desirable and the second challenge to make it doable, then the biggest challenge of all is to make it durable and sustainable." To ensure sustainability, Kuiper (2009; also in Kuiper et al., 2013) mentions, in the context of evaluating STEM curriculum changes in the Netherlands, the need to anchor renewals' ambitions in national exam programs (direction and guidance), combined with ample room for local curricular initiatives and decision making of teachers (bottom-up) and growing support facilities (from aside). Fullan (2008, p. 119) argues for a *whole system reform* (WSR), comprising various levels of decision making about curricula, to ensure sustainability. If the growth of so many factors at so many levels is needed to ensure sustainability of renewals' curriculum intentions, then a longer period, allowing for iterations in the feedback between developers and teachers, in the evolvement of written and enacted curricula, and in the evolvement of so many environments, might be more succesful than attempts to ensure sustainability within the cycle of one project.

The role of teachers as sources of intentions

In the model of memes traveling between written and enacted curricula (Fig. 8.1), propagation goes in both directions. Also, in the list of indirectly influencing factors, the category *Sources of curriculum intentions* (Table 8.2, Fig. 8.3) contains the world of research, societal developments, as well as teachers as possible sources.

In the data of Substudy 4, in only one case did the teachers explicitly act as primary sources of curriculum intentions (the teachers interviewed for Substudies 2 and 3 did not bring up such actions). This was in 1972, when physics teachers themselves were asked to list some key issues to be addressed in the innovation project that was going to start (Hooymayers, 1986); as for the curriculum intentions examined in this study, they mentioned more up to date research skills (group work, supporting theory development, quantitative) and strengthening of judgment skills, and more topical physics and philosophy in textbooks. These recommended issues reflect *Advancing skills development*, *Widening the scope of science education* (both *Knowledge development in science* and *Science, technology and society*), and *Coordinating with other STEM subjects*. In the available data on the development of physics education in the Netherlands, no other comparable open consultations of teachers could be found.

The data also report on consultations of Dutch physics teachers responding to American and British projects in 1970, to Dutch draft exam programs during the following decades, and to the NiNa vision document in 2006; these responses all relate to key ideas that had already taken the form of curriculum intentions expressed in (draft or sample) written curricula.

The role of teacher profiles and environments

For many of the interviewed teachers, their enacted curricula seem to have been influenced essentially as much, if not more, by their personal and professional histories as by their environment of material or structural systems. In the interviews, they confirmed that textbooks, digital resources, and conference workshops played a significant role in the likelihood that their intentions were expressed, and in what form that could happen. The interviewees said to use all of these environmental factors to strengthen their repertoire in a direction for which they had apparently already determined their preference in teacher education and professional development. Beijaard et al. (2004, p. 126) in their conclusions about "the role of context in professional identity formation and to what counts as professional in teachers' professional identity" expect that the influences teachers experience from their environment will in turn affect their professional identity.

None of the interviewed teachers refer to experiences or persons from their teacher education or professional development that might have radically *changed* their values and beliefs about education. Rather, their experiences had *confirmed* their pre-existing beliefs and *expanded* these with a vocabulary, some classroom tools, and/or the name of a renowned scholar. If the interviewees mentioned anything in a radical way, then it was this confirmation and expansion of pre-existing intuitions. None of them described a radical conversion, or a change of paradigm.

This key role of already existing beliefs reminds of Noonan's (2019) concept of *anchoring beliefs*, which he connects with personal and professional identity, as a "filter through which learning happens or fails to happen" (p. 535).

Attention for the nature of science key element in some teachers' profiles

In all interviews, the teachers expressed elements of *Advancing concept development* in some way. Some only with the motivation that understanding physics concepts is needed for good exam results, others also with the more epistemological motivation that understanding concepts as *models* of reality is part of understanding "how physics works", the nature of science, as an element of the curriculum emphasis *Knowledge development in science*. This in turn seems to be a basic motivation for the curriculum choices of many interviewees. Two of them even stated that no particular concept or physics domain is sacred, but that the ultimate intention of teaching physics concepts is to practice the way physicists work. Only one of the teachers had studied philosophy of science as a minor, all others with this epistemological interest connected it to a personal fascination or world view, which apparently had found a niche in the profession of physics teacher.

This result does not correspond to a conclusion drawn by Van Driel et al. (2001, p .146) from a review of several studies that "irrespective of their academic background, science teachers possess limited knowledge of the history and philosophy of science [and] hold inadequate or naive conceptions of the nature of science. For example, many teachers appear to hold positivist views, believing that the substantive content of science is fixed and unchangeable rather than tentative." Quite a few of the teachers interviewed for this study at least express as their view that model building is part the nature of physics and more fundamental than particular regularities or concepts; and some of these teachers also say to elaborate this awareness in their teaching. But Van Driel et al. (2001) also note:

> In a review of teacher education programs aimed at improving science teachers' conceptions of the nature of science, Abd-El-Khalick and Lederman (1999) concluded that explicitness and reflectiveness with respect to the nature of science are the most important features of programs that appeared successful in facilitating teachers to develop conceptions of the nature of science that are consistent with those advocated by current reforms, and to translate these conceptions into an appropriate classroom approach. (p. 146)

The fact that many teachers interviewed for this study refer to their teacher education or continued professional development to explain their attention for concept development and its epistemological base, seems to support the influence from teacher education that Van Driel et al. read in Abd-El-Khalick and Lederman (1999), in which we can understand teacher education more broadly, extended with continued professional development.

Discussion of the conceptual framework

A perspective of evolution and ecology

The question of whether the ecological-evolutionary perspective used in this study led to different insights than evaluations shortly after the introduction of the renewals would have done can only be answered very partially, because most of the renewals that were included in this study were not thoroughly evaluated shortly after their introduction. The subsection *Long time spans and short term evaluations* above already discussed that. What the first two substudies do show is that after those fifty years, much of the intentions of developers documented in their written curricula over those decades is reflected in current teachers' practices, as teachers describe them in interviews. That conclusion, drawn within the limits of this study, contradicts the pessimism that prevails in the literature based on evaluations conducted shortly after the introduction of a curriculum renewal. There may be some explanations for that in the nature of an ecological-evolutionary perspective, which was the basis for the design of this study.

One possible explanation for the conclusion that contradicts the general pessimism may lie in the choice of the case: upper general secondary physics education. The pessimism in the literature refers to all kinds of curriculum changes, often also changes that involve school reform, whereas the case of this study relates only to one subject, much of which can be adapted by teachers without facing constraints in their school. Adapting primarily one's own teaching practice, usually without having to involve colleagues or school leaders, is less comprehensive and perhaps less complex than adapting a school's practice; this adaptability indeed does not apply to expressing *Coordinating with other STEM subjects*, for which support from school is indispensable. This explanation stresses the role of the environment.

Another explanation can be that intentions in written and enacted curricula were compared based on elements in those curricula that met descriptions of intentions with a certain *tolerance*. These descriptions of intentions leave much more room for expression than, as Snyder et al. (1992, p. 405) call it, an "implementation scale or checklist . . . developed to match desired practices, such as use of materials and activities, new roles/behavior, new understandings and attitudes". These authors mention such checklists to describe the *Fidelity Perspective* of curriculum implementation (after Fullan & Pomfret, 1977). An ecological-evolutionary perspective might come close to the *Mutual Adaptation Perspective*, which was defined by Fullan and Pomfret (1977, p. 340) as "innovations [that] become developed/changed etc. during the process of implementation." If 'mutual' is left out of *Mutual Adaptation Perspective* or at least interpreted as non-simultaneous mutuality, in which developers and teachers may influence each other in subsequent cycles of mutual reflections on their written, resp. enacted curricula (see Figure 8.1), then this perspective and the ecological-evolutionary perspective may be closely related. Snyder et al. (1992, p. 404) seem to allow for that also when mentioning that "researchers with this orientation are interested in studying how the innovation is adapted during the implementation process," but even then, that implementation process is what immediately follows the developers' activities.

Other models, like, for example, the *Curriculum Continuum* model described by Marsh and Willis (2003) can also be read as an iterative mutual adaptation process without the need of simultaneous mutuality, but accepting time delays that allow profiles and environments of teachers as well as of developers to change.

Linked to these deliberations, also the *Curriculum Enactment Perspective*, described by Snyder et al. (1992), deserves attention. Research in that perspective focuses on “teachers’ and students interpretations of what is happening in the classroom and changes in their ways of thinking and believing” (Snyder et al., 1992, p. 429). This perspective seems to allow more tolerance in comparing written and enacted curricula, but the authors warn that in examining curricula in the *Curriculum Enactment Perspective*, researchers’ interest “is not in measuring how faithfully the curriculum is carried out, nor even so much how the original curriculum is adapted, but rather in describing and understanding the meaning given the evolving curriculum by those creating it – the teacher and students” (Snyder et al., 1992, p. 430). Thus, research using the *Curriculum Enactment Perspective* stays away from *comparing* intentions of written and enacted curricula; the description even leaves out that teachers and students might try to *interpret* a written curriculum, it focuses on the “evolving curriculum by those creating it”. The ecological-evolutionary perspective used in this study shares the tolerance of the *Curriculum Enactment Perspective* but on the other hand does allow for the comparison of enacted curricula with written curricula (addressed as *the original curriculum* by Snyder et al.). As opposed to the *Fidelity Perspective* it does so at the level of intentions, rather than comparing elaborations in teachers’ enacted curricula with “desired practices” (Snyder et al., 1992, p. 405).

A third explanation can be that curriculum intentions may come to expression in enacted curricula to a significant extent only after a time delay that is missed in evaluations subsequent to the introduction of the renewals. Indications for what may have happened in that time can be found in what teachers interviewed in Substudy 3 report about their life and professional history, in particular about teacher education and earlier professional development experiences. Indications can also be found in developments that took place in that time as found in Substudy 4, such as developments in the world of science education, in teacher support, or society in general.

This shows yet another characteristic of the perspective taken in this study: it examined factors that, directly or indirectly, may have influenced a teacher’s enacted curriculum, in a system as visualized in Figure 8.2. This study did not produce one-to-one relations between influencing factors and particular expressions of curriculum intentions, as if these factors were a set of knobs that can be turned with predictable effects. Rather, it showed which factors appeared influential, even if some seemed only indirect, and thus might be considered to explain why some curriculum intentions are expressed more easily in teachers’ practices than other. Fullan (2008, p. 119), explaining why he applies a *whole system reform* (WSR) in his own projects, stresses the importance of system factors. In Fullan’s argument, this whole system applies to the various levels of governance (which are different in the Netherlands than in the United States): the school-community level, the district level, and the policy or government levels. The ecological-evolutionary perspective is akin to Fullan's whole system approach, though for the case of this study it is applied to a wide variety of subsystems related to the education system (such as teacher education, or professional development provisions) rather than to Fullan's levels of governance, which, moreover, are different in the United States than in the Netherlands.

Authors like Coburn (2003), who proposes rethinking the concept of *scale*, and Penuel (2019), who uses *infrastructuring* as part of design-based research projects aimed at curriculum change, also stress the importance of the system in which a teacher works. For these authors, awareness of this system is also a condition for increasing the sustainability of an innovation. This attention for the quality of the infrastructure, or the system, as a criterium for upscaling brings the design-and-upscaling perspective close to the ecological-evolutionary perspective. Fullan's (2007, p. 11) "shift . . . from innovation to innovativeness" characterizes this key role of the environment.

The approaches of Coburn (2003), Fullan (2007, 2008), and Penuel (2019) are more than perspectives for analysis, they are also, or even primarily, approaches for curriculum change. The ecological-evolutionary perspective of this study was not meant as an approach for curriculum change, but only as a basis for analysis. However, the findings of this study, in particular those about factors that may influence teachers' practices, can be used to improve approaches for curriculum change. This will be addressed in Section 8.4, *Possible implications*.

An ecological-evolutionary perspective, like any other metaphor, has its limitations. In particular, the crucial absence of design from Darwin's evolution theory is not adopted in the evolutionary perspective used in this study. I approached the choice of intentions by developers and teachers and the way they express these in their written or enacted curricula as *design*: developers and teachers have intentions with these curriculum intentions, they serve their purposes. This interpretation stays close to Walker's (1990, p. 5) definition of *curriculum* as referring to "the *content* and *purpose* of an educational program". A possible objection might be that even design criteria or purposes have emerged from evolutionary processes of random variation and natural selection. I leave that aside and use the term *design* in connection with purposes and criteria for education, regardless of mechanisms that led to their origin.

The model of influencing factors

From the chosen ecological-evolutionary perspective, teachers' practices were environments in which renewals' curriculum intentions, as memes, could be expressed. Teachers' practices, in turn, were assumed to be influenced by teachers' profiles and environments. The search for a model that could capture these kinds of influences led to the *teacher agency* model of Priestley et al. (2013), even though the concept of teacher agency itself was not part of the conceptual framework of this study. Figure 8.2 visualizes the model used to analyze factors from teachers' profiles and environments that may directly influence enacted curricula, inside the dotted circle. Still, the references that the teachers interviewed for Substudy 3 make to their values and beliefs – as biographical and psychological factors – and to factors in their material and structural environment – as ecological factors – suggest that they refer to what Priestley et al. (2013) would call teacher agency. Their model (see Section 2.4) connects an iterational dimension with a projective dimension. Together, these two correspond with the three systems included in the *teacher's profile* of the model for influencing factors used in this study: *personal history*, *professional history*, and *values and beliefs* – the latter is also addressed as the *cultural system*, which in this study's model refers to the teacher, not to the school or other systems. The practical-evaluative dimension of the teacher agency model corresponds with the systems included in the *teacher's environment* of our model: *material system* and *structural system* (partly adaptable, partly unadaptable, and including what Priestley et al. mean by *cultural system* in their model).

The distinction between and the elements included in the categories *teacher's profile* and *teacher's environment* appeared fruitful in finding and organizing factors that may have influenced the enacted curricula of the teachers interviewed. The study gives no reasons to change that part of the model, although a cultural system as part of the teacher's environment might have done more justice to the conceptually convincing distinction of *cultural*, *structural*, and *material*, like the one used by Priestley et al. (2013). In the data of this study, references to the school's philosophy would have been scored in the cultural rather than, as is now the case, the structural system.

The model of directly influencing factors used in this study was extended by categories of indirectly influencing factors, drawn outside the dotted circle of Figure 8.2, or, in the case of the category *sources of curriculum intentions*, as crossing that circle. The distinction between the categories of unintended influences (*survival and propagation of curriculum intentions*) and intended influences (*improving or creating circumstances favoring curriculum intentions*) was inspired by different ways for genes to propagate in a system that includes human interventions next to other ("natural") processes. Dennett (1996, p. 118) also describes this distinction, when he argues that the travels of genomes, needed for biological possibilities to be realized, can go "'in the course of nature' – without human manipulation – or with the help of such artificial cranes as the techniques of traditional animal-breeding." The distinction may sometimes have been a bit forced in the analysis of Substudy 4, due to the fact that even applied to the widest contexts of curriculum change, no development is entirely "the course of nature." Still, the distinction helps to acknowledge that many relevant factors that may have influenced teacher profiles and environments may have originated and evolved independently from targeted interventions by curriculum developers. The rise of computer and information technology is a good example.

In the interviews and written sources for Substudy 4, both interviewees and authors referred to sources of curriculum intentions that they considered relevant to the development of physics education. While those sources were not themselves influencing factors, they helped to understand how those influencing factors fit into the picture as "conductors" of curriculum intentions. This led to an additional category, labeled *sources of curriculum intentions*, which also allowed to visualize the role of teachers reflecting on their practices and helped to find corresponding events in the data.

This part of the model also, indirectly influencing factors together with sources of curriculum intentions, has appeared to be fruitful in finding and categorizing factors, and to distinguish indirectly influencing factors from teacher profiles and environments, which consist of factors that may directly influence enacted curricula.

In their evaluation of innovations of STEM subjects, Volman et al. (1995) used a list of factors collected from literature to analyze strategies for development and implementation of curriculum renewals. These factors appear similar to those used in the conceptual models for Substudies 3 and 4 as elements of the categories of intended and unintended factors influencing teacher profiles and environments.

Influences between teacher's environment and teacher's profile

The *teacher's environment* influences the *teacher's profile* indirectly: a teacher's environment influences their enacted curricula, which in turn affect what students learn and value, represented in Figure 8.2 as students' learning outcomes and attitudes; these learning outcomes and attitudes feed back into the *professional history* of a teacher, which had been categorized as part of the *teacher's profile*. If the present situation is seen as tomorrow's past, then the current environment of a teacher would merge with their professional history. Still, there is a difference: the past cannot be adapted, the interaction with today's school, colleagues, students, textbooks, professional development provisions, and other environmental factors can be adapted, by the teacher and by others. Thus, we also see how teachers, with their values and beliefs, can influence their environments. Changing the standard textbook is one example that interviewees mentioned, as well as using written or digital resources, and asking for facilities for professional development, research or development work. This can be understood as a direct influence from a teacher's profile on the teacher's environment. The data of this study did not show an influence from the teacher's environment on the teacher's profile other than through students' learning outcomes and attitudes. The model of Figure 8.2 shows a possibility of direct influences between the teacher's environment and the teacher's profile in an overlap of the ellipses. In this study, influence in this overlap appeared from profile to environment. According to Beijaard et al. (2004), influence may also be expected from environment to profile: the "professional landscape," a metaphor coined by Connelly and Clandinin (1999), may offer a perspective for professional identity formation.

Influences on developers

Given the symmetry in influences between written and enacted curricula, as outcomes by developers' and teachers' actions, respectively, as suggested in Figure 8.1, a model like Figure 8.2 might also apply to developers. Some evidence for teachers' influences on developers emerged from the data of Substudy 4, in particular from the references to the WND conferences of the 1970s, in which American and British projects were discussed among (future) developers and teachers, to formative evaluations of pilots, to the teachers' consultation in 1972, referred to by Hooymayers (1986), and to discussions with teachers organized by renewal teams or commissions around their vision documents, sample teaching materials, and draft exam programs. How exactly these influences were exerted, through "developer profiles" or "developer environments," was not included in the research question, nor could it be established from the data of this study. The symmetry is not complete: the primary target group of developers is teachers, where the primary target group of teachers is students. The feedback from teachers through their enacted curricula to developers needs considerably more time than the feedback from students through their learning outcomes and attitudes to teachers. A study by Judson et al. (2020) went into the question what influences the development of science content standards, by asking what beliefs, values, and experiences have influenced developers of Arizona's NRC Framework-based science standards. Their categories of influences show similarities with the categories used in Substudy 3. A difference is indeed in a much stronger influence than what was found in Substudy 3 of "future-looking", in Judson et al.'s study regarding developers imagining what educators would do with their products: "In fact, the foremost concern involved thinking about educators trying to read and interpret the standards they were drafting—90% of the developers indicated this had some or a lot of influence" (Judson et al., 2020, p. 68).

Discussion of the research design

Choice of the case

The choice of physics education as the case was primarily based on my personal involvement, but was confirmed by the fact that there had been several innovation projects and formal reforms since the 1970s in Dutch physics education. In addition, the case of upper general physics education in the Netherlands is also interesting in an international context, as the projects and reforms have always strongly been influenced by science curriculum development projects in other countries.

Particularities of the case

The choice of upper general secondary physics education in the Netherlands since 1970 brought with it some particularities, which put limits on the generalizability of this study's findings. Most relevant is that the choice of the case concerns a school subject characterized by:

- a central examination, different from, for instance, Belgium or Finland;
- a structure and culture, within the limits of a central examination system, in which teachers are trusted as competent to shape their own curriculum enactment, with the help of textbooks and other resources from which they make their own choice, in coordination with colleagues; predominantly academically educated teachers, different from, for instance, lower secondary education;

- strong connections between fellow upper secondary teachers at the regional and national level: some school leaders and teachers tend to notice (personal communication) that upper secondary teachers are more connected to their professional group than to their school;
- strong connections in the discourse about its content and teaching approach (*didactiek*) with other science subjects and with mathematics, different from the school subjects in social sciences and humanities or languages;
- a focus, for many decades, given by stakeholders in society, to the country's, or European or Atlantic economic and military competitiveness; this also differs from school subjects other than STEM subjects.

Researcher's position

As for the personal involvement of the researcher: I was a physics teacher between 1981 and 1986, pilot teacher of the PLON project, and co-author of some PLON pilot materials in those years. In the 1980s and 1990s, I contributed as author of chapters about physics and society, and biophysics to commercial physics textbooks. From 2004 through 2010, I was secretary of the NiNa commission, which prepared a proposal for a new exam program, and project leader of NiNa's pilot schools project. I co-authored both of the NiNa publications, which were used in this study as documentation of the intentions and implementation activities of the NiNa commission (see Chapters 4 and 7). From 2011, I was project leader for the implementation of the new exam programs for the sciences, including physics.

The advantage of this involvement is that it allowed quick access to many individuals and written sources that could provide information about the projects under study; I could also more easily go into underlying details if I suspected they might play a role. To reduce the risk of selective recall, I interviewed people who were involved in or witnessed the renewals in other roles, including those who were critical about intentions or strategies. I was not involved in any of the written sources about the renewals before 2004. The publications about the work of the NiNa commission and pilot in which I was involved have passed, as drafts, many eyes and many hands before final publication.

A standard written procedure was used for the data collection and all interviews were based on a semi-structured list of focal points, discussed in advance with the supervisors of the study, in order to reduce the risk of a narrow view by a single researcher. Interviewed teachers were asked to approve transcripts or summaries of their interviews and included their corrections. When summaries of interviews were used with renewal participants for analysis in Substudy 4, I asked those interviewees to correct and validate the summaries. Some full interview transcripts were discussed with the supervisors about the selection of quotations to be coded. And I discussed the selection and coding of transcripts and written sources with a second coder or, in the case of Substudy 1, in a meeting with project leaders, chairpersons, and others who had been active in or around the renewals. Also, feedback was used from presentations I gave during the course of the study at working meetings and conferences with teachers, curriculum developers, and researchers.

Choice of methods

Document analysis and participants meeting

Substudy 1 was needed to identify a set of curriculum intentions that could serve as *memes* characterizing what the renewals since the 1970s had aimed for. The documents produced by those renewals as written curricula or to explain them were one group of sources that could be analyzed in search of what might be suitable representations, interviews with some participants in the renewals were used to supplement lacking information or add details. To validate and where needed to supplement the tentative set of curriculum intentions emerging from that analysis, key participants from all examined renewals were invited to a three hour meeting where they could retrieve, refresh, and check memories, in groups per renewal, followed by mixed groups. The discussions in these groups were centered around the proposed set of curriculum intentions and its explanations. Thus, virtually all available written and well informed oral sources were involved in the construction of a valid set of curriculum intentions.

This set may be useful as a model for sets of curriculum intentions for other subjects than physics, in particular for other science subjects. The written sources used for this substudy can be used as a comparison by researchers of other cases.

Teacher interviews about curriculum intentions

For Substudy 2, the choice was made to interview 13 teachers , rather than do fully fledged lesson observations of several lessons in more than one class for each teacher. Although such observations would have yielded additional and more direct evidence about the teachers' enacted curricula, they would also have restricted the number of teachers that could have been studied and thus would have strongly reduced the diversity. The consistency in the interviews between how teachers described their practices and how they motivated them, also from their development as a teacher, may have supported the validity of the interviews.

The cases of the 13 interviewed teachers were analyzed (mainly qualitatively), with descriptions of curriculum intentions used for coding. Refining the descriptions in the codebooks when going back and forth between the transcripts, and corroborating them in the procedure of intercoder agreement, was primarily meant to strengthen the validity of the analyses. But this method also allows the codes to be applied to new cases in which curriculum intentions are studied. Thus, this method can contribute to analytical generalization of the results (Yin, 2009). The quotations and paraphrases presented in Chapter 5 may help researchers who study similar cases to link to their cases.

In a tentative part of this substudy, I asked, in some classes of some interviewed teachers, students to fill out a 10 minutes survey, based on a questionnaire used by De Putter-Smits (2012) and designed as a form of triangulation, to examine the correspondence between what teachers express as curriculum intentions and what students experience from their teacher's teaching. Even within the limits of the trial, such as its administration in only one or two classes per teacher and without a further check on the students' interpretations of the terminology, it turned out to be too time consuming. Consequently, it was not expanded to become a full part of Substudy 2.

Van Driel et al. (2001, pp. 145-146) warn that “studies focusing on the actual implementation of constructivist approaches in classroom practice . . . have revealed that although teachers may express cognitions about the teaching and learning of science which are consistent with constructivist ideas, their actual classroom behavior may be more or less ‘traditional.’” This warning may also apply to the consistency of what teachers in this study say they do and their actual practice. The *goal system* interview approach, which Westbroek et al. (2017) described in their search for a teacher’s goal system, seemed an adequate approach to reduce the risk pointed out by Van Driel et al.. The *goal system* interview approach inspired me to structure the teacher interviews in a similar way, by asking the interviewees to first describe their practices, in their own words, and only then go into the “why” of these practices, which could include their cognitions. To prepare the interviews with teachers for Substudy 2, I discussed and practiced, in the role of interviewee, this approach with two of the authors.

A reason to choose interviews with about a dozen teachers rather than questionnaires for several hundreds is in the possibility to go back and forth in *what* and *why* questions about their teaching, and to ask the interviewees what has influenced them in their practices and motives. This could not have been done in questionnaires with the depth possible in interviews.

Teacher interviews about influences

Another major advantage of interviewing teachers for Substudy 2 was that during the interview, the focus could shift to Substudy 3, into what influenced or had influenced the teachers in their practices. Again, questionnaires to hundreds of teachers about these influences would have yielded data from a larger group, but these would not have provided the possibility to link between answers, to zoom in, or to link back to “why”-answers to the other substudy’s questions.

For the substudy into influences, the cases of 13 teachers were analyzed (mainly qualitatively) with the help of codes which had initially been derived from the conceptual framework described in Chapter 2, visualized inside the dotted circle of Figure 8.2. These codes and their descriptions in the codebooks were also refined when going back and forth between the transcripts, and were corroborated in the procedure of intercoder agreement. Like with the curriculum intentions codebook, this method was primarily meant to strengthen the validity of the analyses but it also allows that the codes are applied to new cases in which influencing factors in teacher profiles and environments are studied. Thus, this method, supported by the quotations and paraphrases presented in Chapter 6, can also help researchers who study similar cases to link to their cases, and thus contribute to finding which of the results can be generalized.

Publications, participants, and witnesses from the period studied

For Substudy 4, sources of data were interviews and discussion reports from participants in and witnesses to the renewals, and written publications. The analysis of textbooks from different years might have added indications of influences on teacher environments over the decades; but, as reported in Chapter 7, a study by Ververs (2016) into the Mechanics sections in subsequent editions of four textbooks showed that most of the results were not sufficiently unambiguous to be trusted as characterizing the textbooks as a whole. Similarly, CE tasks could have been analyzed, or the reports of WND teacher conferences. Tentative attempts to do this showed that these analyses and validations were too time-consuming to do them properly within the possibilities for this study. They would have gone at the cost of the opportunity to interview participants and witnesses; I chose to prefer that opportunity.

For this substudy into indirectly influencing factors, the written sources and interviews were analyzed (qualitatively) with the help of codes which emerged from the texts and interviews and were organized in categories as visualized in Figure 8.2, outside the dotted circle and as sources of intentions from practice and from outside. These codes were also corroborated in a procedure of intercoder agreement. As with the other substudies, this method allows that the codes are applied to new cases in which factors are studied that may be influencing teacher profiles and environments. Thus, this method, supported by the references and paraphrases presented in Chapter 7, can also help to find which of the results can be generalized.

8.4 Implications

This section describes possible implications of the findings from this study. Some of these implications apply to particular curriculum intentions, though most of them are more general. They are described for the various roles actors may take. The first subsection below describes those roles.

Different roles: developers, teachers, facilitators, coordinators

This study distinguished various roles in which actors can operate. Actors, either individuals or organizations, can have more than one of these roles at the same time. One role is that of *developers*: individuals or groups of individuals involved in the development of a written curriculum at a national scale, which is meant to get shape in the practices of all teachers of the target group. They are, for example, members of a curriculum reform commission, pilot teachers in a project, or authors of sample teaching materials. Their backgrounds can vary from higher education professors, school teachers, science education researchers, and teacher educators to physicists from universities or industry. The term *teachers* refers to the role of teaching one's own students and developing lessons and assessment practices for one's own classes. In their possible role as developers on a national scale, teachers are included in the term *developers*. Developers and teachers can be visualized as the actors in the left-most, resp. right-most "clouds" in Figure 8.1, while their curriculum intentions are expressed in respectively the written and enacted curricula.

This study's findings may also be relevant for *facilitators*. In this role, someone, whether planned or not, may facilitate the propagation of curriculum intentions between teachers and developers. Facilitators can be, for example, syllabus authors, exam task constructors, textbook authors, teacher educators, or providers of professional development facilities. The role of facilitator can be visualized in the arrows in Figure 8.1. Facilitators are, as actors, included in the term *influencing factors*, used for the conceptual model guiding the analyses of Substudies 3 and 4.

A fourth role, next to developers, facilitators, and teachers, is that of *coordinators*, individuals or organizations who oversee and bridge the various other roles. Coordinators are not drawn in Figure 8.1, but can be imagined as observing the figure and activating actors in the other roles and their connections. They are knowledgeable about the issues from practices, policy, and research (Van den Akker et al., 2012). The role of coordinator, which can also be combined with other roles, can be relevant for a particular curriculum change or for a more general system for watching over the connection between written and enacted curricula, in both directions. It may include *dovetailing* the contributions of the various actors in their own responsibilities (Nieveen & Kuiper, 2021), or optimizing the whole of those contributions by *nimble network governance (*Hooge, 2017). A Ministry of Education can take on such a role, but so can an expert organization such as, in the Netherlands, SLO. Or, for a particular subject field, a university-based research group or a teacher association.

General recommendations applicable to all roles

First, implications that emerge as most comprehensive will be described, in terms of recommendations. After that, some more specific implications will be described for each of the roles distinguished.

Foster the increase of infection chances

In the metaphor of this study, many implications of this study boil down to fostering the increase of infection chances, in which curriculum intentions are seen as the memes, traveling between written and enacted curricula (Fig. 8.1) in both directions, whose infection chances are to be stimulated in accordance with the roles described. Whether the infecting intentions are benign or malign for the quality of curricula was not examined in this study, the word *success* was used only for matching intentions between written and implemented curricula.

Infections with curriculum intentions, as memes, appear in the analyses of this study as exchange of knowledge and values. Knowledge appeared about subject matter, theories of knowledge and learning, teaching approaches, experiences of teachers; it was expressed in the beliefs of teachers. Values appeared about what should be key content of physics education and about what the role of the teachers should be. As vectors of such knowledge and values, interviewed teachers and renewal participants, as well as written sources of data for Substudy 4, referred to a variety of “biotic and abiotic” elements in their environment. Such vectors are scientific publications, project documentation, written curricula from diverse countries, teaching materials, teacher educators, previous or current colleagues in school or other teams, or students who gave feedback.

Results show that facilitators can support the propagation of particular curriculum intentions between written and enacted curricula, so that what is expressed in either side can influence the other side. They also show that facilitators can support this propagation regardless of any particular curriculum intention. This distinction is in line with the distinction between intended influences (the category of *improving or creating circumstances favoring curriculum intentions*, used for the analysis of Substudy 4) and unintended influences (*survival and propagation of curriculum intentions*).

Support a variety of expressions with clarity about key ideas

The analyses showed that whether in written curricula or in interviews with teachers about their enacted curricula, curriculum intentions were rarely expressed in a way that met *all* descriptors of these intentions. But there was a sufficient fit at the level of key features from the descriptions. A recommendation to developers is to develop written curricula that offer clarity about key ideas (Fullan, 2007) and that support expressions in enacted curricula that may deviate from the developers' sample elaborations without getting detached from the core of the original curriculum intentions. This recommendation is consistent with what other authors recommend, as room for *adaptation* or *transformation* by teachers of developers' proposals or of mandatory curricula (McLaughlin, 1976; Fullan & Pomfret, 1977; Westbroek et al., 2017; Ogborn, 2002). Some recommend mutual adaptation in the course of collaborative design processes (Snyder et al., 1992).

The results to which the implications refer confirm recommendations by Fullan (2007, 2008) to establish professional learning communities and by Kuiper (2009; also in Kuiper et al., 2013), to support curriculum practices at school and classroom level with and within national frameworks, room to elaborate site-specific interpretations, and "support from aside," which refers to the role of facilitators. Some of the implications show that facilitators have to dovetail with fellow facilitators, as noted by Nieveen and Kuiper (2021).

Offer safety, support, room for local curricular initiatives, and guidance in concerted action

The results of the study show that the combination of safety, provided by the school or the examination system and by sufficient time, and the availability of material and immaterial resources is recommended as giving teachers room to be innovative, whether they look for forms to enact new elements from written curricula or experiment in their classes following their own curiosity. That innovativeness appears to work, whether intendedly or not, in favor of the expression of some renewals' curriculum intentions with the teachers interviewed. The effectiveness of this combination may also be fostered by the trust, or "curricular space" (Nieveen & Kuiper, 2012), given to upper general secondary teachers in the Dutch education system, albeit in the constraints of the central examination dominated procedure for specifying and assessing curriculum content.

This recommendation is consistent with the development that Fullan (2007, p. 11) observes with approval as a “shift . . . from innovation to innovativeness.”

It is also consistent with the emphasis by Kuiper (2009), summarized by Kuiper et al. (2013, pp. 159-160), on the need for support from “at least three sources: to direction and pressure from the top, room for teachers taking initiatives from the bottom, and support provided from aside” to ensure sustainability of curriculum changes. An addition to Kuiper et al’s recommendation about “direction and pressure from the top” can be that “the top,” understood as national or school-based regulations, can also provide safety and thus mark out a space for experimentation. A key condition is that these regulations are not too detailed or overload the teachers with prescriptions. “[R]oom for teachers taking initiatives from the bottom” may also be interpreted as allowing teachers time for such initiatives, and offering them support in the meantime.

The recommendation is also consistent with Penuel’s (2019) plea for building a good infrastructure along with developing curriculum changes to support design-based research. Adding to Penuel, this study showed that such infrastructure also may support experiments and changes that were not part of the design from a particular design-based research project.

In the case of this study, it appears that teacher education and professional development are key elements of an innovative infrastructure. Van Veen et al. (2010) list and categorize features of effective forms of professional development.

Results also show that, through concerted action, facilitators and coordinators can support propagation of curriculum intentions not only for *particular* curriculum intentions, but also regardless of any particular intention. This distinction is related to the distinction between intended influences and unintended influences, as made in Substudy 4.

Support intended as well as unintended influences

In this study, teacher profiles and environments appeared to have been affected by *unintended* indirectly influencing factors, next to *intended* factors. As unintended factors, the influence of elements of *teacher education* not aimed at renewals’ curriculum intentions was shown, as well as *professional development provisions*, *written resources*, and *digital environments*. Intended factors were activities aimed at feeding these same provisions with content related to the favored curriculum intentions, and/or extending these provisions. A recommendation to coordinators and facilitators could be to safeguard a good quality of these provisions for (future) teachers. This recommendation may sound trivial because that safeguarding is part of their jobs, but the results of this study may be seen as an encouragement.

Safeguarding a good quality of these provisions for (future) teachers is not just important during and in the years immediately following renewals, but is also a good use of the time between renewals. As discussed in the subsection *Long time spans and short term evaluations* of Section 8.3, some curriculum intentions may need time to become expressed in enacted curricula. During that time, intended as well as unintended influences may work, and they can be supported by the provisions mentioned.

Coordinators and developers can also use these same provisions by feeding them with documentation about the curriculum intentions in renewals, including sample elaborations, and by promoting the involvement of people with experiences in renewals as staff in those provisions.

Allow expressions to develop as time goes by

The results of this study justified the conclusion that after 50 years, meaningful changes, part of which had not been found before, have apparently taken place in the lessons of at least the interviewed teachers. One example is the observation by Volman et al. (1995) that PLON's ambitions were too far-reaching to be adopted in teachers' practices, whereas this study showed, 25 years later, quite a good match between many of PLON's ambitions and today's enacted curricula. A recommendation to coordinators, developers, and facilitators is to accept that time is needed and to facilitate that it is used wisely by arranging the environment of teachers to also support delayed expression of curriculum intentions. For teachers, the recommendation is to take that time and to ask for those facilities. If, in the meantime, new insights should refute the desirability of a particular curriculum intention or a particular expression, this should, of course, be brought to the attention of those concerned and, if possible, supported by suggestions for alternative expressions in written and enacted curricula.

Specific implications for each of the four roles

In the following, some more specific implications will be described for each of the roles distinguished.

Implications for teachers

A general recommendation to teachers who are interested in reflecting on their practices, in influencing written curricula at national scale, or both, is to ask for the provisions mentioned in the following, addressed there to coordinators, developers, and facilitators. Such questions can be directed at school leaders, or have the form of an application for a research or development grant, or for participation in renewal as a pilot teacher or commission member. This study showed how some teachers took the curricular space (Nieveen & Kuiper, 2012) they had within the constraints of national and school regulations to experiment with curriculum emphases and teaching approaches, even if no additional provision like a grant or pilot hours was available. As examples in this study showed, several teachers benefited from professional development provisions, in regional networks in the national WND conference, or by attending the British ASE conference, for their professional development or for the development of their practices.

Collectively, teachers can strengthen the opportunities for such opportunities with the help of a teachers' association.

To influence developers, examples of which were shown in this study, teachers can get involved in discussions about vision documents and intermediate products of project teams and reform commissions, or they can join a project as a pilot teacher or commission member, and thus become a developer oneself, alongside their teaching practice.

Through such actions, teachers can contribute to the two-way traffic of memes between written and enacted curricula.

Implications for coordinators

The following possible implications emerge particularly for coordinators.

- To foster the increase of infection chances, coordinators can promote involvement from a variety of people in various roles at different stages of curriculum renewals. For example, this study showed that renewal projects that involved teachers in developing roles as authors and/or pilot teachers and brought them together with professional developers and researchers contributed to the professional quality of all participants and discussants, and to the building of networks. Thus, curriculum renewal projects can also, next to designing written curricula, lever professional development and network building opportunities (Hofman & Dijkstra, 2010; Huizinga et al., 2019; Westbroek et al., 2019). Similarly, research or development facilities for teachers, such as in professional learning communities or through grants, contributed not only to their products, but also to the professional development of participants, which became available in other roles. The *Dudoc* PhD projects[1] illustrate this effect in the case of this study. Many of those role changes seem to happen without needing coordination, but they may benefit from active support.
- To offer safety and support in concerted action by actors in the various roles described above, coordinators have a particular role because they can stimulate and help developers, facilitators, and teachers to collaborate.
- An important contribution to safety appeared to be avoiding curriculum overload. To avoid overload, coordinators would do well in providing actors in other roles with guidance on how to avoid it. Overload was a threat to renewal intentions, particularly to those that were not included in the CE part of exam programs. However, even if the influence of developers on the quantity of curriculum content is strong, it has its limits. While the NiNa commission had explicitly sought to avoid overloading, and had checked this in formative evaluations with pilot teachers during the project years, this remained a problem. A number of the pilot teachers had already reported that overload remained a threat, even though they appreciated all new elements of the exam program (Kuiper et al., 2011). A few years after the national implementation of the exam program, a study by Pieters et al. (2020), following the SLO-evaluation of the implementation of the new biology, chemistry, and physics programs (Ottevanger et al., 2018), showed that maximum elaborations of attainment

1 See www.nro.nl/onderzoeksprogrammas/dudoc-beta.

targets and syllabus specifications by textbook authors and by teachers also contributed to overload.

Implications for developers

The following possible implications emerge particularly for developers.

- Developers should inform themselves about trends in the development of the subject, of sensitive points, teachers' concerns, and zones of proximal development. This allows them to be infected by teachers' curriculum intentions and experiences with enacted curricula, and thus supports two-way infection chances between written and enacted curricula. This study showed how such information can come from evaluations of current teachers' practices; from discussions with teachers about vision documents, draft exam programs, and sample teaching materials; and, if possible, from formative evaluations through pilot lessons and with pilot materials. Information by teacher educators about the drives of teacher students may also be recommended as useful input for developers.
- The usefulness of evaluations of pilots that include a full central examination is clearly illustrated by the example of the NiNa pilot project, which ran from 2007 up until 2010, with 35 teachers. The pilot was evaluated by the commission itself (Commissie Vernieuwing Natuurkundeonderwijs havo/vwo, 2010) and by SLO (Kuiper et al, 2011). The evaluations showed how the reflections on experiences in pilot schools and with pilot exams had influenced the exam program, and provided recommendations about what should be taken into account to support all teachers and other actors after the national implementation of the exam program.
- By offering clarity about curriculum intentions, developers can help to keep piecemeal developments, intended and unintended, on track over a longer period of time. Earlier, the subsection *Long time spans and short term evaluations* discussed how this clarity may explain the relative success that aspired curriculum intentions had after a longer period of time, intentions that were initially considered too ambitious. This recommendation is consistent with Fullan's (2007) conclusion that clarity is essential, but that false clarity, due to oversimplification, is to be avoided. In this study, clarity about curriculum intentions as strategic benchmarks seems to have helped to keep piecemeal developments on track.
- By offering clarity about the *scope* of a proposed curriculum change (also recommended by Fullan, 2007), developers may contribute to teachers experiencing a feeling of safety and a feeling that their concerns have been taken into account. This study showed examples of how lack of clarity about the scope of a renewal caused unease and resistance.
- Developers do well to agree with the examination board and CE task constructors which skills will be tested in which way in the CE. This includes the skill to apply conceptual thinking to solving exam problems, and the skill to interpret a problem in a context by using concepts, even if this emphasis on skills and

the role of conceptual thinking in physics has consequences of a pedagogical nature: the 'what' of the curriculum cannot be detached from the 'how' (Kind, 1999). Both this study and the SLO evaluation of the implementation of the 2013 (NiNa) program (Ottevanger et al., 2018) and of the following central exams for *havo* and *vwo* (Michels et al., 2018; Woldhuis & Paus, 2018) show how exam tasks that assess conceptual thinking, rather than only assessing 'the math' of a problem, can foster the curriculum intention *Advancing concept development*, which in itself might be regarded to be of a pedagogical nature. Similarly, developers can stimulate ways to include assessing skills, for instance, by other forms of examination than pen-and-paper only.

- Another strategy for developers to support skill assessment opportunities is to expand the space and weight of the SE domain, and to protect it from a status as resource for solving the problems caused by CE domain overload.
- Avoid overload in attainment targets, sample teaching materials, and other written curricula. This includes avoiding fragmentation of subject matter by adding domains, compensated by reducing the number of concepts per domain: to learn to use a concept, students may be helped by using other concepts from the same conceptual network (Pieters et al., 2020).

Implications for facilitators

As stated above, facilitators can contribute to the propagation of specific curriculum intentions, for example, those of a recent renewal, but also regardless of any specific intention.

Implications for improving or creating circumstances favoring specific curriculum intentions

In this subsection, possible implications for facilitators are described that may favor specific curriculum intentions by improving or creating circumstances.

- Let facilitators provide (future) teachers with proven theories as well as with resources that can be already applied in their next class. Thus, (future) teachers are informed about the sources from which innovations also draw. Supporting teacher educators with professional development dedicated to recent written curricula and their intentions may be added to that. This recommendation is supported by the result of this study that teacher education and professional development provisions appeared strikingly influential on teachers' profiles and environments, and thus on the possibility of curriculum intentions to be expressed in enacted curricula. For the cases in which those factors were influential, the combination of "great names and small tools" seemed effective.
- Show the synergy between the curriculum intentions *Advancing concept development*, attention for the *nature of science* (*Knowledge development in science*), and *Using contexts* to teachers because this may strengthen the position of each intention. In this study, teachers appeared susceptible to *Advancing concept development*; its expression appeared to be supported by influences from both the *teacher's profile* and the *teacher's environment*

categories. This curriculum intention links the desire to increase students' performances in the exams with attention for the *nature of science* and *Using contexts*.

- Attention for the history and philosophy of science, in particular the nature of physics, deserves a place in the curriculum of teacher education and professional development. The results discussed in Section 8.3 under the heading *Attention for the nature of science key element in some teachers' profiles*, showed that a significant part of the teachers interviewed refer to their interest in the nature of physics, or other elements of the history and philosophy of science, as underpinning the expression of *Using contexts*, *Widening the scope of science education*, *Advancing concept development*, or *Advancing skills development* in their practices. Moreover, most of these teachers explained how this interest had been raised or confirmed by teacher educators or in professional development.
- Pay attention to rationales that help select and organize curriculum content. This recommendation is related to the previous one, about attention for the history and philosophy of science. Teachers from Dutch primary and secondary education who worked in development teams on the design of a framework for the whole curriculum[2] in 2018 and 2019 appeared to need, and use, such rationales to structure their thought processes and designs. Such rationales can also be part of teacher education and professional development curricula, to serve the kind of interests referred to above. For science education, including physics, rationales can be found in the *Principles and big ideas of science education* (Harlen, 2010) or the *Next Generation Science Standards* (*NGSS*, National Research Council, 2012). The Dutch *Knowledge base of natural sciences and technology for lower secondary education* (Ottevanger et al., 2014), inspired by the NGSS, can also offer a rationale, including a reasoned, meaningful structuring of goals and content, for upper secondary physics education. Yet another rationale for selecting and ordering goals and content can be the broader (than science education only) *Perspective based approach*, formulated to select and organize curriculum content by Janssen et al. (2019), which Logman and Van Bemmel (2019) applied to the subject of physics.
- Provide a wide choice of good quality written and digital resources, professional development provisions, and facilities to visit research institutes and companies. Results of this study indicated that, guided by their values and beliefs, teachers draw on the variety of resources in their material and structural environment. To influence teachers in a way that may favor the expressions of specific curriculum intentions, "educative curriculum materials" (Davis & Krajcik, 2005) can be included in the collection of resources, i.e., curriculum materials that not only promote student learning, but also support teacher learning in a certain field in the context of and as part of a curriculum renewal. Davis and Krajcik (2005), building on Ball and Cohen (1996), developed design heuristics for such educative curriculum materials. To enhance the quality of resources in

2 https://www.curriculum.nu

general, the designers of resources should also be professionalized. McKenney and Schunn (2018, p. 1091) recommend that researchers help designers of resources to "optimise key product characteristics which inherently involve opposing tensions," such as comprehensiveness, flexibility, and practicality; and that researchers provide knowledge for designed products as well as for design processes.

- Special attention is needed for curriculum intentions which, like *Coordinating with other STEM subjects*, need support at school level. This study showed that without such support, even well elaborated cross-cutting domains of attainment targets like Medical Imaging or Biophysics may still remain enacted without connections to other subjects than physics. And for a CE domain like Medical Imaging, central exam questions that, for good reasons, only go into the physics aspects of the matter, confirm this mono-disciplinary approach.
- Construct exam tasks that assess cross-disciplinary issues, if *Coordinating with other STEM subjects* is part of the written curriculum to be facilitated. Data in this study did not show how the enactment of cross-cutting issues in teachers' practices would have benefited from cross-cutting central exams, because all of these exams were subject specific. In the Netherlands, a recommendation to offer CE tasks which combine assessment of physical and biological knowledge would collide with the limits of the system because only part of the students who chose physics as part of their profile also chose biology. For exam tasks that cross the borders between physics and chemistry exam programs, or of physics and mathematics, such limitations would not exist.

Implications for improving or creating circumstances regardless of any specific curriculum intention

In this subsection, possible implications for facilitators are described that may favor curriculum intentions by improving or creating circumstances regardless of any specific curriculum intention.

- Secure the position of the school exam against the pressure of the high-stakes central exam. The SE part of the exam program offers room to teachers to elaborate their own focuses in curriculum intentions and teaching approaches. The results of this study show that this room is limited by the need teachers feel to meet at least the requirements of the CE, and their tendency to treat the SE related activities as an adjusting post.
- Create possibilities for teachers to choose a central exam that may, like their school based exam, match their preferred focus. Results indicated that for teachers who want to experiment with an enacted curriculum of a different focus, similar to teachers who participate in an experiment on larger scale, the possibility of not only working with so-called educative materials (Ball & Cohen, 1996; Davis & Krajcik, 2005) but also of choosing a central exam from a few options to match the teachers' focus, increases their safety and willingness to try out new practices. A system like in England where teachers can choose from a few elaborations of the attainment targets into different exams and matching textbooks may also offer such safety. It implies that in the Dutch

context, this would include a possibility for teachers to choose from various syllabuses, with matching textbooks and central exams, all based on the national exam program. This recommendation is supported, even if on a small scale, by experiences *within* renewal projects in which pilot teachers could work in "safe conditions": they could work with dedicated teaching materials and their students were assessed with dedicated exams. Within the context of this study, the HBB and VBB projects (in which PLON and several universities participated) and NiNa are such projects. These projects offered occasions for *mutual adaptation* (Snyder et al., 1992; Fullan, 2007) of written and enacted curricula by developers and teachers.

- A well disclosed repertory, of relevant (international) research and project evaluation findings, of project publications showing options for new subject matter or teaching approaches, of experiences of teachers, and of matching sample materials has to be available for actors in all roles. This study showed the effectiveness of such disclosure. In the 1970s and 1980s, disclosure only took the classical routes through scientific and project publications and personal contacts. These routes are still effective today and can be supplemented by digital facilities. In the Netherlands, interfaces such as those offered by natuurkunde.nl[3] for physics, ECENT/ELWieR[4] for the STEM subjects, and SLO's subject portals[5] or Kennisrotonde[6] in general can contribute to this disclosure. In the UK, the *Education Endowment Foundation*[7] offers an inspiring example.
- This study showed how grants can support research work on specific curriculum intentions, even if only offered without such specificity. Some of the interviewed teachers had applied for a grant to support further investigation of their own questions, for instance, into inquiry based learning or the quality of students' research activities. The Dudoc program has already been mentioned; the *Lerarenontwikkelfonds* (*Teachers' Development Fund*)[8] is another good example, also used by one of the interviewed teachers. It implies that continuation of research grants for teachers is recommended.
- Schools are recommended to support experimenting teachers. This study showed that several teachers also try out possible improvements of their teaching without the help of a grant. Facilities offered by their school or moral support also appeared in this study as an encouragement for those teachers. Other facilitating agencies are recommended to help schools in their turn, for example by providing support for the development of curricular leadership of team leaders and school leaders, as well as of teachers' curriculum development competencies.

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3 www.natuurkunde.nl
4 elbd.sites.uu.nl
5 www.slo.nl/vakportalen, for the science subjects: www.slo.nl/vakportalen/vakportaal-mens-natuur
6 www.kennisrotonde.nl
7 educationendowmentfoundation.org.uk/guidance-for-teachers, for science: educationendowmentfoundation.org.uk/guidance-for-teachers/science
8 www.lerarenontwikkelfonds.nl

- Professional development networks like the national WND physics teachers conference[9] and regional networks[10] should be promoted and sustained, offering professional development provisions to teachers and increasing connections between secondary and higher education teachers. This study showed the use that teachers made of such provisions.
- The combination of trials by teachers who experiment in small steps with professional development provisions of any scale is recommended. Schön (1983) described this combination as a *reflective practitioner.* In this study, examples of this combination appeared to allow teacher development and curriculum development at the same time (Huizinga et al. 2019; Westbroek et al., 2019). Facilitators can, indeed, facilitate these reflective practices by offering teachers, developers, and other actors the occasions described above.

8.5 Unanswered and new questions

Along with answers to the main research question and the substudies' research questions, some new interesting questions came up during the data collection and analyses, which can not be answered without further research.

Some of these questions relate to the choice of zoom level. The choice for Substudies 2 and 3 to focus on interviews with about a dozen teachers was argued in Section 8.3, under *Choice of methods*. This study raises curiosity into what would have been found in a more zoomed-out setting, with several hundred teachers involved in a survey study, and/or in a more zoomed-in setting, with a smaller number of teachers involved in observations in their classes, combined with interviews with themselves and their students, colleagues, and school leaders. The main and subordinate research questions, the conceptual framework, and the codebooks used for the analysis of data of this study can, together with its results, be used as input for such studies with different zoom levels.

These elements can also be useful as input for the studies into aspects of this study that may go beyond the particularities of its case.

Similar exploratory studies into chemistry, biology, or mathematics education would probably tell different stories, but might yield similar conclusions. A comparison with the developments in teaching chemistry would be interesting in particular, as the renewal teams for both chemistry and physics in the 1970s and 1980s had clear strategies, but these diverged quite a lot: the chemists (the *CMLS-project*) opted for smaller steps than the physicists, to quickly reach consent with a large group of teachers, whereas PLON opted for more ambitious intentions, even if it would take more time for those intentions to be adopted by many teachers, taking the chance that the expression of the intentions would be different from what the developers had in mind. In the period 2004-2010, commissions for both subjects worked in parallel, and with commissions for other STEM subjects as well,

9 https://wndconferentie.nl
10 www.vohonetwerken.nl

so a comparison of teachers' enacted curricula between those subjects, in addition to a comparison of strategies during the decades would offer an interesting check on the generalizability of conclusions drawn for this study. It would be interesting to use this comparison to know more about the question of whether "piecemeal engineering" of written curricula and teachers' practices, by small adjustments and readjustments, or "incremental changes" (Wyse et al., 2015, p. 24) can be a way of design-and-upscaling that automatically includes the patience and tolerance of an evolution-with-some-design approach.

Another variation on the case is to study curriculum intentions and influences on teachers in lower secondary (physics) education, where teachers generally have a different balance between their attachment to the subject community and the school than upper secondary teachers. Also, educational goals in the Netherlands are less detailed and prescriptive for lower secondary education than the attainment targets and syllabus specifications of upper secondary education.

Yet another variation of the case is to look at upper secondary (physics) education in a country or jurisdiction without a central exam system. As the CE system appears as a self-evident basis for the enacted curriculum of Dutch teachers, it would be interesting to see how influences like in Figures 8.2 and 8.3 would differ from the Dutch case. Sample teaching materials might perhaps have a more dominant role.

A starting point for follow-up research about the curriculum intention *Coordinating with other STEM subjects* may be the role of the cross-cutting school research project (*profielwerkstuk*), as an element of the school exam. It has been part of the *teacher's environment* of upper secondary teachers since 1998. In some of the interviews for Substudy 4, this project appeared as having influenced cooperation between teachers from different subjects, and some teachers interviewed for Substudies 2 and 3 indicated that their schools had established cross-cutting learning trajectories for research skills – the rare occasions that supported the curriculum intention *Coordinating with other STEM subjects*. I add to that a personal conversation with a school leader who told me that he had hardly seen any change in the education system influencing teachers so much as the school research project, because now the *students* came up with research questions, sometimes into new topical areas of a discipline or into interdisciplinary fields, that the teachers did not want to refuse. An evaluation of how the school research project may have affected the expression of *Coordinating with other STEM subjects* in enacted curricula, and what the choices of students and of the status of school exams may have contributed would be useful. It would also be useful to examine which characteristics of the school research project could be used in other parts of the curriculum that are assessed in the school examination.

Another angle for follow-up research may be found in the effects of social developments, such as the Cold War from the 1950s on, and the need for more scientist and technicians in the 2000s, on the curriculum intentions that were promoted (*Using contexts*, *Advancing concept development*, more stress on *Science, technology and society*). Given the influence of social developments, one might presume that the current increase in fake news, and the degrading in social media of scientific knowledge as "just an opinion," would increase attention for the curriculum emphasis *Knowledge development in science* in written and enacted curricula. An investigation into this presumption may also act as a check on the generalizability of conclusions in this study about the influence of developments in society on curricula.

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Appendices

Appendix 1 Portraits of the interviewed teachers

The following descriptions of the teachers interviewed for the Substudies 2 and 3 are based on the forms they had previously completed and from the interviews. When necessary, I emailed some of the interviewed teachers for additional information, or made use of sources on the web, such as LinkedIn and www.lerarenontwikkelfonds.nl.

Ages and similar indications apply to the day of the interview. Characteristics that might harm the anonymity of the participants have been omitted. After e-mail correspondence, all participants have given their agreement for publication of their portrait in this report as shown below. Some adjusted the text, but the content remained consistent with the situation at the time of the interview.

The portraits show a great diversity in the group selected for this study and support the notion that *the* physics teacher does not exist.

A

A is 59 years old and has been a teacher for 28 years. A entered secondary education teaching after a long study in astronomy, physics, philosophy of physics and teacher education, and a few years of teaching physics in adult education.

A's study history illustrates an interest in existential questions. During teacher education, a supervisor advised *Project Physics* as an orientation, A then bought the project's textbooks. The renewal projects from the 1970s and 1980s had been inspired by *Project Physics*. A knows these projects and has some of their materials, but hardly ever used them in the classroom, unlike *Project Physics,* which is a source of inspiration to this day, in particular for the historical line of physics education.

A stresses that there are multiple ways of understanding phenomena. One is the regular, and legitimate, way of looking at things that most scientists use: as an unattached observer. For that purpose, A has the students spend a lot of time observing and experiencing phenomena and asks them to come up with explanatory models. Students must learn to distinguish a phenomenon from a model. A works toward the standard models of physics but wants students to realize that historically, phenomena have been explained with other models. The topic of light, for example, is used to show that there have been several theories of observation as alternative ways of understanding the same reality. In A's own words: "Abstraction . . . is important because it allows you to distance yourself from the phenomena.… They have to learn, by abstracting, to look at phenomena in a different way." A adds another way of understanding to this, as practiced in A's school, a Waldorf school. In the interview, A had mentioned it a few times without elaborating much on it, but in response to the draft of this portrait, sent for accordance, A emphasizes that this other way of understanding means "a more intuitive way, in which we not only observe, but seek to participate in and relate to the phenomena. That is building a relationship with the phenomena and ask questions like 'What does this phenomenon tell me about myself, about reality, about life?' . . . In asking those questions we in Waldorf education believe that it gives a human being a richer understanding of reality and a more balanced capability of judgement and making choices."

Part of A's lessons are given in periods with daily physics lessons. These are used in particular for the orientation on phenomena and models in one of the physics domains. The remainder of the lessons, between these periods, is used for exercises that fit the regular curriculum.

B

B is 44 years old and has been a physics teacher for 12 years. After a master study in applied physics, B worked in the business sector, then switched to teaching after a year of teacher education. Initially, B learned the teaching profession just by staying one hour ahead of the students and by trying more every year – the time in teacher education had not given B much. After a few years, the school supported B's participation in a professional learning community (PLC), for about 100 hours a year. Again a few years later, B was awarded a scholarship for developing a method, which covers 25% of a full-time job. The PLC provided an opportunity to study inquiry-based learning (IBL), in the participants' own practices and with the support of scientific literature and lecturers. The importance of finding out things yourself, an element of IBL, is supported by B's personal experience, for example with computer programming, which B learned without being taught. Only in B's final year of high school did *student* B discover that all pieces of physics are connected in a larger frame. *Teacher* B now wants students to experience this connectedness earlier than in the final year.

When a lesson series about a new topic starts, B introduces the basics that are just enough to get started. Then B gives assignments that allow students to discover the complete theory and coherence for themselves. B has a collection of self-developed assignments for the various topics. Finding the right balance is challenging, "how far can you go in making them figure it out for themselves and to what extent should you spell it out for them in advance?"

Having students puzzle things out and find connections appear as strong themes for this teacher, as does increasing students' involvement. B involves students by making them work in small groups on realistic problems, like estimating the force needed for a good penalty kick. Groups with different tasks of this kind discuss their projects through poster presentations and may discover that in spite of the diversity in problems, they all use the same regularity, in this case Newton's laws – or rather "*called* Newton's laws," because the regularities are more significant than their names, B notes, criticizing the textbook.

B wants students to become flexible in using connections or patterns learned in one context in another context and uses the term 'transfer' several times. B believes that working on realistic problems helps in this transfer.

For B, connecting physics models with reality not only serves the involvement of students, but is also part of physics itself. If possible, B keeps experimental setups at hand to show the phenomena for students with questions.

B spends a lot of time in developing and using own teaching materials. “I could make my lessons more time-efficient and effective by not doing all this, and instead giving classroom instruction, having assignments made, discussing an assignment in the next lesson, further instruction . . . (but I would) lose involvement for myself.”

C

C is 55 years old and has been a teacher for 24 years. C has a PhD in physics but chose to change careers and did a teacher education course. C has worked a few years in Africa before starting in the current job.

C’s goal as a teacher is to help students gain insight in how the world works, “the skills to see it.” The ideal is that they know so much about physics or a particular content domain that they start finding it simple. C acknowledges that some students need more detailed guidance and practice but tries to keep students from drowning in details, which textbooks often do.

For C, a teacher’s task is also to make physics lessons attractive to students, for example through contexts, experiments, or site visits. C thinks that technical automation should have been a school subject, given its relevance and the interest of many students, and therefore makes more room for it than strictly demanded by the formal physics program.

The basic structure of much of C’s approach is to offer instruction through video clips in EDpuzzle, a student response system, which students start practicing at home. During the lessons, C goes around while students continue working from EDpuzzle and from the textbook. At the request of the students, the vwo classes work mostly independently, while C walks around, checks what students write down in notebooks or in EDpuzzle and gives support when needed. The havo classes need more help, which C offers for example by checking the EDpuzzle responses in advance, identifying the problems that students have and discussing these in a plenary setting. For that level, C is now considering a different textbook that offers more guidance.

C is a member of a professional learning community and takes ideas from it: “You hear things that other people do, and you get a little inspired.” Many ideas, too, were taken from the UK, C visited the ASE conference a few times.

D

D is 31 years old, has been a physics teacher for nine years and started teaching after a physics study. D is a member of a professional learning community and is conducting a PhD study into the didactics of practicals.

Outstanding sources of inspiration are D's father, D's physics teacher, and D's teacher educator. A key value, strongly connected to D's father: "I am responsible for my own performance, no one else. . . . An important point in my development is being able and daring to experiment. Reflect on it, keep what's good and watch what doesn't work as expected." The teacher educator stimulated D in this reflective attitude.

For D, an important goal is to make clear to students that we can describe the world around us with models and that if we know how to do that, we can benefit from it in our personal life and in future jobs. Raising students' interest is an important goal; contexts are used for that, as well as varying working methods, in particular by using demonstrations and practical work.

In the plenary conversations around new theory, students are challenged to give their own explanations and definitions of demonstrated phenomena. However, D makes sure that in the end they do have the correct definitions. D uses contexts for connecting new matter to prior knowledge, as part of concept development, along with showing the relevance of the content. Still, D is careful about students' interest in contexts that the teacher has picked as probably motivating.

D reserves a lot of time for design activities, because students have to use all physics knowledge available to them to make something useful, for example a thermostat. Thus, design activities help concept development, and at the same time show the relevance of the content.

In planning the curriculum, D works from the final requirements: "What is a logical structure for me and for the students to get there?" The lesson series are organized in a structured way: "The repetition in sequence contributes to this: introduction, explanation and definitions, practice, application, introduction . . . each exercise is a kind of formative assessment."

E

E is 31 years old and has been a teacher for six years. E studied technology and did an additional course in philosophy. During an internship in Asia, dedicated to sustainable technology, E taught science lessons to village children as a side activity. Back in the Netherlands, E took the course for physics teacher education and started teaching at the same time. The video lectures by Richard Feynman and by Walter Lewin have always been sources of inspiration. Colleagues in school were important too, where E could observe various approaches. The supervisor in the teacher education course had an inspiring focus on how you discover things together with students.

E has developed the insight that philosophy and education are connected. In both, knowledge development is the key theme, a deeper layer of physics than "knowing how things work."

Much of what E explains about activities and motives circles around a strong vision on the nature of knowledge: science is being curious; making errors is part of the game (even Einstein was sometimes wrong); physics-based technology is everywhere, we rely on it constantly; physics works with models, as approximations of reality. Understanding (in Dutch: *begrijpen*) is not the goal of physics, "real understanding is very difficult, learning how to tackle (*aanpakken*) something to solve a certain kind of problem says it better." This view also explains E' cautious reaction to a question about concept development: "Concept development involves all kinds of concepts that you should know, of course there are terms in physics. You just have to know them. I can't change much about that."

Contexts are important to show the relevance of physics and technology, which is even a matter of citizenship education, but also to make students experience the approximating nature of physics, when going from the context to the model.

E starts a lesson, after a welcome, with telling or showing something, like a video clip, that makes a connection between what students already know and the theory on the agenda, or between physics and the real world. Then E asks what problems there are with previously covered material, and discusses it again, unless only a few students have a problem, in which case they are helped individually later. New content will be discussed in plenary for a maximum of 20 minutes. Then, while students are working, the teacher walks around to see their approach. Over the course of a topic, E wants to have seen the approach of every student, "over a period of ten weeks I have a good picture of all students about how they have the structure (of the topic) in their heads."

F

F is 63 years old and has been a teacher for 16 years. F has a PhD in physics and worked for a university and research organizations. After that, F followed a training for second career teachers. The course, for a mixed population, did not really offer science education theory, but during the teaching internships, F could observe lessons and reflect on physics education questions with the supervisor. Alongside physics teaching, F has experience from a previous school in teaching the subject Nature, Life and Technology and in tutoring university students. F assisted in authoring teaching materials by discussing the content but does not regard that as authorship.

A major task that F stresses in activities and intentions is to take students to the national exam. F trains students on how to best prepare for the exams, models test papers on national exam tasks and makes sure that only national exam content is worked on in the final year.

F pays attention to contexts, for example through excursions or demonstrations, to show physics research practices and relevance for professions, in particular medical professions. F does not favor using contexts for concept development, as they may hinder seeing the conceptual structure of physics.

The organization of F’s lessons follows the school default of a division in college hours (70 minutes) and guidance hours (70 minutes). Fostering independent working plays an important role. During college hours, F explains new subject matter in front of the classroom, preferably limited to 40 minutes. The remaining college time is reserved for a short experiment, a demonstration, a video clip. Guidance lessons are used for working on assignments, including practical work. In addition, guidance in those hours can be offered by another teacher or a technical assistant. Research skills are trained in particular in practical assignment periods planned through the years. F regrets being short of time to offer guidance on design activities, apart from incidental school exam design projects.

G

G is 53 years old and has been a physics teacher for eight years. G studied physics and business administration and worked in business as a consultant. G was drawn to a career in education through experiences with G’s own children in various education systems and took a course to qualify for physics teaching up to secondary school exam level. An influential author has been Chris Argyris, especially his work on miscommunications between people. This leads G to put more effort in exploring the actual thought processes of students and to adapt the way to work with them. G feels more like a consultant than a teacher, as the motivation to work in education focuses on contributing to effective learning processes in the school system as a whole, for which the lessons in G’s own classroom and school provide experiences and allow experimenting. G sees many similarities between processes in business and in education: the importance of a systemic approach, of the role of emotions and self-confidence, and of learning opportunities for work satisfaction.

For G, studying physics is essentially a training in modeling. In addition to just teaching students to explain the world around them, physics education trains analytical skills: finding patterns, and working with ever-increasing abstract representations of reality in your head. It is also part of citizenship education: being able to critically read an investigation and to assess experimental data relevant to issues in society. G’s role as a teacher is first and foremost focused on building confidence, “Only someone with self-confidence can fully use his abilities and is open to new knowledge and insights. Confirmation, confirmation, confirmation.” G feels confirmed in this philosophy and activities by above-average results from G’s students in national exams.

To prepare the lessons, G composes PowerPoints with pictures. Meanwhile, G has made a repository of transparencies. A lesson on a new topic starts with an explanation. G sees this as a story, in which explanations have to be very clearly phrased, and for which a student needs time to let the words and reasoning sink in. “I look for fewer words and exactly the right ones.” Applets and small tasks are woven into the explanations. To make the lesson more interactive, G challenges students to discuss errors in applets, and prepares tasks that can be used for fast feedback.

The approach to covering a new topic is to start with a good look at the theory. G tells the students to make an overview of the topic before starting the exercises and to ask themselves what is applicable from the overview. G sees this as a way to gradually improve students' understanding and command of the theory. G encourages students not to make elaborate summaries, but instead to limit themselves to concise lists of vocabulary, formulas, and drawings. G believes that little is truly memorized during summarizing. "The goal is not to have a nice summary, but to build up a vocabulary."

H

H is 57 years old and has been a teacher for 24 years. While studying physics, H also followed the teacher education course, which inspired H's view on learning. However, experiences during the teaching internship were discouraging. After finishing the study, H worked for several years in developing computer aided education, until that job ended, and gave teaching another try. This time, the first school, a Montessori school, appeared to be a match and offered a most inspiring senior colleague, whom H quotes several times during the interview. Stimulated by this colleague and more recently also by PhD facilities, H developed inquiry and modeling activities for students. H does not deny some influence from renewal projects, DBK for differentiation, PLON for student-orientation and awareness of misconceptions ("I am a child of the eighties"), but the school and collegial experiences are much more influential. After finishing the PhD thesis, H also started work at a second school, where things have not yet settled as H would like.

A theory that inspires H is Russian learning psychology. H became acquainted with it due to a teacher education assignment, and it was an eyeopener in explaining H's experiences as a chess coach many years before. Referring to Galperin's concept of orientation base, H explains why an orientation on reality is key in science education. This is not the same as starting from a context, which may be selected because it is motivating, but can be unsuitable as an orientation base.

H's goals are to help students learn to make choices, to pass the exam, to develop problem-solving strategies and to gain an overview over the subject field.

H starts each sequence of lessons with an explicit planning activity, an exercise in making choices. H cannot describe a typical setup for how lessons progress after that, also because, in the new school, new routines still have to develop. In both of H's schools, in classes that need guidance, "culture requires that I do a lot with the group. I'll tell something, explain, pepper it with little demonstrations. Then the kids get started and I walk around and coach. The fast feedback method is my favorite way of working in those classes." In the Montessori school, where H has built up an own approach, students work with a practical file too, carrying out their experiments in the lab room, while H walks around and looks what is needed. Practical experiments, little demonstrations and exercises are all meant to build up the orientation base.

A few times a year, H gives students a goal free assignment: “These are your data, what can you discover with them?” Such an assignment stimulates students to activate all the physics knowledge they have so far acquired. H mentions the “Cognitive Load Theory” as an inspiration for these assignments.

J

J is 38 years old and has been a teacher for 16 years. J studied physics and noticed a preference for a career outside physics research. J asked a school for permission to observe in classrooms as a preparation for teacher education and was invited within two weeks for a job as a teacher of physics and of General Sciences. What attracted J to the profession is “conveying some content and interest in physics, and being in contact, seeing students grow up, helping them with stupid errors, giving confidence, motivation.”

During teacher education, J learned most from the internship’s host teacher, as a role model in making students think, rather than teaching physics facts. Later, a colleague from the first school involved J in a project for developing teaching materials about modeling. J discovered the importance of cooperating with physics colleagues from other schools, which in the end led to joining a professional learning community and author teams of teaching materials, in a renewal project and for a publisher. Writing textbooks changed J’s way of teaching and of planning the curriculum. In the PLC, J learned to work with fast feedback.

J’s ultimate goal is to make students ask questions and to think logically. There is a pragmatic motive: “At least half of the students will never use the pure physics knowledge of my lessons again, and those who do, will get everything again.” This puts other things in perspective too, like J’s acceptance of almost any particular physics topic prescribed in the curriculum, or STEM-coordination not being essential. Another goal is to train students for the exam, which requires explaining things in a straightforward way.

J does not name practical work in any other way than to train the skills necessary for the practical school exams. Modeling skills are the only skills that J mentions as something to promote, supported by the importance of thinking like a physicist.

J opens each lesson series with a question and spends a lot of preparation time on formulating the right question. Only after having answered that question, will the students get a new question. J picked up this idea of giving questions this structural role a year ago, a colleague mentioned it during an in-school workshop. The opening question is followed by an explanation of theory or by a demonstration. During the remaining time, students work on tasks that they find in a planner, prepared by the teacher for both classroom and homework. J then walks around, talks with the student groups, and may ask a group to share a problem or a solution centrally. In this phase, J uses the fast feedback approach too.

J does not follow the didactic structure of the textbook; the book serves as reference and source of exercises for the students.

K

K is 44 years old and has been a physics teacher for 13 years. After obtaining a master's degree in physics, K worked in business for about three years. From that job, K has learned the importance and the technique of planning and of quality management. After that, K combined a job in business on a part-time basis with post-Master teacher training to become a 1st grade physics teacher. K did development work for the subject Nature, Life and Technology (NLT) and, in school, for a STEM-wide learning line for research skills. K has learned a lot by observing other teachers in action, and by cooperating with fellow NLT teachers.

An important goal is that students learn to plan, from homework to a research project. Another prominent theme is the power of discussion in small groups, about subject matter and the problems that students are faced with. In K's conviction, discussion brings real understanding, much more than just completing series of tasks can do. Similarly, practical work stimulates students to reflect on the theory, more than written tasks.

K distinguishes two kinds of typical lessons. In type 1, K starts by walking around for a few minutes to find out what problems students have with the previous lesson or with homework. Then, 15 to 25 minutes are used for plenary teaching, concluded with assignments for the remaining time, in which students work individually or together. In type 2, the class is divided in two halves, unless it is a small class already. One half works on a research project of about eight lessons, supported by the technical assistant. Meanwhile, the other half, working in a circle with the teacher, discusses subject matter from the book, problems that students mention and ideas from other sources, like a movie on relativity theory. For the research projects, students propose a research question, which is checked by the teacher. Students write an action plan, with as much theory behind it as possible. After the teacher has approved that plan, they can reserve materials and start on their experiments. They conclude the project with a final report.

Next to those typical lessons, students in the final year often work on every topic they want, using a website with elaborated exam tasks, where K is available for support.

L

L is 34 years old, has been a physics teacher for nine years, after a physics study and teacher education. The current school is the second school; L teaches both physics and Nature, Life and Technology. For use in addition to the textbooks, L has developed presentation material for explanation purposes, insight questions and practicum instructions.

L is fascinated by nature: “I can still look at the starry sky with amazement. I can tell my six-year-old son: Look at that spot of light there, do you know how far away it is? 37 light years, the light you see now is older than me.” L admits that amazement is hard to express in a test, that there is a gap between fascination and everyday practice in education.

Another gap is between research skills that are important to learn and the stress that the school management puts on student results in the national exams and their comparison to national averages, “an annual phenomenon that gives you a little headache.”

In L’s view, physics is about the world around us, so students must learn to look and observe. Physics helps you find an explanation for what you see, why things work the way they work and how you can apply that in daily life. L also wants students to know that in history, people have changed explanations of certain phenomena at quite a few moments. And L wants students to experience that physics also is doing research, not just working out written tasks.

A typical lesson starts with retrieving what was done last time. Then, a selected homework task is discussed and analyzed in detail. L tries to find a pattern with the students for how to work out assignments. L promotes the SPA method with the students[1]: “Write everything down, check at the end. Is the significance correct? Is the final answer correct?” Language plays an important role as well: move from one step to another with if-then reasoning, keep the sentences running smoothly. The other homework assignments, with elaborations, can be found in the electronic learning environment. All this takes place in the first 15 minutes.

New topics are introduced with a short demonstration. The explanation, if possible including its historical background, is followed by a phase of students working in groups. Conceptual questions come first; math-like questions will follow later. Often, L writes a concept question on the board after a while and discusses it according to the peer instruction method. Students are stimulated to argue why they give a certain answer, the arguments help clarify misconceptions and foster qualitative thinking.

Another type of lessons is meant for practical work. Colleagues from all three sciences have developed a module for research skills, on how to conduct a research task. L finds it difficult to find the right balance in instruction for such tasks, “If you give them too little, they have no idea what to do and if you give them too much,

1 The Systematic Problem Analysis (SPA) method was originally developed by H. Kramers-Pals as a heuristic for solving chemistry problems. The Netherlands institute for curriculum development SLO has further developed it as a tool for students with reasoning exercises in the sciences.

they have no idea why they should do this." L emphasizes the students making a lab journal, it will give them a head start on college.

M

M is 58 years old and has been a physics teacher for 30 years, after a physics study concluded with environmental science and teacher education. M was impressed by some physics professors, by the way they could explain, the good stories they had. The teacher education period did not leave a strong impression. However, when M started as a teacher at a gymnasium (pre-university secondary school), a senior colleague impressed in the same way as the professors: he knew physics thoroughly and knew how to explain it to students. M attended this colleague's classes for two years.

M states on the intake form to have developed own teaching material; M does not refer to it at any time, neither in terms of use in the lesson, nor as an element in M's biography.

M acknowledges the importance of contexts, which make physics relevant for students, but contexts must be supported by thorough knowledge of physics. M compares physics to a building, a structure with rooms, "like the room with MRI or the room with musical instruments. Those rooms become extra beautiful when the structure is first applied." Still, compromises have to be made, like in the case of Medical Imaging, which M deals with prior to nuclear physics, with the risk of "discussing things in an irresponsible way." Musical instruments, on the other hand, appear in M's lessons after students have learned about waves and interference. M likes the modern and topical domains in the new physics curriculum since 2013. They challenge to study these topics and to design education about them.

M's lessons start with discussing theory, followed, ideally, by time for students to work on assignments. *Ideally*, because M is honest about the pitfall that the discussion takes up the whole lesson. M tries to involve students in the discussions, to get them to take a stand, argue their opinion, and then find a reason to change positions in response to the arguments. Eventually, M tells "how it is", hopefully in an insightful way. M likes this way to confront students with possible misconceptions.

Though there is a textbook, M mostly uses self-made teaching materials, collected from various textbooks and internet sources like demonstrations, videoclips, applets.

M regretfully admits that practicing skills is a neglected element and hopes that with the help of a new colleague, this part of education can be strengthened. "But the teacher gets away with that because . . . it is not tested in the central exam. There is nobody except my own conscience or a critical colleague who confronts me with this flaw, but I am not judged by the central exam, on the contrary."

N

N is 49 years old, has been a physics teacher for 22 years and started teaching after a teacher education bachelor and a physics and teacher education master including an internship in the United States.

N had good physics teachers in school, but learned more from the teacher educators: know your goal, go towards that goal in an improvising way, use humor, practice with a variety of learning lines. Theoretical support comes from Kolb's model and an in-school course in activating didactics and collaborative learning.

N starts each lesson with a video clip, max. 5 minutes, with a striking or surprising phenomenon, not necessarily connected to the theme of the lesson, but to show: this, too, is physics, and we may encounter it in the future. After that, N talks for max. 15 minutes, after which students start to work with written or practical tasks, while the teacher walks around, asks questions, sometimes in plenary, looks for and gives "feedback, feed forward and feed up." For N, the main goal is to make students think, "stimulate an investigative attitude;" physics is a subject that is well-suited for that. Another way to express that is "make students flexible," which also has the benefit of preparing them for new contexts in the national exam. Students who are less able in flexible thinking
are supported with training activities, to prepare them at least for the national exams.

N acknowledges the relevance of STS-contexts and STEM-cooperation but is careful that the physics part does not become shallow.

Appendix 2 People interviewed for Sub-studies 1 or 4

Interviews with the following people were used for Sub-study 1, Sub-study 4, or both. They participated in, or were otherwise active in the period of one or more of the physics education renewals examined for this study. In the table, the role of author of sample teaching materials is included in the role of curriculum developer.

Name	**Interview used as a source for Sub-study:**	**Functions or roles at the time of the relevant renewals**
Hubert Biezeveld*	4	teacher, teacher magazine editor, textbook author
Twan Brouwers	1, 4	teacher educator, curriculum developer
Willem Bustraan	4	teacher educator
Ton Ellermeijer	1, 4	curriculum developer, researcher
Harrie Eijkelhof	4	curriculum developer, researcher, teacher educator
Ineke Frederik	1, 4	curriculum developer, teacher educator
Frits Gravenberch	4	curriculum developer
Pieter Hogenbirk	4	curriculum developer, textbook author
Koos Kortland	4	curriculum developer, teacher educator, textbook author
Pieter Licht	1, 4	curriculum developer, researcher
Piet Lijnse	4	curriculum developer, researcher
Louis Mathot*	4	teacher, textbook author
Ad Mooldijk	4	curriculum developer, teacher
Hans Poorthuis	4	teacher educator
Frank Seller	4	curriculum developer, teacher
Bert Snater	1, 4	curriculum developer, school leader
Ed van den Berg	4	curriculum developer, researcher, teacher educator
Chris van Weert	4	curriculum developer, professor of physics

*) Hubert Biezeveld and Louis Mathot were interviewed together in one interview.

Appendix 3 Codes referring to curriculum intentions

This table contains codes and their descriptions per curriculum intention used for analyzing interviews in Sub-studies 2, 3, and 4. Codes are displayed in the left column, curriculum intentions in the shaded rows.

Code	**Description: an activity or planning …**
Using contexts	
Contexts as content	Uses contexts to prescribe subject content, including concepts. Note: this also refers to 'context as goal,' which had been used by the New Physics commission (2005-2010) to make a distinction from 'context as a didactic means.' Example: astrophysics as the context for radiation spectra.
Contexts as a teaching strategy	Uses contexts as a strategy for, for example: • contributing to concept development; • contributing to STS emphasis; • contributing to use of concepts and skills in future jobs; • contributing to orientation on career in physics or STEM (study, profession); • motivating students for a specific physics domain.
Widening the scope of science education	
KDS Knowledge development in science	• Gives attention to how scientific knowledge is developed, e.g., by one or more of the following: ◦ the relationship between evidence and theory; ◦ the adequacy of a model to explain phenomena; ◦ the self-correcting features of science. • Reflects on sophisticated investigative, conceptual and manipulative skills such as observing, measuring, experimenting, hypothesizing. • Invites students to understand their own efforts to explain phenomena, and students are exposed to the conceptual underpinnings that influenced scientists developing explanations. • Promotes knowledge on the nature of science. Note: • Here, reflection on research skills as part of knowledge development is focused on, as opposed to the code *Advancing research skills development*, which refers to the practicing of those skills by students.
	• Attention for phenomena is only coded as KDS if phenomena are presented as part of an epistemological reflection, e.g., if the relation between phenomenon and model / concept is made explicit.

Code	Description: an activity or planning …
STS Science, technology, and society	Advances one or more of the following: • insight in the use of physics knowledge in technical applications, in the living environment, in society and in relation to other sciences. • a critical attitude towards social problems with physics and technology aspects, insight into the interaction between science, technology and society. If this orientation is an integral part of the physics lessons: Helps students with possible career perspectives. Note: the term relevance of physics, science, technology is an indicator.
Coordinating with other STEM subjects	
Work on targets regarding STEM-shared competencies or content	• Uses cross-STEM competencies or content in lessons, lesson series and/or attainment targets. • Includes mathematics as instrument or language for physics.
Use of cross-cutting STEM-contexts	• Uses cross-cutting STEM-contexts as prescribed content or as organizing principles of subject content.
Advancing concept development	
Providing a sense of purpose	• Makes the purposes of this part of the curriculum explicit and meaningful, in particular by: ◦ Framing. Are important focus problems, issues, or questions about phenomena offered that are interesting and/or familiar to students? ◦ Connected sequence. Are students involved in a connected sequence of activities (versus a collection of activities) that build toward understanding of a benchmark(s)?
Taking account of student ideas	• Identifies and relates to student ideas in one or more of the following ways: ◦ Addressing prerequisite knowledge/skills. Are prerequisite knowledge/skills specified that are necessary to the learning of the benchmark(s)? ◦ Alerting to commonly held ideas. Is there awareness of commonly held student ideas (both troublesome and helpful)? ◦ Identifying students’ ideas. Is there room to find out what students think about familiar phenomena related to a benchmark before the scientific ideas are introduced? ◦ Addressing commonly held ideas. Are commonly held student ideas explicitly addressed? This code includes establishing students’ initial situation / initial concepts.

<table>
<tr><th>Code</th><th>Description: an activity or planning …</th></tr>
<tr><td>Engaging students with phenomena</td><td>Enables students to see that phenomena are explained in terms of a small number of principles or ideas and have a sense of the range of phenomena that science can explain. One or more of the following apply:
First-hand experiences. Are students offered activities that provide first-hand experiences with phenomena relevant to the benchmark when practical and when not practical, make use of videos, pictures, models, simulations, etc.?
Variety of contexts. Are experiences promoted in multiple, different contexts so as to support the formation of generalizations?
Questions before answers. Are problems or questions about phenomena linked to solutions or ideas?
This code also connects to inquiry-based learning and to stimulating transfer.</td></tr>
<tr><td>Developing and using scientific ideas</td><td>Provides links between phenomena and ideas and demonstrates the usefulness of the ideas in varied contexts. One or more of the following apply:
Building a case. Are students helped to draw from their experiences with phenomena, readings, activities, etc. to develop an evidence-based argument for benchmark ideas? (This could include reading material that develops a case.)
Introducing terms. Are technical terms introduced only in conjunction with experience with the idea or process and only as needed to facilitate thinking and promote effective communication?
Representing ideas. Are appropriate representations of scientific ideas provided?
Connecting ideas. Is attention explicitly drawn to appropriate connections among benchmark ideas (e.g., to a concrete example or instance of a principle or generalization, to an analogous idea, or to an idea that shows up in another field)?
Demonstrating/modeling skills and use of knowledge. Are skills or the use of knowledge demonstrated/modeled?
Practice. Are tasks/questions for students provided to practice skills or using knowledge in a variety of situations?
This code also connects to stimulating transfer if the usefulness of the ideas in varied contexts is shown.</td></tr>
</table>

Code	Description: an activity or planning …
Promoting student reflection	• Helps students express, think about, and reshape their ideas to make better sense of the world. One or more of the following apply: ◦ Expressing ideas. Are activities organized (such as group work or journal writing) to let each student express, clarify, justify, and represent his/her ideas? Does (s)he offer ways for students to get feedback from peers and the teacher? ◦ Reflecting on activities. Are tasks and/or question sequences provided to guide student interpretation and reasoning about phenomena and activities? ◦ Reflecting on when to use knowledge and skills. Are students helped to know when to use knowledge and skills in new situations? ◦ Self-monitoring. Are students supported to check their own progress and consider how their ideas have changed and why? This code includes references to • concept check; • fast feedback; • formative assessment; • inquiry-based learning; • Mazur's peer instruction.
Assessing progress	• Uses one or more of the following goal-relevant assessments. ◦ Alignment to goals. Are assessment items provided that match the content? ◦ Application. Are assessment tasks provided that require application of ideas and avoid allowing students a trivial way out, like using a formula or repeating a memorized term without understanding? ◦ Embedded. Are some assessments embedded in the curriculum along the way? Are the results used to choose or modify activities?
Enhancing the learning environment	• Contributes to one or more of the following. ◦ Classroom environment. Is a classroom environment created that welcomes student curiosity, rewards creativity, encourages a spirit of healthy questioning, and avoids dogmatism? ◦ Welcoming all students. Is a classroom community created that encourages high expectations for all students, that enables all students to experience success, and that gives all different kinds of students a feeling of belonging in the science classroom? Offering facilities for differentiation between students is coded in this category.

Code	**Description: an activity or planning …**
Advancing skills development	
Research skills	• Includes or facilitates doing science; • Is explicitly indicated by the word 'onderzoek' [research, investigation] as done or intended, or • Supports one or more elements from the following list: ◦ preparing an experiment or observation: hypothesize, formulate research question, design experiment, choose equipment, make a research or work plan, prepare processing of results; ◦ running an experiment or observation: set up equipment correctly, perform measurements correctly, read off instruments, set measuring limits, store measurement results clearly; ◦ evaluating an experiment or observation: process measurement results into qualitative or quantitative relationships, relate found results to hypotheses, draw conclusions; ◦ reporting about the above steps of experiment or observation. Note: • Experiments that are only intended to prove that the book is right are not coded as contributing to research skills. • Experiments that are only intended to make students experience phenomena, without further reflection, are not coded as contributing to research skills. • Practical work without any reference to elements of investigation is not coded as contributing to research skills. • References to reflection on research skills as part of knowledge development are coded as curriculum emphasis KDS.
Design skills	• Includes or facilitates doing science; • Is explicitly indicated by the word 'ontwerp' (design), or • Supports one or more elements from the following list: ◦ recognize and specify a problem; ◦ reduce a problem to a design assignment; ◦ determine priorities, possibilities and preconditions for implementing a design; ◦ make a work plan for the execution of a design; ◦ build a design; ◦ evaluate the design process and product, taking into account design requirements and preconditions; ◦ make proposals for improving the design.

Code	Description: an activity or planning …
Modeling skills	• Includes or facilitates doing science; • Is explicitly indicated by the word 'model', 'modelleren' or 'modelvorming' (modeling), or 'denkwijze' (way of thinking), or • Supports developing students' consciousness of and thinking in patterns, structures, models, or • Supports developing students' knowledge of preconditions and assumptions of the most important models with regard to their applicability, or • Supports one or more elements from the following list: ◦ use a model to describe reality; ◦ analyze a problem; ◦ select an adequate model; ◦ generate and interpret model outcomes; ◦ use consistent reasoning and relevant mathematical skills; ◦ make a computer model of a dynamic process.
Judging or decision-making skills	• Includes or facilitates doing science; • Is explicitly indicated by the word 'oordeelsvorming' or 'besluitvorming' [judgment, decision making], or • Refers to one or more activities that support the development of a reasoned opinion about a situation in nature or a technical application, and a distinction in the reasoning between scientific arguments, normative social considerations and personal views.

Appendix 4 Codes referring to factors that directly influence teachers

This table contains codes and their descriptions per curriculum intention used for analyzing interviews in Sub-studies 3 and 4. Codes are displayed in the left column, code groups in the shaded rows.

Codes	Description: addressed or interpreted as a possible influence
Teacher's profile	
Life history	
life histories general	Personal biography or development other than personal school experiences or professional development.
life histories school / college/university time	Experiences as a student in school, college, university.
Professional history	
teacher education	Lessons learned; expertise acquired in teacher education.
colleagues in the past	Influences from colleagues in previous teaching or previous other jobs (current colleagues coded as *Professional history: collaboration with colleagues*), including leadership experienced from colleagues.
previous classroom experiences	Teacher experiences with classrooms or students, including feedback from individual students, current or former.
previous school experiences	Experiences with school organization or rules from (earlier) jobs as a teacher.
professional development in the past	Professional development experiences in the past (current professional development is coded as *professional development incentives*, roles as researcher, textbook author, or other developer are coded as *curriculum development or research activities in the past*), including: • experiences from professional learning communities, also incidental development or trial activities in PLCs; • coaching by peers in school or in PLCs; • having read articles; • having attended conferences (like in the Netherlands: WND-conference, in UK: ASE-conference).
curriculum development or research activities in the past	Experiences as author, member of curriculum project team, science education researcher, including: • more than incidental design activities in professional learning community (PLC) in previous years (if still involved in PLC, then coded in *professional development provisions* of *adaptable structural system*; • research experience, also part time, e.g., the teacher-researchers program "Dudoc".
previous professions	Experiences from previous professions, including: • teaching another subject than physics; • serious hobbies.

Codes	Description: addressed or interpreted as a possible influence
curriculum renewals	Experiences, other than as researcher or developer, or familiarity with one or more renewals limited to explicit references to one or more renewal projects. For physics education: PLON, DBK, NiNa/ Nieuwe Natuurkunde; for other subjects, e.g., NLT (Nature, Life and Technology) or NME (environmental education).
Cultural system	
values about the goals of physics education	Principles about what physics education is for, including: • promote students' learning outcomes, performances; • promote students' attitude towards science; • prepare students for tertiary study; • refer to students' needs (whatever they are in the eyes of the interviewed person); • refer to society's needs (whatever they are in the eyes of the interviewed person).
beliefs about effective education and teaching strategies	Knowledge or assumptions about effective education and teaching strategies, often used as justifications, including: • about the development (stages) of children; • about what insight ('snappen') is, as a measure for effectiveness of education. Note: knowledge is not separately coded, as it cannot be distinguished from assumptions with the available data.
values about the role of the teacher	Principles about what a teacher is for.
views on the nature of physics	Epistemological beliefs of the teacher about the nature of physics, • including view on the nature of science; • including view on the nature of knowledge.
self-image	Belief of the teacher about who or how (s)he is or about his or her capabilities, including self-efficacy, In the words of Bandura (1982, p. 122): "Perceived self-efficacy is concerned with judgments of how well one can execute courses of action required to deal with prospective situations."
Teacher's environment	
Material system	
written resources	Textbooks and other written sources available to the teacher, including the textbook chosen to use with the students (called *standard textbook*), including self-developed materials.
physical school environment	The school building, its facilities, including computer facilities in school.
digital environment	The availability of information technology, videoclips, animations, and applets, including: • introduction of computer technology in science education; • videoclips on internet, www.natuurkunde.nl, applets.
organizational environment	Universities, companies, including supply of PLCs, conferences.
other facilities & resources	Other facilities and resources from Material system than described above, including SPA tool [Systematic Problem Analysis], described by SLO (Netherlands institute for curriculum development).

Codes	Description: addressed or interpreted as a possible influence
Structural system, adaptable	
classroom interaction	Rules and settings in current (as opposed to *Professional history*) classroom interactions (as opposed to rules and settings on *school organization* level) that limit or stimulate forms of enactment.
school organization	Rules, settings, philosophies on school level that limit or stimulate forms of enactment, including: • philosophies of ambition schools, such as Waldorf school or Technasium; • what is imposed or encouraged by school leaders.
collaboration with colleagues	Experiences with current colleagues (with former colleagues coded as *colleagues in the past*), including influences from one's own department, or collaborating fellow departments.
professional development provisions	Sources and settings of professional development, including: • reading or having read books, articles; • visiting or having visited conferences; • participating or having participated in a professional learning community (PLC).
school examination	Rules laid down in the school examination attainment targets and their organization in domains.
Structural system, unadaptable	
national exam program	The attainment targets and their organization in the national exam program.
national syllabus	The specifications of attainment targets laid down in the syllabus for the central exams.
central examinations	The central exam tasks, as expected and derived from what has already been asked in previous years. Including references to: • preparing students for the national exam; • raising their final exam mark; • increasing their chances of passing the exam.

Appendix 5 Codes referring to factors that indirectly influence teachers

This table contains codes and their descriptions per curriculum intention used for analyzing interviews and written sources in Sub-study 4. Codes are displayed in the left column, code groups in the shaded rows.

Codes referring to who and what influences teachers as observed or exerted from the outside	
Code	***Description (not limitative)***
Sources of curriculum intentions	
from outside: theories and studies about knowledge, learning and teaching	• As sources, insights, models, metaphors, Great Names can be mentioned ◦ from learning psychology (e.g., Vygotsky); ◦ language for discussing intentions; ◦ from didactic research (e.g., on concept development, or on modelling or investigative skills). → *references to scientific publications or project publications from curriculum projects or curriculum evaluations are coded in 'through project material'*
from outside: developments in society	• General curriculum discussions, such as Onderwijs2032, or more differentiation possibilities in favor of students. • Technological developments, such as computers and ICT. • Advice or wishes from academic research, either on content (like topical physics) or on more effective teaching/learning. • Need to make students appreciate topical physics, e.g., medical physics, geophysics, astrophysics. → *references to developments in learning or educational science as a source of curriculum intentions on didactics or pedagogy are coded in 'learning theory'*
from practice: teachers' reflections on their experiences	• Teachers' reflections on their experiences, articulated as curriculum intentions.
Survival and propagation of curriculum intentions (unintended influences)	
through international project material, publications, exam programs, presentations	• International project publications, teaching materials, manuals, exam programs. • Publications in scientific media about curriculum projects (e.g., evaluations). • Workshops or presentations at teacher conferences. • The name of a person who is only involved as an author is coded here, as 'via project materials etc.'.

Codes referring to who and what influences teachers as observed or exerted from the outside	
Code	***Description (not limitative)***
through persons	Situations in which individuals take an idea from one job or role to another, e.g., by • introducing the idea to other persons; • being credible to other persons who are then willing to apply the idea.
through research projects and dissertations	May connect to international expertise, as good vehicles (in both directions). → *no problem if this coincides with with the code 'through persons', this code shows a specific way of how persons guide or develop intentions*
through settings with a different focus	"other settings" include • Popularity of a related trend (e.g., "more students' experiments") helps to 'ship' unpopular intentions or intentions from unpopular projects (e.g., working with "themes" with "working questions"). • Example: SPA-method [Systematic Problem Analysis] facilitates concept development. • Intentions as elements in textbooks other than from project. • Intentions as elements in handbooks for teacher education. • Intentions developing in parallel or consecutive paths ◦ when intentions from one project develop in another; ◦ via universities, teacher education institutions, projects ; ◦ examples: environmental education, ANW (science for public understanding, strongly KDS oriented), NLT (Nature, Life, Technology, cross-cutting), introduction of new constellations in education (e.g., basisvorming, tweede fase).
Improving or creating circumstances favoring curriculum intentions (intended influences)	
designing for teachers' concerns or zone of proximal development	• Knowledge about teachers' concerns or their zone of proximal development is investigated or used for design of teaching materials of professional development. • Awareness of: ◦ "what's in it for them?" ◦ market pull; ◦ interests shown for conference themes; ◦ low immunity reactions to intentions. • Offering teasers or examples ◦ small steps that allow practicing or getting acquainted; ◦ examples to motivate teachers; ◦ materials that meet the needs or motivation of students in a clear way, because that is what teachers like. • Elaborate in teaching materials with a familiar setup.
providing clarity about curriculum intentions	• Ensure a project or developer is clear about curriculum intentions, whatever the intentions may be. • Provide a key document describing initial intentions, e.g., a vision document, a source from research or society, whatever the intentions may be.

<table>
<tr><th colspan="2">Codes referring to who and what influences teachers as observed or exerted from the outside</th></tr>
<tr><th>Code</th><th>Description (not limitative)</th></tr>
<tr><td>informing and involving teachers inside and outside project</td><td>• Activities to foster confidence and understanding of teachers for project ambitions and activities.
• Activities to engage other than project teachers in trying out their own selections.
• Activities to prevent mistrust and immune reactions.</td></tr>
<tr><td>securing in central examination (CE) part</td><td>In the Dutch context, for each school type and subject, there is only one central exam program, syllabus, and annual national exam; relevant elements
• the central examination (CE) program part describing the content assessed at national level, specified in the syllabus that specifies content and mastery levels in detail;
• content and format of the CE assignments;
• the parts of the textbooks about the content assessed at CE level.</td></tr>
<tr><td>developing or feeding infrastructure</td><td>• Support informal committees like the national working group of physics teacher educators.
• Connect with possible partners for curriculum development, like
◦ pre-service teacher education institutes;
◦ continued professional development, e.g., ECENT (Expertise Center for Teacher Training in Science and Technology) or the network of professional learning communities;
◦ textbook publishers;
◦ schools;
◦ external teacher support, e.g., national STEM Platform PBT.</td></tr>
<tr><td>facilitating experiences in a safe setting</td><td>• Facilitate experiences in an authentic and complete system environment, so that teachers do not need to improvise or make compromises between regular demands and experiments.
• Avoid curriculum overload, replace rather than add in attainment targets or teaching materials.
• Allow interested teachers to experience a different approach in a normal setting with teaching/learning materials, school-based and central exams
◦ e.g., a complete curriculum in a complete own setting;
◦ e.g., a complete textbook that contains new elements but matches the regular program and syllabus;
◦ e.g., parts that can be practiced in the regular setting.
• Make sure that enough resources are available for teachers to meet their wishes and obligations
◦ what has been laid down nationally in the exam program and syllabus and at school level in the school program for testing and assessment;
◦ what national exams test, as elaboration and interpretation of the syllabus;
◦ what is available as professional development courses or in textbooks addressing new content.</td></tr>
</table>

Appendix 6 Glossary and abbreviations

The terms and abbreviations in the table below refer to the context of the Dutch education system and infrastructure, and to the renewals studied for this thesis. Years in brackets indicate the period of a project's or commission's activity, see also Table 4.1.

term or abbreviation	**meaning**
ANW	General Natural Sciences, a subject compulsory since 1998 for all students in upper general secondary education, optional since 2007/2013 (havo/vwo)
CE	central (i.e., national) exams, or the nationally assessed part of the exam program
Cito	national Institute for Educational Measurement
CMLN	Commission Modernization of the Physics Curriculum (1965-1974)
CvTE	national Board of Tests and Examinations (previously: CEVO, CVE)
DBK-na, or DBK	Differentiation within Classroom, physics (1974-1985)
exam program	formal document with national force, consisting of attainment targets; since 2007, the attainment targets have a concise character, leaving details for the *SE* to the teachers' choice; the details for the *CE* are specified in the *syllabus*
havo	higher general secondary education
HBB	a coordinated set of activities by PLON, aimed at senior general secondary education, for developing teaching materials as well as an experimental exam program, acronym *EPEP-havo* (PLON, 1983)
NiNa	Renewal upper general secondary physics education (2005-2010)
NLT	interdisciplinary STEM subject *Nature, Life and Technology*, optional for students in upper general secondary education
PLON	Physics Curriculum Development Project (1972-1985)
school research project	a cross-cutting research project (*profielwerkstuk*), to be done by all students as part of their school exam; for this project, a student has 80 hours available; it must be connected to at least one major subject from the profile chosen by the student
SE	school exams, or the part of the exam program assessed by the school or the teachers themselves
Second Phase	Upper Secondary Education (reform commission active 1994-1995)
SLO	national Institute for Curriculum Development
syllabus	a formal document that specifies attainment targets that are assessed centrally (in the CE), maximizing the content that the exam construction groups can use in exam tasks, and signaling to textbook authors and teachers the minimum content of the curriculum to be taught
VBB	a coordinated set of activities by PLON, University of Amsterdam, University of Groningen, and a group of teachers, aimed at pre-university education, for developing teaching materials as well as an experimental exam program, acronym *EPEP-vwo* (PLON-UvA-RUG,1983)
vwo	pre-university education
WEN	Working Group Exam Revision Physics (1982-1987)

Samenvatting in het Nederlands

Inleiding

Het idee voor dit onderzoek komt voort uit ongeloof. De conclusie uit veel curriculumevaluaties is dat van de intenties van ontwikkelaars weinig terechtkomt bij leraren, en veel verwatert. Wanneer ik dat afzet tegen mijn eigen ervaringen als ooit leerling en later leraar en curriculumontwikkelaar, dan trek ik een andere conclusie, namelijk dat de ontwikkelactiviteiten op het gebied van curricula in de bètavakken in Nederland door de decennia heen de praktijk van leraren niet onberoerd lijken te hebben gelaten. In lesbezoeken en conferentieworkshops zag ik hoe bètaleraren wel degelijk aandacht besteden aan preconcepten van leerlingen, of gestructureerde onderzoeksactiviteiten voor hun leerlingen organiseren. Dat zijn voorbeelden van wat curriculumontwikkelaars voor ogen hadden. Vandaar mijn ongeloof in de algemene pessimistische conclusie over de aansluiting tussen de bedoelingen van ontwikkelaars en de praktijk van leraren. Gemotiveerd door dit ongeloof wilde ik in dit onderzoek achterhalen of, over een periode van tientallen jaren, belangrijke intenties van ontwikkelaars niet toch op enigerlei wijze tot uitdrukking komen in de huidige lespraktijk, welke factoren de kansen daartoe hebben bevorderd of belemmerd en of sommige intenties misschien meer tijd nodig hadden om hun weg te vinden naar de lespraktijk dan ze in de evaluaties met die sombere conclusies gegund was.

Als casus voor dit onderzoek zijn curricula zoals natuurkundeleraren van nu die uitvoeren vergeleken en gecontrasteerd met curricula die door zes opeenvolgende vernieuwingsprojecten en commissies sinds 1970 op landelijk niveau voor het natuurkundeonderwijs in bovenbouw havo en vwo in Nederland zijn geformuleerd. Binnen dit onderzoek wordt de term *geschreven curriculum* (*written curriculum*) gebruikt voor examenprogramma's die door projecten of vernieuwingscommissies werden voorgesteld, voor de verplichte examenprogramma's als vervolg op deze aanbevelingen, en voor voorbeeldlesmateriaal, publicaties en andere verslagen waarin ontwikkelaars hun bedoelingen tot uitdrukking brachten over wat leerlingen geacht worden te leren en hoe dat leren het beste georganiseerd kan worden. De term *uitgevoerd curriculum* (*enacted curriculum*) verwijst naar de praktijk van leraren, in de vorm van lessen en lessenseries, waarmee zij hun bedoelingen uitdrukken over wat leerlingen moeten leren en hoe dat leren georganiseerd moet worden. In dit onderzoek zijn dus de intenties zoals uitgedrukt in de geschreven curricula vergeleken en gecontrasteerd met de intenties van leraren zoals uitgedrukt in door hen uitgevoerde curricula.

Bij het analyseren van landelijke curricula, geschreven door ontwikkelaars (een rol die bijvoorbeeld wordt vervuld door vakdeskundigen, lerarenopleiders, docenten uit het hoger en voortgezet onderwijs, naast professionele curriculumontwikkelaars) en de curricula die leraren op klasniveau uitvoeren, is een perspectief gekozen dat is geïnspireerd door de evolutietheorie en de ecologie. In dat perspectief worden intenties die zowel in geschreven als in uitgevoerde curricula tot uitdrukking komen, beschouwd als *memes*, eenheden van culturele informatie (Dawkins, 1976/2016). Analoog aan genen in een genetisch-evolutionaire benadering, kunnen die zich vermeerderen in ecosystemen en tot expressie komen in individuen. In dit onderzoek worden deze *memes* aangeduid met de term *curriculumintenties*. En zoals individuen met vergelijkbare genen kunnen verschillen in hun uiterlijk, geldt dat ook curricula met vergelijkbare intenties. En zoals de expressie van genen in individuen afhankelijk is van omgevingsfactoren, kan dat ook het geval zijn met de expressie van intenties in uitgevoerde curricula. En zoals de expressie van genen soms een of meer generaties overslaat, zo kunnen ook intenties met enige vertraging tot uitdrukking komen in uitgevoerde curricula.

Het bestuderen van curriculumverandering vanuit een ecologisch-evolutionair perspectief vereist het onderzoeken van een langere periode dan een paar jaar. Waar evaluatiestudies gewoonlijk worden uitgevoerd kort nadat de curricula door de ontwikkelaars zijn afgerond, kijkt dit onderzoek over een periode van 50 jaar. De veronderstelling daarbij was dat terugkijken over een langere periode misschien meer uitdrukkingen van de bedoelingen van de curriculumontwikkelaars zou laten zien in de door leraren vandaag de dag uitgevoerde curricula dan wat gewoonlijk wordt gevonden in evaluaties kort na de invoering van een curriculumvernieuwing. En bij een onderzoek naar ontwikkelingen over een relatief lange periode zou het ook zinvol kunnen zijn om op een open manier alle mogelijke factoren te onderzoeken, met inbegrip van factoren die de praktijk van leraren onbedoeld beïnvloed zouden kunnen hebben. Zo'n verkenning zou misschien nieuwe inzichten over zulke factoren opleveren naast die van eerdere onderzoeken naar de implementatie van vernieuwingen.

Het ecologisch-evolutionair perspectief werd in dit onderzoek toegepast op vijf decennia curriculumontwikkeling voor natuurkundeonderwijs in bovenbouw havo en vwo in Nederland, met inbegrip van de geschreven curricula van zes landelijke vernieuwingen sinds de jaren 1970 en de uitgevoerde curricula van dertien huidige leraren natuurkunde.

Deze overwegingen en de keuze van de casus leidden tot de volgende, tweeledige, hoofdvraag van het onderzoek:

> *In hoeverre weerspiegelen de uitgevoerde curricula in het natuurkunde-onderwijs in de bovenbouw van havo en vwo in Nederland de intenties van de vernieuwingen zoals tot uitdrukking gebracht in de geschreven curricula die sinds de jaren zeventig zijn opgesteld, en welke factoren kunnen van invloed zijn geweest op het tot uitdrukking komen van de vernieuwingsintenties in de door natuurkundeleraren uitgevoerde curricula?*

Om deze vraag te onderzoeken, zijn vier kwalitatieve deelonderzoeken uitgevoerd, voortbouwend op een conceptuele reflectie en literatuurstudie. De eerste twee deelonderzoeken omvatten een documentenanalyse en analyse van reflecties en discussies uit een bijeenkomst met veertien deelnemers (leden van een projectteam of commissie) en getuigen (tijdgenoten) van de vernieuwingen sinds de jaren zeventig, en interviews met dertien huidige leraren. Deze deelonderzoeken hingen sterk samen en gingen in op het eerste deel van de hoofdvraag. Ook het derde en vierde deelonderzoek (interviews met diezelfde leraren en met achttien deelnemers en getuigen van de vernieuwingen) hadden een sterk onderling verband; zij richtten zich op het tweede deel van de hoofdonderzoeksvraag. Hierna worden de vraagstelling, de onderzoeksopzet en de conclusies samengevat voor elk tweetal deelonderzoeken.

Eerste deel van de hoofdvraag: intenties in geschreven en uitgevoerde curricula

Het eerste deel van de hoofdonderzoeksvraag luidt:

> *In hoeverre weerspiegelen de uitgevoerde curricula in het natuurkunde-onderwijs in de bovenbouw van havo en vwo in Nederland de intenties van de vernieuwingen zoals tot uitdrukking gebracht in de geschreven curricula die sinds de jaren zeventig zijn opgesteld?*

Dit deel stond centraal in de eerste twee deelonderzoeken. De onderzoeksvragen daarvan waren respectievelijk:

1. *Welke curriculumintenties geven op een valide manier weer wat ontwikkelaars nastreefden met de verschillende vernieuwingen van het natuurkundeonderwijs in de bovenbouw van havo en vwo in Nederland sinds 1970?*
2. *In hoeverre weerspiegelen beschrijvingen door natuurkundeleraren in de bovenbouw van havo en vwo in Nederland van hun lespraktijk en hun intenties de intenties van curriculumvernieuwingen die sinds de jaren zeventig in gang zijn gezet?*

In deze deelonderzoeken werd een beeld gehanteerd (Figuur 8.1) waarin curriculumintenties zich als *memes* voortplanten tussen de geschreven en uitgevoerde curricula.

Opzet en uitkomsten van deelonderzoek 1: intenties in geschreven curricula

Voor deelonderzoek 1 werden zes deelnemers van vernieuwingen in het natuurkundeonderwijs geïnterviewd en werd een analyse uitgevoerd van geschreven curricula: aanbevelingen voor examenprogramma's, publicaties en andere verslagen van projectteams of vernieuwingscommissies. Op basis van een initiële lijst van curriculumintenties werden de documenten geanalyseerd door relevante citaten te selecteren en te coderen. De resultaten van de analyse werden vervolgens besproken in een bijeenkomst met veertien projectleiders, voorzitters en andere personen die actief waren geweest in of rond die vernieuwingen. Met de conclusies van deze bijeenkomst kon de lijst van curriculumintenties gevalideerd worden. De uitkomsten van deelonderzoek 1 rechtvaardigden de conclusie dat de aanvankelijk gekozen set van curriculumintenties en hun beschrijvingen adequaat weergaf wat de onderzochte vernieuwingen hadden beoogd en dat die dus kon worden gebruikt als een valide basis voor het analyseren van interviews met leraren over hun uitgevoerde curricula. Deze set (toegelicht in Tabel 5.2, uitgewerkt in Appendix 3) bevat de volgende curriculumintenties:

- Gebruiken van contexten;
- Verbreden van het science-onderwijs, verder onderverdeeld in nadrukken op:
  - Kennisontwikkeling in de wetenschap;
  - Wetenschap, technologie en maatschappij;
- Afstemmen met andere bètavakken;
- Bevorderen van begripsontwikkeling;
- Bevorderen van de ontwikkeling van vaardigheden.

Opzet en uitkomsten van deelonderzoek 2: vergelijking van intenties in geschreven en uitgevoerde curricula

Voor deelonderzoek 2 werden dertien leraren, geselecteerd met het oog op verschillen in leeftijd, leservaring en andere professionele ervaring naast lesgeven, geïnterviewd over hun uitgevoerde curricula aan de hand van een half-gestructureerde interviewleidraad. De analyse van de interviews was gericht op het vinden van curriculumintenties van de geïnterviewden en op de vraag in hoeverre de gerapporteerde lesuitvoeringen en intenties de curriculumintenties van de vernieuwingen weerspiegelden. De interviewgegevens werden voornamelijk kwalitatief geanalyseerd.

De resultaten van deze analyses rechtvaardigden de conclusie dat er, afgemeten aan wat de geïnterviewde natuurkundeleraren rapporteerden, na 50 jaar wel degelijk belangrijke veranderingen in de lespraktijk hebben plaatsgevonden. De negatieve evaluaties die de algemene aanleiding vormden tot het onderzoek, lijken dus voor de curriculumvernieuwingen voor het natuurkundeonderwijs in de bovenbouw havo/vwo te pessimistisch te zijn geweest, of te generaliserend.

Over het geheel genomen kwamen vier van de vijf curriculumintenties die in deelonderzoek 1 waren geïdentificeerd tot uitdrukking in de uitgevoerde curricula, zoals genoemd door de geïnterviewde leraren. Alleen over de intentie *Afstemmen met andere bètavakken* gaven de leraren zelden aan dat die werd uitgevoerd. Zowel in de geschreven curricula als in de interviews over de uitgevoerde curricula kwamen curriculumintenties zelden tot uitdrukking op een manier die voldeed aan alle beschrijvende elementen van deze intenties (uitgewerkt in Appendix 3, samengevat in Tabel 5.2). Maar op het niveau van die beschrijvende elementen kwam voldoende aansluiting tussen geschreven en uitgevoerde curricula naar voren in de deelonderzoeken 1 en 2 om te concluderen dat vier van de vijf curriculumintenties van de vernieuwingen tot expressie kwamen in de uitgevoerde curricula.

Over de aansluiting van curriculumintenties tussen geschreven en uitgevoerde curricula kan het volgende aan bovenstaande worden toegevoegd:

- *Gebruiken van contexten* kwam duidelijk naar voren als gerealiseerd in zijn beide componenten: aansluiten bij relevante vraagstukken uit het dagelijks leven of de samenleving, en leerlingen helpen concepten toe te passen in verschillende contexten. Dit spectrum van *Gebruiken van contexten* kon worden teruggevonden zowel in wat de vernieuwingen beschreven als in wat de geïnterviewde leraren rapporteerden.
- *Verbreden van het science-onderwijs* leek in beide deelonderzoeken eerder een overkoepelende term dan een op zichzelf staande curriculumintentie; de intentie bleef in gebruik als naam van de categorie, die aandacht omvatte voor de curriculumnadrukken *Kennisontwikkeling in de wetenschap* (KDS) en *Wetenschap, technologie en maatschappij* (STS). Zowel aandacht voor KDS als STS werd volgens wat de geïnterviewde leraren rapporteerden in belangrijke mate in de praktijk gebracht.
- *Afstemmen met andere bètavakken* bleken de meeste geïnterviewde leraren alleen uit te voeren op het niveau van bètabrede vaardigheden. Geen enkele leraar gaf aan deze intentie op vakoverstijgende inhoudsdomeinen te hebben uitgevoerd.
- In de meeste interviews met de leraren wordt *Bevorderen van begripsontwikkeling* het duidelijkst uitgedrukt in de kenmerken *bevorderen van reflectie bij leerlingen* en *ontwikkelen en gebruiken van wetenschappelijke ideeën*, waarbij dit laatste ook het gebruiken van concepten in verschillende contexten omvat. Deze kenmerken waren ook in de geschreven curricula als ambitie te vinden voor *Bevorderen van begripsontwikkeling*.
- *Bevorderen van de ontwikkeling van vaardigheden* kwam zowel in geschreven als in uitgevoerde curricula in verschillende mate tot uitdrukking, afhankelijk van de groep van vaardigheden. De term voor deze curriculumintentie blijft gebruikt worden als de naam van een categorie. Bevorderen van onderzoeksvaardigheden en van modelleervaardigheden werd in belangrijke mate aangetroffen in de analyse van de interviews, voor ontwerpvaardigheden was dat minder, voor oordeelsvaardigheden kwam het nauwelijks voor.

Tweede deel van de hoofdvraag: directe en indirecte beïnvloedende factoren

Het tweede deel van de hoofdvraag luidt:

> *Welke factoren kunnen van invloed zijn geweest op het tot uitdrukking komen van de vernieuwingsintenties in de door natuurkundeleraren uitgevoerde curricula?*

Aan het tweede deel van de vraag waren de, nauw met elkaar verbonden, derde en vierde deelonderzoeken gewijd. Zij hadden een verkennend karakter, uitgedrukt door ‘kunnen zijn geweest’, zoals ook in de vragen die richting gaven aan deze deelonderzoeken:

3. *Welke factoren in profiel en omgeving van natuurkundeleraren, zoals door hen gepercipieerd, kunnen van invloed zijn geweest op het in hun onderwijs tot uitdrukking brengen van curriculumintenties van vernieuwingen?*
4. *Welke factoren kunnen profiel en omgeving van leraren hebben beïnvloed tegen de achtergrond van de curriculumvernieuwingen in het natuurkundeonderwijs in de bovenbouw van havo en vwo in Nederland sinds 1970?*

Opzet en uitkomsten van deelonderzoek 3 en 4: direct en indirect beïnvloedende factoren

Voor deelonderzoek 3 zijn dezelfde dertien leraren geïnterviewd als voor deelonderzoek 2, als onderdeel van een en dezelfde sessie. Bij het selecteren en coderen van citaten tijdens de kwalitatieve analyse van de interviews is gebruik gemaakt van open codering, naast codering met een set van beïnvloedende factoren op basis van een conceptueel model (Figuur 8.2). Dit model, dat een onderscheid maakt tussen het profiel en de omgeving van een leraar, is afgebeeld binnen de gestippelde cirkel van Figuur 8.2. Factoren in *profiel* en *omgeving van de leraar* kunnen van invloed zijn op het tot uitdrukking komen van curriculumintenties in het uitgevoerde curriculum. De analyse, grotendeels kwalitatief, was gericht op het vinden van factoren waarvan de geïnterviewde leraren invloed op hun uitgevoerde curriculum hadden genoemd. De codes voor de data-analyse voor deze factoren staan in onderstaande tabel.

Categorieën factoren	**Direct beïnvloedende factoren**
Profiel van de leraar	
levensgeschiedenis	levensgeschiedenis algemeen levensgeschiedenis school/hogeschool/universiteit
professionele geschiedenis	lerarenopleiding geleerd van collega’s eerdere ervaringen in de klas eerdere ervaringen in scholen ervaringen in professionele ontwikkeling ontwikkel- of onderzoeksactiviteiten in het verleden vroegere beroepen curriculumvernieuwingen
cultureel systeem: waarden en overtuigingen	waarden over de doelstellingen van het natuurkundeonderwijs overtuigingen over effectief onderwijs en effectieve onderwijsstrategieën waarden over de rol van de leraar opvattingen over de aard van natuurkunde zelfbeeld

Categorieën factoren	Direct beïnvloedende factoren
Omgeving van de leraar	
materieel systeem	schriftelijk materiaal fysieke schoolomgeving digitale omgeving organisatorische omgeving andere faciliteiten en middelen
aanpasbaar structureel systeem	interactie met klassen schoolorganisatie samenwerking met collega's voorzieningen voor professionele ontwikkeling uitvoering schoolexamenprogramma
niet-aanpasbaar structureel systeem	centraal-examenprogramma landelijke syllabus centrale examens

Voor deelonderzoek 4 zijn relevante documenten geanalyseerd die door vernieuwingsprojecten of commissies zijn geschreven, of waarin deelnemers of getuigen reflecteren op vernieuwingen. Ook zijn achttien deelnemers aan en getuigen van de vernieuwingen geïnterviewd, waarbij werd teruggekeken op de vernieuwingen en op datgene wat in en rond de wereld van het natuurkundeonderwijs in Nederland is gebeurd sinds de jaren 1970. De oriënterende interviews die voor deelonderzoek 1 zijn gehouden, zijn ook deels gebruikt als bronnen voor dit vierde deelonderzoek. De kwalitatieve analyse van de data begon met open codering van geselecteerde citaten. Dit leverde codes op voor een verdere analyse van schriftelijke bronnen en interviews, en een categorisering van die codes, zoals weergegeven in onderstaande tabel. De categorieën van factoren zijn ook afgebeeld in Figuur 8.2, als de twee groepen van factoren buiten de gestippelde cirkel en als de groep van *Sources of intentions*.

Categorieën factoren	Indirect beïnvloedende factoren
bronnen van curriculumintenties	van buiten: theorieën en onderzoeken over kennis, leren en onderwijzen van buiten: ontwikkelingen in de samenleving uit de praktijk: reflecties van leraren op hun ervaringen
onbedoelde invloeden op natuurkundeleraren: overleven en voortplanten van curriculumintenties	via projectpublicaties, voorbeeldexamenprogramma's, presentaties via personen via onderzoeksprojecten en proefschriften via trajecten met een andere focus
bedoelde invloeden op natuurkundeleraren: verbeteren of creëren van omstandigheden die curriculumintenties bevorderen	borgen in centraal examen (CE) deel duidelijkheid verschaffen over curriculumintenties ontwerpen met het oog op *concerns* van leraren of hun zone van nabije ontwikkeling informeren en betrekken van leraren binnen en buiten project infrastructuur ontwikkelen of voeden faciliteren van ervaringen in een veilige omgeving

De analyse was gericht op het vinden van factoren die ofwel bedoeld waren om het profiel en de omgeving van natuurkundeleraren in bovenbouw havo/vwo te beïnvloeden, ofwel dat onbedoeld leken te doen, en die dus indirect van invloed kunnen zijn geweest op de uitgevoerde curricula. Daarom worden ze in het onderzoek beschouwd als *indirect beïnvloedende factoren*, in tegenstelling tot de *direct beïnvloedende factoren* die in deelonderzoek 3 zijn onderzocht. Figuur 8.2 visualiseert indirect beïnvloedende factoren buiten de gestippelde cirkel; deze worden onderscheiden in onbedoelde en bedoelde invloeden op de kans dat curriculumintenties zich, als *memes*, verspreiden in de wereld van natuurkundeleraren en tot uitdrukking komen in hun uitgevoerde curricula.

In de analyse van de interviews met leraren in het kader van deelonderzoek 3 konden verbanden worden gelegd tussen *direct* beïnvloedende factoren en de expressie van de verschillende curriculumintenties in de lespraktijk van de dertien geïnterviewde natuurkundeleraren. Uit de gegevens van deelonderzoek 4, over factoren die van invloed zijn op het profiel en de omgeving van leraren, bleek niet of en hoe dergelijke factoren *indirect* van invloed kunnen zijn op de curricula die natuurkundeleraren in praktijk brengen. Alleen de evaluatie door SLO van de vernieuwingen van het bètaonderwijs na 2013 biedt enige gegevens over de invloed van indirecte factoren op uitgevoerde curricula, afgeleid van antwoorden op een vragenlijst die door ongeveer 100 natuurkundeleraren is ingevuld over hun lespraktijk. Wat de gegevens van deelonderzoek 4 echter wel laten zien, is dat elke *indirecte* factor de uitdrukking van curriculumintenties in de praktijk van leraren kan ondersteunen, door invloed uit te oefenen op een of meer *directe* factoren in het profiel of de omgeving van leraren, waarvan de invloed op uitgevoerde curricula in deelonderzoek 3 was gebleken. Samen geven beide deelonderzoeken een beeld van factoren met mogelijke invloed op de uitdrukking in uitgevoerde curricula van curriculumintenties van de vernieuwingen.

In Figuur 8.3 zijn de grafische samenvattingen van invloeden van indirecte op directe factoren (Figuur 7.3) en van directe factoren op curriculumintenties (Figuur 6.2) samengevoegd.

Het combineren van directe en indirecte invloeden leidt tot de volgende conclusies met betrekking tot de tweede helft van de hoofdvraag.

- In het *profiel van de leraar* kwamen de invloeden van *lerarenopleiding*, *ervaringen in professionele ontwikkeling* en *ervaringen in de lespraktijk* naar voren in de interviewgegevens, als onderdeel van de *professionele geschiedenis*. Deze profielfactoren werden beïnvloed door voorzieningen in de omgeving van de leraar, zoals *voorzieningen voor professionele ontwikkeling* of mogelijkheden om deel te nemen aan pilots.
- In de *omgeving van de leraar* bleken alle drie de systemen (*materieel*, *aanpasbaar structureel*, en *niet-aanpasbaar structureel*) van invloed op het ondersteunen of belemmeren van de expressie van curriculumintenties in

uitgevoerde curricula. Alle drie systemen bleken op hun beurt beïnvloed te zijn door elementen in de categorieën van onbedoelde en bedoelde invloeden (respectievelijk *overleven en voortplanten van curriculumintenties* en *verbeteren of creëren van omstandigheden die curriculumintenties bevorderen*), en door de dieper liggende *bronnen van curriculumintenties*.

- De gegevens lieten zien dat de invloeden door onbedoelde factoren niet minder significant zijn dan die door bedoelde factoren. Dat wijst erop dat curriculumintenties, als *memes*, zich ook zonder gerichte implementatiemaatregelen kunnen verspreiden naar de door leraren uitgevoerde curricula. Deze *memes* bereikten leraren via de *lerarenopleiding* (*professionele geschiedenis*), *voorzieningen voor professionele ontwikkeling* (*aanpasbaar structureel systeem*), en *schriftelijk materiaal* en *digitale omgevingen* (*materieel systeem*).

Waar mogelijk werden de verschillende factoren in verband gebracht met curriculumintenties waarvan zij het tot uitdrukking komen in uitgevoerde curricula kunnen hebben beïnvloed.

Over direct en indirect beïnvloedende factoren, inclusief hun verband met curriculumintenties, kan daarnaast nog het volgende worden opgemerkt.

Direct beïnvloedende factoren

Profiel van de leraar

De curriculumintenties waarvan in de interviewgegevens de uitvoering het vaakst of sterkst leek te worden ondersteund door factoren uit het *profiel* van de leraar, waren *Bevorderen van begripsontwikkeling* en *Verbreden van het science-onderwijs*, die laatste meestal als gevolg van de rol van *Kennisontwikkeling in de wetenschap* in de uitgevoerde curricula van leraren. De intenties *Gebruiken van contexten* en *Bevorderen van de ontwikkeling van vaardigheden* in uitgevoerde curricula leken juist veel minder gerelateerd te zijn aan factoren uit het profiel van de leraar. *Afstemmen met andere bètavakken* werd niet genoemd.

Omgeving van de leraar

De curriculumintentie die bij de analyse het sterkst ondersteund bleek te worden door factoren uit de *omgeving* van de leraar is *Bevorderen van de ontwikkeling van vaardigheden*. De geïnterviewden verwezen naar factoren die vallen in:

- het *materiële systeem* (vooral *schriftelijk materiaal* en *digitale bronnen en faciliteiten*), en
- het *aanpasbare structurele systeem* (vooral *voorzieningen voor professionele ontwikkeling* gekoppeld aan *schoolexamenprogramma* de *schoolorganisatie*).

Ook steun voor *Gebruiken van contexten* kwam duidelijk naar voren, dankzij:

- het *materiële systeem* (vooral *schriftelijk materiaal, digitale voorzieningen*, en *organisatorische voorzieningen*), en

- het *aanpasbare structurele systeem* (vaak vanwege *interactie met klassen* en door contexten in het *examenprogramma*).

Ook *Bevorderen van begripsontwikkeling* kwam sterk naar voren:
- in het *niet-aanpasbare structurele systeem* door de meer conceptuele benadering van de meest recente *centrale examens*, en
- in het *aanpasbare structurele systeem* door duidelijke hulp in de methodes en in aanvullend *schriftelijk materiaal* en de *digitale omgeving.*

Minder ondersteund door factoren uit de *omgeving* van de leraar leken *Verbreden van het science-onderwijs* en *Afstemming met andere bètavakken*. Uitzonderingen waren het gebruik van applets om de aard van modellen te bespreken, en excursies naar bijvoorbeeld een lab om te laten zien hoe en aan welke onderwerpen wetenschappers werken.

Over factoren die de uitdrukking van curriculumintenties in uitgevoerde curricula belemmeren, werd veel minder gezegd dan over ondersteunende factoren. De geïnterviewden rapporteerden meer over wat hen stimuleerde om te doen wat ze doen dan over wat hen hinderde als verklaring voor wat ze niet deden. Toch werd belemmerende invloed gerapporteerd: voor *Bevorderen van vaardigheidsontwikkeling*, *Gebruiken van contexten*, en *Bevorderen van begripsontwikkeling*, door de tijdsdruk van het *centraal examenprogramma* en de *centrale examens*, in een enkel geval versterkt door druk vanuit de *schoolorganisatie*.

De rol van het *niet-aanpasbare structurele systeem*, dat wil zeggen van *centraal-examenprogramma*, *syllabus* en *centrale examens*, was in de interviewgegevens minder geprofileerd dan wat voor de hand lijkt te liggen vanuit de taak van leraren om hun leerlingen voor te bereiden op schoolexamens (SE) en centrale examens (CE). Een secundaire bron, een evaluatie door SLO, uitgevoerd met een vragenlijst onder bovenbouwleraren in dezelfde periode als dit onderzoek, toonde echter dat voor een meerderheid van de responderende natuurkundeleraren het CE-deel van het programma een belangrijke rol speelde, blijkend uit de meldingen van de respondenten dat het CE overladen is, ten koste van andere elementen van hun uitgevoerde curriculum, bijvoorbeeld practicum of computerwerk, wat typisch bij het SE hoort, of tijd voor begripsontwikkeling. Wat de leraren in het onderzoek voor dit proefschrift zeggen over de centrale examens liet zien dat deze zowel ondersteunend als belemmerend kunnen zijn voor de expressie van de onderzochte curriculumintenties in hun onderwijs; zowel ondersteuning als belemmering tellen als invloeden, hun combinatie heft de relevantie als invloed niet op. De geïnterviewden noemden zowel ondersteuning als belemmering voor *Bevorderen van begripsontwikkeling* vanuit de nieuwste examens, en belemmering voor *Bevorderen van de ontwikkeling van vaardigheden*. De genoemde SLO-evaluatie versterkte deze conclusie en legde een verband met de overladenheid aan leerstof die voor het centraal examen wordt voorgeschreven.

Samenvattend leek de nadruk in het curriculum op *Kennisontwikkeling in de wetenschap*, een element van *Verbreding van het science-onderwijs*, meestal expliciet te worden ondersteund door elementen uit de *profielen van leraren*, en verankerd in het *culturele systeem: waarden en overtuigingen*. De geïnterviewden verwezen relatief vaak naar de aard van natuurkunde en het doel van natuurkundeonderwijs, als factoren die de uitdrukking van *Kennisontwikkeling in de wetenschap* en *Bevorderen van begripsontwikkeling* ondersteunen; diverse geïnterviewden meldden dat hun ideeën over deze factoren gevormd of versterkt zijn door hun ervaringen in hun *professionele geschiedenis*. Aan de andere kant leken *Gebruiken van contexten* en *Bevorderen van de ontwikkeling van vaardigheden* vooral te worden ondersteund door elementen van de *omgeving van leraren*. Gedrukte en online leermiddelen, en ervaringen (excursies) en materialen die door derden worden aangeboden, werden door veel geïnterviewden genoemd als bijdragen aan die curriculumintenties. De curriculumintentie *Bevorderen van begripsontwikkeling* leek door beide categorieën van beïnvloedende factoren (*profiel* en *omgeving*) te worden ondersteund.

Indirect beïnvloedende factoren

Invloeden op profiel en omgeving van de leraar

Wat betreft effecten op het *profiel* van leraren: de onderzochte indirecte factoren waren het duidelijkst van invloed op hun *professionele geschiedenis*, vooral op hun *lerarenopleiding* en *ervaringen in professionele ontwikkeling*. Wat de *omgeving* van leraren betreft: het *materiële systeem* werd vooral door de *beschikbaarheid van leermiddelen* beïnvloed; het *aanpasbare structurele systeem* vooral door de *beschikbaarheid van professionele ontwikkeling*; en het *niet-aanpasbare structurele systeem* door wat is voorgeschreven in *examenprogramma's* en *centrale examens*. Voorzieningen voor professionele ontwikkeling in de *omgeving van leraren* beïnvloedden uiteindelijk hun *professionele geschiedenis*, en daarmee het *profiel van leraren*.

Uit de gegevens bleek dat de *bronnen van curriculumintenties* hun invloed op de praktijk van leraren vooral hadden uitgeoefend via producten van curriculumvernieuwingen, en lerarenopleiders, aanbieders van professionele ontwikkeling en auteurs van methodes. De *onbedoelde invloeden* bleken zowel de *omgeving* als het *profiel van de leraar* te hebben beïnvloed, via schriftelijk materiaal, de praktijk van projectleraren, netwerken, en persoonlijke contacten. De *bedoelde invloeden* bleken alle elementen van *omgevingen van leraren* te hebben beïnvloed, en die kunnen na verloop van tijd ook hun *profielen* hebben beïnvloed, in het bijzonder hun *professionele geschiedenis*.

De resultaten lieten ook zien dat experimenterende leraren veiligheid ontleenden aan steun van hun school, en aan de beschikbaarheid van tijd en andere hulpbronnen. Ook werden de mogelijkheden van leraren sterk beïnvloed door de grenzen van het CE, waarbij het CE ook veiligheid bood door bijvoorbeeld aandacht voor begripsontwikkeling te legitimeren. Die combinatie, van veiligheid (geboden door de school of het examensysteem en door voldoende tijd) en de beschikbaarheid van materiële en immateriële middelen, kwam naar voren als sterk bevorderend om leraren ruimte te bieden voor streven naar vernieuwing, of ze nu elementen uit geschreven curricula vormgaven dan wel vanuit hun eigen nieuwsgierigheid experimenteerden. Dat streven naar vernieuwing leek, bedoeld of onbedoeld, bij de geïnterviewde leraren te werken in het voordeel van het tot expressie brengen van de curriculumintenties van sommige vernieuwingen.

Curriculumintenties in verband gebracht met indirecte factoren

De curriculumintenties *Gebruiken van contexten*, *Wetenschap, technologie en maatschappij* (een element van *Verbreden van het science-onderwijs*), *Bevorderen van begripsontwikkeling*, en *Bevorderen van de ontwikkeling van vaardigheden*, of componenten daarvan, kwamen in de gegevens regelmatig naar voren voor alle categorieën van de indirecte invloeden.

Voor de curriculumnadruk *Kennisontwikkeling in de wetenschap* (element van *Verbreden van het science-onderwijs*) kon de relatie het meest gelegd worden met de *bedoelde invloeden*.

De curriculumintentie *Afstemmen met andere bètavakken* kwam naar voren in verband met diverse *bedoelde invloeden*. In verband met de *onbedoelde invloeden* komt ze alleen voor in de factor *via trajecten met een andere focus*.

Implicaties

Uit de resultaten van dit onderzoek kunnen enkele aanbevelingen worden afgeleid voor verschillende rollen die betrokkenen bij curriculumontwikkeling kunnen hebben. Onderscheiden worden de volgende rollen, die ook gecombineerd kunnen voorkomen.

- De *ontwikkelaar* is betrokken bij de ontwikkeling van een geschreven curriculum op landelijk niveau. Het kan bijvoorbeeld gaan om leden van een vernieuwingscommissie, pilotdocenten of auteurs van (voorbeeld)lesmateriaal. Ontwikkelaars brengen hun curriculumintenties tot uitdrukking in geschreven curricula.
- De *leraar* geeft les en ontwikkelt onderwijs en toetsen voor eigen leerlingen. De curriculumintenties van de leraren komen tot expressie in hun uitgevoerde curricula.
- Ook de *intermediair* is actief op het gebied van onderwijs en onderwijsondersteuning, maar dan bijvoorbeeld als lerarenopleider of auteur van lesmateriaal, examenopgaven of syllabi. In deze rol kan iemand, al dan niet bedoeld, de voortplanting van curriculumintenties tussen leraren en ontwikkelaars faciliteren. De rol van intermediair kan gevisualiseerd worden in de pijltjes in Figuur 8.1.
- De *coördinator* overziet en overbrugt de andere rollen. Deze rol kan gericht zijn op een specifieke curriculumverandering of op een meer algemene vorm van bewaken van de verbinding tussen geschreven en uitgevoerde curricula, in beide richtingen.

Implicaties los van specifieke rol

Enkele algemene aanbevelingen zijn, nog los van een specifieke rol:

- Bevorder infectiekansen. In de metafoor van dit onderzoek worden curriculumintenties gezien als *memes*, reizend tussen geschreven en uitgevoerde curricula (Figuur 8.1), in beide richtingen. Zulke infecties kwamen in dit onderzoek naar voren als uitwisseling van kennis en van waarden. Bij kennis ging het om leerstof, theorieën over onderwijzen en leren, didactische benaderingen en ervaringen van leraren. Bij waarden ging het om wat de belangrijkste inhoud van het natuurkundeonderwijs zou moeten zijn, en de rol van de leraren. Bij die uitwisseling bleek materiaal een rol te spelen, zoals publicaties uit projecten of onderzoek, geschreven curricula uit diverse landen en lesmateriaal; maar ook personen waren van belang, zoals lerarenopleiders, collega's of leerlingen die feedback gaven.
- Ondersteun een verscheidenheid aan expressies van curriculumintenties, maar wees duidelijk over de kernideeën. Curriculumintenties bleken weliswaar noch in uitgevoerde curricula (zoals weergegeven in de interviews met leraren), noch in schriftelijke curricula te worden uitgedrukt op een manier die aan alle descriptoren van deze intenties voldeed, maar op het niveau van de sleutelkenmerken was er steeds voldoende overeenstemming. Een aanbeveling aan ontwikkelaars is dan ook om schriftelijke curricula te ontwikkelen die duidelijkheid bieden over kernideeën, maar ruimte bieden voor eigen uitwerking door leraren, ook als uitgevoerde curricula dan gaan afwijken van bijvoorbeeld uitwerkingen van de ontwikkelaars in lesmateriaal.
- Bied veiligheid en ruimte voor het uitwerken van curriculumideeën door leraren en stem daarbij de verschillende soorten ondersteuning in de infrastructuur op elkaar af. Een combinatie van veiligheid, geboden door de school of het examensysteem, voldoende tijd en de beschikbaarheid van middelen bleek in dit onderzoek ruimte te bieden aan docenten om innovatief te zijn, of zij nu vormen zochten om nieuwe elementen uit geschreven curricula in te voeren of in hun klassen experimenteerden op basis van hun eigen nieuwsgierigheid. Voor het ondersteunen van vernieuwing door leraren bleken lerarenopleiding en een aanbod van professionele ontwikkeling (zoals professionele leergemeenschappen) opvallend invloedrijke elementen van de infrastructuur.
- Ondersteun zowel bedoelde als onbedoelde invloeden. Profiel en omgeving van leraren bleken in dit onderzoek niet alleen door bedoelde factoren beïnvloed te zijn, maar ook door onbedoelde. Bij die laatste viel de invloed op van onderdelen uit de lerarenopleiding die niet speciaal gericht waren op de curriculumintenties van vernieuwers. Dat gold ook voor wat voorzieningen als professionele leergemeenschappen, schriftelijke bronnen en digitale omgevingen boden. Bedoelde invloed was te zien daar waar deze voorzieningen gevoed werden met inhoud gerelateerd aan de curriculumintenties van vernieuwingen, of daarvoor werden uitgebreid. Bedoelde invloed was ook

te zien waar mensen met ervaring met ontwikkelwerk in vernieuwingen als medewerkers bij die voorzieningen werden betrokken. Een aanbeveling aan coördinatoren en intermediairs kan dus zijn om een goede kwaliteit van deze voorzieningen te waarborgen voor (aanstaande) leraren. Deze aanbeveling ligt weliswaar erg voor de hand, maar de resultaten van dit onderzoek kunnen toch als een aanmoediging worden gezien. Dat waarborgen blijkt niet alleen van belang tijdens vernieuwingen en in de jaren direct daarop volgend, maar is ook een goede besteding van de tijd tussen vernieuwingen; sommige curriculumintenties blijken tijd nodig te hebben om tot uitdrukking te komen in uitgevoerde curricula. Gedurende die tijd kunnen zowel bedoelde als onbedoelde invloeden werkzaam zijn, ondersteund door de genoemde voorzieningen.

- Laat toe dat de expressies van curriculumintenties zich in de loop van de tijd ontwikkelen. Dit onderzoek laat zien dat er na 50 jaar kennelijk betekenisvolle veranderingen hebben plaatsgevonden in de lespraktijk, in elk geval in de praktijk van de geïnterviewde leraren, waarvan een deel nog niet eerder was aangetroffen. De beschrijvingen van die leraren laten een ander beeld zien dan met name het verzet tegen de ambities van het PLON-project in de jaren tachtig, waar verschillende bronnen over rapporteerden. Een aanbeveling aan coördinatoren, ontwikkelaars en intermediairs is: aanvaard dat tijd nodig is en zorg dat die verstandig wordt gebruikt door de omgeving van leraren zo in te richten dat ook latere expressie van curriculumintenties wordt ondersteund. Voor leraren is de aanbeveling: neem die tijd en vraag faciliteiten. Als intussen nieuwe inzichten de wenselijkheid van een bepaalde curriculumintentie of een bepaalde uitwerking weerleggen, moet dit uiteraard onder de aandacht van betrokkenen worden gebracht en worden ondersteund door suggesties voor alternatieven.

Implicaties voor de verschillende rollen

Implicaties voor leraren

Een algemene aanbeveling voor leraren die geïnteresseerd zijn in reflectie op hun lespraktijk, of in het beïnvloeden van geschreven curricula op landelijk niveau, of beide, is: vraag om de faciliteiten waarvan de coördinatoren, ontwikkelaars en intermediairs wordt geadviseerd die aan te bieden (zoals elders in deze paragraaf beschreven). Die vraag kan gericht zijn aan schoolleiders, of de vorm hebben van een aanvraag voor een onderzoeks- of ontwikkelbeurs, of voor deelname aan een vernieuwing als pilotdocent of commissielid. Dit onderzoek liet zien hoe sommige leraren de ruimte die ze in schoolorganisatie en regelgeving hadden, benutten om te experimenteren met nieuwe accenten in het curriculum en/of didactische benaderingen, zelfs als geen aanvullende voorziening zoals een subsidie of piloturen beschikbaar was. Verschillende leraren uit dit onderzoek profiteerden bijvoorbeeld van een aanbod voor professionele ontwikkeling, in regionale netwerken, de WND-conferentie, soms ook de Britse ASE-conferentie. Een lerarenvereniging, in dit geval de NVON, kan voor leraren collectief zulke mogelijkheden versterken.

Om ontwikkelaars te beïnvloeden kunnen leraren zich mengen in discussies over visiedocumenten en tussenproducten van projectteams en hervormingscommissies, of zich ook om deze reden proberen aan te sluiten bij een project als pilotdocent of commissielid. Zo kunnen zij zelf ontwikkelaar worden, naast hun onderwijspraktijk.

Door dit soort acties kunnen leraren bijdragen aan het tweerichtingsverkeer van *memes* tussen geschreven en gerealiseerde curricula.

Implicaties voor coördinatoren

De volgende mogelijke implicaties komen met name voor coördinatoren naar voren.

- Om infectiekansen te vergroten, kunnen coördinatoren de betrokkenheid van mensen in verschillende rollen in verschillende stadia van curriculumvernieuwingen bevorderen. Uit dit onderzoek bleek bijvoorbeeld dat vernieuwingsprojecten waarbij leraren werden betrokken bij het ontwikkelwerk in een rol als auteur en/of pilotdocent, en waarin leraren samenwerkten met professionele ontwikkelaars en onderzoekers, bijdroegen aan de professionele kwaliteit van alle deelnemers en discussianten, en aan het opbouwen van netwerken. Projecten voor curriculumvernieuwing kunnen dus ook, naast het ontwerpen van geschreven curricula, een krachtige hefboom zijn voor professionele ontwikkeling en netwerkopbouw. Ook faciliteiten voor onderzoek of ontwikkelwerk door leraren, zoals in professionele leergemeenschappen of via beurzen, leverden niet alleen producten op, maar droegen ook bij aan de professionele ontwikkeling van de deelnemers. De Dudoc-promotieprojecten illustreren dit effect. Veel van die rolveranderingen lijken te gebeuren zonder dat coördinatie nodig is, maar kunnen baat hebben bij actieve ondersteuning.
- Coördinatoren hebben een bijzondere rol bij het bieden van veiligheid en steun, en bij het afstemmen van gezamenlijke actie van actoren in de verschillende rollen, omdat zij de actoren in rollen kunnen stimuleren om samen te werken.
- Een belangrijke bijdrage aan de veiligheid van leraren in nieuwe situaties bleek het vermijden van curriculumoverladenheid te zijn. Coördinatoren doen er goed aan, actoren in andere rollen daarop te blijven attenderen en daarin te begeleiden. Overladenheid bleek een bedreiging voor vernieuwingsintenties te zijn, vooral voor wat geen plaats heeft gekregen in het CE-gedeelte van examenprogramma's. En al is de invloed van ontwikkelaars op de kwantiteit van curriculuminhoud groot, toch heeft deze zijn grenzen. Zo bleek enkele jaren na de landelijke invoering van het examenprogramma van 2013 dat ook maximale uitwerkingen van eindtermen en syllabusspecificaties door auteurs en leraren bijdroegen aan overladenheid.

Implicaties voor ontwikkelaars

De volgende mogelijke implicaties komen vooral naar voren voor ontwikkelaars.

- Ontwikkelaars moeten op de hoogte zijn van trends in de ontwikkeling van het vak, van wat leraren bezighoudt en van zones van nabije ontwikkeling van leraren. Op die manier kunnen ontwikkelaars zich laten besmetten door de curriculumintenties van leraren en door hun ervaringen met uitgevoerde curricula. Dat vergroot de besmettingskansen in twee richtingen tussen geschreven en uitgevoerde curricula. Het onderzoek liet voorbeelden zien van de manier waarop zulke informatie kan komen uit evaluaties van praktijkervaringen; uit gesprekken met leraren over visiedocumenten, concept-examenprogramma's en voorbeeldlesmateriaal; en uit formatieve evaluaties van lessen met pilotmateriaal. Ook informatie van lerarenopleiders over de drijfveren van aanstaande leraren (enkele geïnterviewde leraren noemden de doorwerking van die vroege drijfveren) kan nuttige input opleveren voor ontwikkelaars.

- Vernieuwingsprojecten met pilots waarin een volledig centraal examen is opgenomen hebben de voorkeur boven ontwikkelprojecten die maar een deel daarvan kunnen realiseren. Het nut daarvan werd duidelijk geïllustreerd door het voorbeeld van de NiNa-pilot. De formatieve evaluaties daarvan lieten zien hoe de reflecties op de ervaringen in de pilotscholen en met de pilotexamens het examenprogramma hadden beïnvloed, en leverden aanbevelingen voor zaken waar rekening mee moet worden gehouden om alle leraren en andere actoren te ondersteunen bij de landelijke invoering van het examenprogramma.
- Ontwikkelaars moeten hun curriculumintenties duidelijk beschrijven. Dit onderzoek liet zien dat duidelijkheid over die intenties, als strategische ijkpunten, zeer bevorderlijk is voor het op koers houden van stapsgewijze (bedoelde en onbedoelde) ontwikkelingen.
- Door duidelijkheid te bieden over de reikwijdte van een voorgestelde curriculumwijziging kunnen ontwikkelaars ertoe bijdragen dat leraren veiligheid ervaren en merken dat er rekening is gehouden met hun wensen en zorgen. Dit onderzoek toonde voorbeelden van hoe onduidelijkheid over de reikwijdte van een vernieuwing (pilot-lesmateriaal bleek soms als verplichte uitwerking voor alle leraren te worden geïnterpreteerd) onrust en weerstand veroorzaakte.
- Ontwikkelaars doen er goed aan met CvTE en CE-opgavenconstructeurs af te spreken welke vaardigheden op welke wijze in het CE worden getoetst. Dit geldt zeker ook voor de vaardigheid om conceptueel denken toe te passen bij het oplossen van CE-opgaven, en voor de vaardigheid om een probleem in een context te interpreteren met behulp van concepten, ook al heeft nadruk op deze vaardigheden consequenties van didactische aard: het 'wat' van het curriculum kan niet los worden gezien van het 'hoe'. Dit onderzoek liet zien hoe examenopgaven die conceptueel denken beoordelen, in plaats van alleen wiskundige oplossingsvaardigheden te beoordelen, de curriculumintentie *Bevorderen van begripsontwikkeling* kunnen steunen. Deze curriculumintentie, die zeker ook van didactische aard is, kan zo toch op een legitieme wijze via het CE worden gesteund.

- Ontwikkelaars kunnen de mogelijkheden voor het beoordelen van vaardigheden ook ondersteunen door de ruimte en het gewicht van het SE-deel uit te breiden en ze te beschermen tegen een status als hulpbron voor het oplossen van de problemen die veroorzaakt worden door de overladenheid in combinatie met de hoge status van het CE-deel. Ook dit onderzoek liet zien dat het CE-deel druk op het SE-deel uitoefent.
- Vermijd overladenheid in eindtermen, voorbeeldlesmateriaal en andere geschreven curricula. Ontwikkelaars moeten daartoe versnippering van leerstof vermijden die ontstaat door het toevoegen van domeinen, gecompenseerd door het verminderen van het aantal concepten per domein: om een concept te leren gebruiken, kunnen leerlingen geholpen worden door andere concepten uit hetzelfde conceptuele netwerk te gebruiken.

Implicaties voor intermediairs

Intermediairs kunnen bijdragen aan de verspreiding van specifieke curriculumintenties, bijvoorbeeld die van een recente vernieuwing, maar ook los van een specifieke intentie. De hieronder beschreven implicaties voor intermediairs zijn in die twee categorieën ondergebracht.

Implicaties voor het bevorderen van specifieke curriculumintenties

Mogelijke implicaties van dit onderzoek voor intermediairs die specifieke curriculumintenties kunnen bevorderen zijn de volgende.

- Laat intermediairs (aanstaande) leraren beproefde theorieën aanreiken, maar ook hulpmiddelen die al in de volgende les kunnen worden toegepast. Zo kunnen leraren worden geïnformeerd over de bronnen waaruit ook innovaties putten. Het ondersteunen van lerarenopleiders met professionele ontwikkeling gewijd aan recente geschreven curricula en hun intenties kan daar aan toegevoegd worden. Deze aanbeveling wordt ondersteund door het resultaat van dit onderzoek dat lerarenopleiding en professionele ontwikkeling opvallend veel invloed bleken te hebben op het profiel en de omgeving van leraren.
- Toon in lerarenopleiding en professionele ontwikkeling de synergie tussen de curriculumintenties *Bevorderen van begripsontwikkeling*, *Aandacht voor de aard van de wetenschap* (als deel van *Kennisontwikkeling in de wetenschap*), en *Gebruiken van contexten* aan docenten omdat dit de positie van elke curriculumintentie kan versterken. In dit onderzoek bleken leraren gevoelig voor het bevorderen van begripsontwikkeling; de expressie ervan bleek te worden ondersteund door invloeden vanuit zowel het profiel als de omgevingscategorieën van de leraar. Deze curriculumintentie koppelt de wens om de prestaties van leerlingen op de examens te verhogen aan *Aandacht voor de aard van wetenschap* en *Gebruiken van contexten*.
- Aandacht voor de geschiedenis en filosofie van de wetenschap, in het bijzonder de aard van de natuurkunde, verdient een plaats zowel in het curriculum

van lerarenopleiding als in het aanbod van professionele ontwikkeling. Een aanzienlijk deel van de geïnterviewde leraren noemde belangstelling voor de aard van de natuurkunde, of andere elementen van de geschiedenis en filosofie van de wetenschap, als onderbouwing van de expressie in hun uitgevoerde curricula van *Gebruiken van contexten*, *Verbreden van het science-onderwijs, Bevorderen van begripsontwikkeling*, of *Bevorderen van de ontwikkeling van vaardigheden*. Bovendien beschreven de meeste van deze leraren hoe deze interesse was gewekt of bevestigd door lerarenopleiders of in de professionele ontwikkeling.

- Besteed aandacht aan redeneringen die helpen bij het selecteren en organiseren van curriculuminhoud. Deze aanbeveling hangt samen met de vorige, over aandacht voor de geschiedenis en filosofie van de wetenschap, die bij een deel van de geïnterviewde leraren een rol speelde. Ook leraren uit het Nederlandse primair en voortgezet onderwijs die in 2018 en 2019 in ontwikkelteams werkten aan het ontwerp van een raamwerk voor het hele curriculum (curriculum.nu), bleken behoefte te hebben aan dergelijke rationales om hun denkprocessen en ontwerpen te structureren. Zulke redeneringen kunnen aandacht krijgen in lerarenopleidingen en professionele ontwikkeling. Voor het natuurwetenschappelijk onderwijs, daarbinnen ook voor natuurkunde, zijn rationales te vinden in de *Principles and big ideas of science education* (Harlen, 2010) of de *Next Generation Science Standards* (NGSS, National Research Council, 2012). Ook de Nederlandse *Kennisbasis natuurwetenschappen en techniek voor de onderbouw van het voortgezet onderwijs* (Ottevanger et al., 2014), geïnspireerd door de NGSS, kan een rationale bieden, inclusief een beredeneerde, zinvolle structurering van doelen en inhouden, voor het natuurkundeonderwijs in de bovenbouw van het voortgezet onderwijs. Nog een andere rationale voor het selecteren en ordenen van doelen en inhouden kan de bredere (dan alleen voor bètaonderwijs) *Perspectiefgerichte benadering* zijn, geformuleerd voor het selecteren en ordenen van curriculuminhouden door Janssen et al. (2019), die Logman en Van Bemmel (2019) hebben toegepast op het vak natuurkunde.
- Bied een ruime keuze aan schriftelijke en digitale bronnen van goede kwaliteit, voorzieningen voor professionele ontwikkeling, en faciliteiten om onderzoeksinstituten en bedrijven te bezoeken. Dit onderzoek laat zien hoe leraren, geleid door hun waarden en overtuigingen, gebruik maken van de verscheidenheid aan hulpbronnen in hun materiële en structurele omgeving. Om leraren te beïnvloeden op een manier die de uitdrukking van specifieke curriculumintenties kan bevorderen, kan voorbeeldlesmateriaal in de verzameling hulpbronnen worden opgenomen dat niet alleen het leren van leerlingen bevordert, maar ook het leren van leraren op een bepaald gebied kan ondersteunen in de context van en als onderdeel van een curriculumvernieuwing.

- Speciale aandacht is nodig voor curriculumintenties die, net als *Afstemmen met andere bètavakken*, steun op schoolniveau nodig hebben. Uit dit onderzoek blijkt dat zonder die steun zelfs goed uitgewerkte vakoverstijgende eindtermen als voor Medische Beeldvorming of Biofysica toch bleken te worden behandeld zonder verbindingen met andere vakken dan natuurkunde. En voor een CE-domein als Medische Beeldvorming bevestigen centrale examenvragen die, om goede redenen, alleen ingaan op de natuurkundige aspecten van de inhoud, deze monodisciplinaire aanpak.
- Construeer examenopgaven die vakoverstijgende kwesties toetsen, als *Afstemmen met andere bètavakken* deel uitmaakt van het te ondersteunen geschreven curriculum. De gegevens van dit onderzoek laten niet zien hoe het werken aan vakoverstijgende vraagstukken in de praktijk van docenten gebaat zou zijn geweest bij vakoverstijgende centrale examens, omdat al deze examens vakspecifiek waren. In Nederland zou een aanbeveling om CE-taken aan te bieden die de beoordeling van natuurkundige en biologische kennis combineren, botsen met de beperkingen van het systeem, omdat maar een deel van de leerlingen met natuurkunde in hun profiel ook biologie hebben gekozen. Voor examenopgaven die over de grenzen gaan tussen examenprogramma's voor natuurkunde en scheikunde, of van natuurkunde en wiskunde, zouden zulke beperkingen niet hoeven te bestaan.

Implicaties voor het verbeteren of creëren van omstandigheden ongeacht een specifieke curriculumintentie

Mogelijke implicaties van dit onderzoek gericht op het verspreiden van curriculumintenties door intermediairs, maar niet gericht op specifieke curriculumintenties, zijn de volgende:

- Stel de positie van het schoolexamen veilig tegen de druk van het centraal examen. Het SE-deel van het examenprogramma biedt ruimte aan docenten om eigen accenten uit te werken in curriculumintenties en didactische benaderingen. De resultaten van dit onderzoek laten zien dat deze ruimte beperkt wordt door de behoefte van docenten om ten minste aan de eisen van het CE te voldoen, en hun neiging om de SE-gerelateerde activiteiten als een stelpost te behandelen. Curriculumintenties die bij uitstek in SE-gerelateerde activiteiten tot uitdrukking komen, raken zo nogal eens in de verdrukking.
- Schep mogelijkheden voor leraren om een centraal examen te kiezen dat, net als hun schoolexamen, kan aansluiten bij hun eigen focus. In dit onderzoek kwam naar voren dat voor leraren die willen experimenteren met een curriculum met een andere focus het kunnen werken met geschikt voorbeeldlesmateriaal, maar zeker ook het kunnen kiezen van een centraal examen uit een paar opties die aansluiten bij hun focus, bijdragen aan hun veiligheid en bereidheid om nieuwe praktijken uit te proberen. Dat is vergelijkbaar met deelnemen aan een experiment op grotere schaal, met eigen lesmateriaal en eigen examens voor het experiment. Ook een systeem zoals in Engeland kan die veiligheid bieden,

waar docenten kunnen kiezen uit enkele uitwerkingen van de eindtermen in verschillende examens en bijpassende boeken. Dit zou in de Nederlandse context betekenen dat leraren zouden kunnen kiezen uit verschillende syllabi, met bijpassende boeken en centrale examens, alle gebaseerd op het nationale examenprogramma.

- Een goed ontsloten database van relevant (internationaal) onderzoek en relevante projectevaluaties, van projectpublicaties met opties voor nieuwe leerstof of didactiek, van praktijkervaringen, en van bijpassend voorbeeldmateriaal moet beschikbaar zijn voor actoren in alle rollen. Dit onderzoek liet de effectiviteit van zo'n ontsluiting zien. Dat kan langs de klassieke wegen van wetenschappelijke en projectpublicaties en persoonlijke contacten, maar ook met digitale voorzieningen. In Nederland kunnen allerlei interfaces bijdragen aan deze ontsluiting (zoals natuurkunde.nl, ECENT/ELWieR, de vakportalen van SLO, of Kennisrotonde). In het Verenigd Koninkrijk biedt de *Education Endowment Foundation* een inspirerend voorbeeld.
- Het onderzoek liet ook zien hoe subsidies onderzoekswerk gericht op curriculumintenties kunnen ondersteunen, ook al worden ze aangeboden zonder op zo'n intentie gericht te zijn. Sommige geïnterviewde docenten hadden een subsidie aangevraagd ter ondersteuning van verder onderzoek van hun eigen vragen, bijvoorbeeld naar onderzoekend leren of de kwaliteit van de onderzoeksactiviteiten van studenten. Het Dudoc-programma, al eerder genoemd, is een goed voorbeeld, evenals het Lerarenontwikkelfonds; ook enkele geïnterviewde leraren werkten met die ondersteuning. Dit impliceert de aanbeveling om onderzoeksbeurzen voor leraren beschikbaar te blijven stellen.
- Scholen wordt aanbevolen experimenterende leraren te ondersteunen. Uit dit onderzoek bleek dat diverse leraren ook zonder de hulp van een beurs mogelijke verbeteringen van hun onderwijs uitproberen. Faciliteiten aangeboden door hun school of morele steun bleken een aanmoediging voor deze leraren. Andere faciliterende instanties wordt aanbevolen om scholen op hun beurt te helpen, bijvoorbeeld met ondersteuning bij de ontwikkeling van curriculair leiderschap van teamleiders en schoolleiders, en van de competenties van leraren op het gebied van curriculumontwikkeling.
- Netwerken voor professionele ontwikkeling zoals de nationale WND-conferentie voor natuurkunde en regionale netwerken moeten worden bevorderd en in stand gehouden, zodat docenten de beschikking krijgen over voorzieningen voor professionele ontwikkeling en er meer contacten komen tussen docenten in het voortgezet en hoger onderwijs. Dit onderzoek liet zien dat leraren van dergelijke voorzieningen gebruik maken.
- De combinatie van experimenten door leraren in kleine stappen met voorzieningen voor professionele ontwikkeling van enige omvang wordt aanbevolen. Dit onderzoek liet zien hoe deze combinatie tegelijkertijd docentontwikkeling en curriculumontwikkeling mogelijk kan maken. Inter-

mediairs kunnen dit soort combinaties faciliteren voor leraren, ontwikkelaars en andere actoren.

Onbeantwoorde en nieuwe vragen

Naast de antwoorden op de hoofdvraag en op de vragen van de deelonderzoeken, kwamen tijdens het onderzoek nieuwe interessante vragen naar voren die zonder verder onderzoek niet kunnen worden beantwoord. Een paar suggesties:

- Een meer uitgezoomde benadering dan voor dit onderzoek zou interessant zijn, met enkele honderden docenten betrokken bij een survey-onderzoek, en/of juist in een meer ingezoomde benadering, met een kleiner aantal docenten geobserveerd in hun lessen, gecombineerd met interviews met henzelf en hun leerlingen, collega's en schoolleiders. De hoofdvraag en deelvragen, het conceptuele kader en de coderingen die gebruikt zijn voor dit onderzoek kunnen gebruikt worden als input voor zulke onderzoeken met andere zoomniveaus.
- Vergelijkbare verkennende onderzoeken naar het scheikunde-, biologie- of wiskunde-onderwijs zouden andere verhalen vertellen, maar misschien soortgelijke conclusies opleveren. Vooral een vergelijking met de ontwikkelingen in het scheikundeonderwijs zou interessant zijn, omdat de vernieuwingsteams voor scheikunde en natuurkunde in de jaren zeventig en tachtig nogal uiteenlopende visies op ambitieniveau en ontwikkelpad hadden. In de periode 2004-2010 werkten commissies voor beide vakken parallel. Het zou interessant zijn om meer te weten te komen over de vraag of *piecemeal engineering* van geschreven curricula en praktijken van leraren, door kleine aanpassingen en bijstellingen, een manier van ontwerpen en opschalen kan zijn die het geduld en de tolerantie van een evolutionair perspectief combineert met ruimte voor ontwerp.
- Een andere variant van deze casus is het bestuderen van curriculumintenties en invloeden op leraren in de onderbouw van het voortgezet onderwijs, waar leraren over het algemeen een andere balans hebben tussen hun verbondenheid met de vakgemeenschap en de school dan leraren in de bovenbouw. Ook zijn de onderwijsdoelen in Nederland voor de onderbouw minder gedetailleerd en voorschrijvend dan de eindtermen en syllabusspecificaties voor de bovenbouw.
- Nog een andere variant is: kijken naar het natuurkundeonderwijs in de bovenbouw van het voortgezet onderwijs in een land of deelstaat zonder centraal-examensysteem. Aangezien het CE-systeem een vanzelfsprekende basis lijkt voor het uitgevoerde curriculum van Nederlandse leraren, zou het interessant zijn om te zien hoe invloeden zoals in de figuren 8.2 en 8.3 zouden verschillen van de Nederlandse casus.
- Voor de curriculumintentie *Afstemmen met andere bètavakken* kan meer inzicht in de rol van het profielwerkstuk nuttig zijn. In sommige interviews voor deelstudie 4 bleek het profielwerkstuk van invloed te zijn geweest op de samenwerking tussen leraren van verschillende vakken, en ook enkele leraren

die voor deelstudies 2 en 3 waren geïnterviewd, gaven aan dat hun school vakoverstijgende leertrajecten voor onderzoeksvaardigheden had opgezet als voorbereiding van het profielwerkstuk.

- De invloed van de toename van nepnieuws en het bagatelliseren in de sociale media van wetenschappelijke kennis als "alleen maar een mening" zou de aandacht voor het curriculumaccent *Kennisontwikkeling in de wetenschap* in geschreven en uitgevoerde curricula kunnen versterken. Een onderzoek naar deze veronderstelling zou interessant zijn en kan ook dienen als een check op de generaliseerbaarheid van conclusies uit dit onderzoek over de invloed van ontwikkelingen in de maatschappij op curricula.

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Curriculum Vitae

Maarten Pieters was born on 24 June 1954 in Gendringen, the Netherlands. He finished pre-university education (Gymnasium β) in 1971 at the Thomas a Kempis College in Arnhem. He studied experimental physics, with mathematics and foundations of physics as minor subjects, at Utrecht University, where he graduated in 1979.

He worked for two years at the same university on the design and organization of an interdisciplinary minor in environmental studies.

From 1981 to 1986 he was a physics teacher at the Eemland College Noord in Amersfoort and participated as a pilot teacher and author for the PLON and VBB projects. As an author, he contributed to several physics textbooks for secondary education, on physics in society and on biophysics.

From 1986 to 1992 he worked as a developer, seconded by the Netherlands Institute for Curriculum Development SLO in the NME-VO project, hosted by Utrecht University, which developed a curriculum for environmental education, embedded in various subjects of secondary education.

In 1993 he worked as an advisor at CEA, a consultancy for environmental communication.

In 1994 he became account manager at Educaplan, the commercial subsidiary of SLO, to return to SLO in 1996 as project leader for the new subject General sciences (ANW), and project leader or researcher for education for sustainable development, and for national curriculum policy development, with assignments in Germany, Lithuania, the Russian Federation, and Costa Rica. In 1998 he became one of the heads of SLO's market group.

From 2002, he worked as a business manager and project leader at the AMSTEL Institute of the University of Amsterdam, with project leadership roles in the development of the new general upper secondary physics exam program (NiNa), of the physics education website natuurkunde.nl, and (seconded to Utrecht University) of ECENT, the expertise center for teacher education in science and technology. He also had assignments in several sub-Saharan African countries and Cambodia.

In 2011 he returned to SLO as curriculum developer for science education and cross-curricular aspects of the curriculum. Since 2015 he has been a fellow of the International Society for Design and Development of Education (ISDDE).

Since 2020 he has worked as an independent consultant.

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This study examines to what extent current teachers' enacted curricula reflect key ideas, called curriculum intentions, from renewals in several past decades. It also explores what factors may have facilitated these intentions to be expressed in enacted curricula. This perspective is inspired by ecology and evolution theory, and investigates curriculum intentions as memes, which can be expressed in both written and enacted curricula over decades.
Case of the study is upper general secondary physics education in the Netherlands since 1970. In interviews, teachers indicate to express most of the renewals' intentions investigated. Professional development, a resource-rich environment, and mobility between roles of stakeholders appear as increasing the "infection rate" for curriculum intentions between teachers and developers.