It’s not rocket science
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Conclusion and Discussion
6.1 INTRODUCTION

The applied context of this thesis is the implementation of the Northern Netherlands Science Network (“Wetenschapsknooppunt Noord-Nederland” in Dutch), which is a cooperation between schools, universities and out-of-school facilities. The main question is *Do out-of-school science programs contribute to the elicitation, emergence and development of science talent in pupils, and if so, how do situated teaching and learning processes in these programs contribute to the elicitation, emergence and development of science talent?* In this introduction we shall describe the context of the current research, the central concepts, and the structure of the dissertation.

### 6.1.1 Research context

Out-of-school environments are highly valued resources for learning as these contexts usually encompass authentic material and realistic, real-world issues, creating excitement and interest for science (Rickinson et al., 2004) that is less easily accomplished in formal, in-school settings (Bransford et al., 2006). Bridging the gap between different learning contexts (Kumpulainen & Lipponen, 2011) – in-school and out-of-school – is important for making scientific knowledge meaningful. Therefore, connecting in-school learning with learning that takes place during out-of-school visits might foster the elicitation, emergence and development of science talent.

In this thesis, we used the theory of complex dynamic systems (CDS) to identify significant properties that indicate this elicitation, emergence and development of science talent. Although the theory of CDS has rarely been used in research in educational settings (Koopmans & Stamovlasis, 2016b; Kupers, 2014), it does have added value because it provides insights in properties of complex dynamic processes, such as iterativeness and self-organization. These properties help us to understand change in teaching and learning processes (Van Vondel et al., 2016a). Changes within short-term micro-interactions might be signs
for emergent science talent (Steenbeek, Van Geert, & Van Dijk, 2011), which could develop into long-term change. By studying the dynamics of the micro-interactions in the ongoing processes as they occur in reality (Lavelli, et al., 2005), information about the characteristics of these processes can be obtained.

We used the Northern Netherlands Science Network as a context to study the elicitation, emergence, and development of science talent. This network uses the Curious Minds perspective (“TalentenKracht” in Dutch) as a means to understand, approach, and investigate pupils’ science and technology talents. This perspective derives from the assumption that talents emerge and develop in an optimal context in which pupils, adults (the classroom teacher or instructor of an out-of-school activity) and materials interact (Steenbeek & Uittenbogaard, 2009; Steenbeek, Van Geert, Van Dijk, 2011; Steenbeek et al., 2012; Van der Steen, Steenbeek, & Van Geert, 2012). In interaction science talent can enter into a positive spiral of change, in which increasing levels of talent yields further increase in the levels of talent (Steenbeek, Van Geert, Van Dijk, 2011; Wetzels, 2015). Using this prospective point of view, pupils’ talents for science can thus be defined as potentials that can excel within a domain under optimal circumstances. Pupils’ potentials can be recognized by a range of properties, e.g., pupils’ curiosity (Van Benthem et al., 2005) and level of scientific reasoning (Meindertsma, 2014; Van der Steen, 2014; Wetzels, 2015; Zimmerman, 2000).

6.1.2 Central concepts

Three concepts play a central role in this dissertation, namely that of a science network, conceptual understanding, and Expressed Pedagogical Content Knowledge.

A science network, also defined as Science Educational Hubs (Van Uum, Verhoeff & Peeters, 2016), serves as a community of practice in which schools, universities and out-of-school facilities collaborate. The advantage of such collaboration is that, in principle, it enables all parties to work from the same perspective and share the same goals. For successful collaboration that leads to the invocation and stimulation of science talent in pupils, it is necessary that all parties communicate about their goals (Kisiel, 2010, 2014; Wenger, 1999). Additionally, it is important to communicate about how to embed a visit to an out-of-school facility in the school curriculum, by preparing and following up on the visit (Behrendt & Franklin, 2014; Bitgood, 1989; DeWitt & Osborne, 2007; Griffin, 1998; Rennie & McClafferty, 1995).

The second concept is pupils’ conceptual understanding (Scardamalia & Bereiter, 2006), which is a form of operationalization of science talent. According
to Zimmerman (2000), scientific reasoning can either focus on conceptual activities, e.g., the development of conceptual understanding, or procedural activities, e.g., hypothesizing or experimenting. In this dissertation we focused on conceptual activities. Moreover, we focused on conceptual understanding as an aspect of scientific reasoning rather than declarative knowledge (i.e., factual knowledge), because conceptual understanding is a deeper form of knowledge (Ohlsson et al., 2000) that includes the understanding of causal relationships between facts and concepts. “It becomes dark and light because the Earth is spinning” is an example of conceptual understanding, which is much more complex than “That is the Earth”, for example. Conceptual understanding can be elicited by using an open teaching style that is explicitly aimed at conceptual understanding, in the form of thought-provoking questions, encouragements, and think-time. Conceptual understanding is an iterative, socially-situated process of co-construction between instructor (or teacher) and pupil (cf. Azmitia & Crowley, 2001; Kumpulainen & Wray, 2002, Sorsana, 2008), which takes place in real time within a particular context.

The third concept is Expressed Pedagogical Content Knowledge. We introduced this concept to gain more insight into how conceptual understanding is elicited, emerges and develops in a broad network of interconnected variables (Kunnen & Van Geert, 2011), and could achieve this by identifying salient variables that co-occur with conceptual understanding. This means that variables relating to the teacher or instructor were also defined. To that end we used variables associated with Pedagogical Content Knowledge, which is knowledge about ways of representing science content in such a way that pupils can understand it (Shulman, 1986; Van Driel et al., 1998). Although traditionally PCK is conceived of as an internal disposition of the teacher, in this research we picture PCK as concrete, situated and real-time intertwined teaching and learning processes, and for this reason we call it Expressed Pedagogical Content Knowledge (EPCK). Levels of EPCK indicate differences in the quality of the teaching and learning. A high level of EPCK implies a deep transactional process involving both the eliciting activity of the teacher/instructor and the conceptual activity of the pupils. As teaching and learning processes show variability over time and these processes self-organize into (temporary) stable attractor states (Schwartz, 2009; Smith & Thelen, 2003; Van Geert, 2011; Van Geert, 1994), it is likely that EPCK processes themselves can also develop into EPCK attractor states.

6.1.3 Structure of dissertation

This research began by investigating the starting position of ten schools as they entered into collaboration in the, Northern Netherlands Science Network. To indicate potential optimal conditions that contribute to the elicitation, emergence
and development of science talent, an analysis was made of the fit between the aims of the network on the one hand and schools’ goals about science education and science talent on the other (Chapter 2). Then we investigated whether out-of-school practices contribute to the elicitation, emergence and development of science talent, by investigating situated teaching and learning processes in different degrees of program implementation (Chapter 3). To find out how situated teaching and learning processes in these practices contribute to the elicitation, emergence and development of science talent, we investigated a broad network of interconnecting teaching and learning variables that are related to high-quality education. To be able to find significant properties of the CDS in which the teaching and learning processes take place, we investigated whether it would be possible to develop an instrument for measuring EPCK in real-time interaction. To that end, we developed an instrument called the Expressed Pedagogical Content Knowledge Coding Scheme (EPCK-CS) (Chapter 4). To determine how the intertwined teaching and learning processes in out-of-school contexts contribute to the elicitation, emergence and development of science talent, the EPCK-CS was applied to nine cases (Chapter 5).
6.2 SUMMARY OF FINDINGS

In Chapter 2, we investigated the following question: What are the schools’ goals when it comes to science education, science talent, and out-of-school programs, and to what extent are these goals aligned with the aims of the science network that these schools are part of? Key players – namely school managers and teachers who are crucial for maintaining or improving the quality of science education in a particular school – were interviewed using a semi-structured interview design. The ten schools included in this study differed when it comes to a number of characteristics: regular versus special (schools, departments or classes for pupils with special needs due to low achievement or high achievement), reform versus non-reform (schools that have a particular philosophy, e.g., Dalton schools which are based on the philosophy of Helen Parkhurst), and large schools versus small schools. The interviews were transcribed and the data was coded with a multivariate coding system. By applying in-depth analyses of the data gathered, properties were identified of an optimal starting position for collaboration in a science network. Analysis of the data showed that the schools’ key players expressed significantly more goals on classroom level (40% of the utterances; \( p = .001; d = .84 \)) than on school level or outside school level. The key players’ primary concern on classroom level was teachers’ knowledge of science and their skills for developing and carrying out proper science lessons. Based on their characterization schools differed in their uttered goals, which was most salient in specials schools. These schools were more focused on pupils’ inquiry learning (e.g., pupils’ skills in asking questions and scientific reasoning) compared to regular schools. Special schools were also found to be more focused on teachers’ enthusiasm on classroom level, whereas at regular schools there were more preconditions for science teaching, e.g., time constraints, on school level. With regard to the optimal starting position in terms of shared goals between schools and the Northern Netherlands Science Network, it seemed that the best fit concerned the improvement of pupils’ inquiry learning. Friction between goals was found in that the schools were more interested in improving teachers’ knowledge and skills, which is not the primary focus of the network. The Northern Netherlands Science Network was particularly focused on offering stimulating learning environments and on connecting the programs to school curricula, which was of minor interest to the schools. In conclusion, most of the goals of schools tended to be on classroom level, specifically related to teachers’ knowledge. Schools differed in their expressed goals on the basis of their characteristics. In terms of goal alignment, the starting position of schools was only optimal with regard to goals for pupils, and this was especially the case for special schools.
In Chapter 3 we answered the question: Do different degrees of implementation of connected in-school and out-of-school science programs show different situated teaching and learning processes, and if so, does the most optimal implementation show the largest increase in conceptual understanding, relatively to the change in declarative knowledge, in follow-up measurements? The chapter comprises a multiple case study of four upper-primary classes who were involved in a visit to the Kapteyn Mobile Planetarium. Three implementation conditions of a connected in-school and out-of-school program were used: in the optimal program, pupils were prepared for the visit and the instructor and teachers were trained (Case 1); in the marginal program, pupils were unprepared and the instructor and teachers were not trained (Case 4); in the intermediary program, pupils were prepared and only the instructors were trained, whereas the teachers were untrained (Case 2 and Case 3). In each case, the first 800 seconds of the visit and the first 800 seconds of a follow-up lesson were coded with a coding scheme for pupils’ level of cognitive development\(^9\) (conceptual understanding and declarative knowledge) and a coding scheme for the adults’ level of openness\(^10\). Results showed that, regardless of the implementation conditions, pupils’ level of conceptual understanding was related to instructors’ or teachers’ level of support in eliciting pupils’ conceptual understanding over a span of five weeks. On the short-term timescale of a single observation, we found that the instructor/teacher and the pupils co-construct conceptual understanding, although this process was not optimal at every moment during a lesson. This means that at some points in the interaction the support by the instructor/teacher was followed or preceded by pupils’ conceptual understanding, whereas at other points in the interaction no such sequences were found. Trained instructors/teachers (in the optimal and intermediary conditions) showed better support in evoking conceptual understanding than untrained instructors/teachers. Finally, the case in which the optimal program was implemented showed the largest effect on pupils’ conceptual understanding. In this optimal case, the absolute increase in pupils’ conceptual understanding was larger than the absolute decrease in declarative knowledge (p value < .001). This effect was considered to be positive as conceptual understanding is a deeper form of knowledge than declarative knowledge, and therefore a positive change in conceptual understanding relative to the change in declarative knowledge was the preferred outcome. In conclusion, regardless of the implementation condition the adults’ support in eliciting conceptual understanding and pupils’ conceptual understanding was related. Furthermore, trained adults showed more

\(^9\) The scale based on skill theory measures pupils’ cognitive skills and consists of 10 levels, grouped into 3 tiers (sensorimotor, representation, abstraction), and builds in complexity (Van der Steen, Steenbeek, Wielinski, et al., 2012).

\(^10\) The Openness Scale has seven levels to measure instructors’ or teacher’s openness, starting from a closed style, in which the teacher has a leading role (e.g., providing instruction) in the first three levels, moving to a more open form of teaching, in which the pupils have more opportunity to speak (e.g., providing think-time) in the last four levels (Meindertsma et al., 2012).
eliciting of conceptual understanding than untrained adults. Considering the implementation conditions, it seemed that the most optimal implementation resulted in the largest cognitive learning effect.

Chapter 4 describes the development of the Expressed Pedagogical Content Knowledge Coding Scheme (EPCK-CS) and answers the question: *Is it possible to develop an instrument for measuring situated PCK in real-time interaction (EPCK), and if so, how feasible, reliable and valid is such an instrument?* The instrument was developed using theoretical components based on PCK studies and studies about effective science education. Seven theoretical components were defined: Allocated learning time, Teaching style, Instructor’s reaction to pupil’s contribution, Instructor’s reaction to pupil’s conception, Pupil’s complex thinking, Pupil’s contribution, and Pupil’s conception. These components consist of several variables (total of 26), and these variables could be identified as either High-EPCK variables or Non-EPCK variables. Conceptual understanding, for example, was considered to be a High-EPCK variable. The instrument was applied to a 700-second video of a case that comprised pupils of grade 3 (8- and 9-year-olds) visiting a mobile planetarium and an instructor of this out-of-school facility. Results showed that it was indeed possible to develop an instrument and that it was practically feasible to administrate the instrument if the observers were trained in applying the coding scheme. Double coding the data resulted in a satisfying agreement (Viera & Garrett, 2005) with kappa’s between .770 and 1.00 for separate theoretically defined EPKC components. The validity of the instrument was examined by using a principal factor analysis to find latent components that target (aspects) of the theoretical components. The factor analysis revealed that the components together explained 62% of the variance in the data. The first latent component we found was characterized as *Controlled correct declarative knowledge*. This component was related to pupils’ correct declarative knowledge that was reinforced by the instructor as correct. The second component was characterized as *Open teaching, focused on complex thinking (conceptual understanding and declarative knowledge) and pupils’ conceptual understanding*. Teachers’ open teaching consists of asking questions, encouraging pupils to speak, or providing think-time. The third component was characterized as *Closed initiatives*, which encompassed instructors’ initiatives and a closed teaching style (i.e., information, instruction, or confirmation). The fourth component was characterized as *Spontaneous, fragmented conceptions, neutrally judged, extended by means of explanations, or not acknowledged*. This component comprised pupils’ spontaneous contributions in the lessons, which revealed fragmented conceptions (e.g., pupils’ questions). The instructor either acknowledged pupils’ contributions or did not. If the instructor acknowledged the contribution, he or she gave a neutral judgment of the contribution (neither confirmed nor rejected it) and provided follow-up feedback in the
form of explanation (e.g., extended information). A salient result was that a high level of EPCK was distributed over the latent component, and mostly concentrated in the second component. The EPCK-CS was representative of the targeting concept, based on the content found in the transcriptions. It was also representative of the theoretical concept of EPCK. In conclusion, the instrument is feasible, reliable and valid for examining the construct of EPCK, and can thus be fruitfully applied to other cases.

The central question of the study in Chapter 5 was: *Does EPCK show a systematic pattern of variation, and if so, does the pattern occur in recurrent and temporary stable attractor states?* The out-of-school practices comprised an interactive presentation in a mobile planetarium, inquiry-based activities in a science center, a presentation during a lecture for children at the university, inquiry-based activities at a museum, and an interactive presentation in a mobile science classroom. The EPCK-CS was used to code the first 600 seconds of the video recordings of the visits. A principal component analysis was used to reduce the number of components in each case. Cluster analyses were used firstly to give general descriptions of the components, and secondly to find (attractor) states that use the time series of individual cases. Results showed that data on the micro level timescale of seconds could be reduced to a limited number of components by using a principal component analysis. This analysis revealed three or four idiosyncratic components in each case. Together these components explained 55% and 68% of the variance in the data per case. By clustering all components, we found that across cases these components could be described in three ways. Components in the first cluster could be described as *Open teaching focused on eliciting conceptual understanding and pupils’ conceptual (mis)understanding* (General Description 1). The teaching style in these components was focused on eliciting conceptual understanding (rather than on declarative knowledge); and pupils’ conceptual understanding in these components were often related with misconceptions of the science content (e.g., “The Sun shines through the Moon. That is why the Moon shines”). Components with General Description 1 showed a high level of EPCK. The components in the second cluster could be described as *Declarative knowledge and reaction to non-spontaneity* (General Description 2). Components with General Description 2 revealed pupils’ declarative knowledge and the instructor’s reaction to pupils’ non-spontaneous utterances. Hence, these components encompassed a guided discussion about facts, and therefore components with General Description 2 showed a low level of EPCK. The components in the third cluster could be described as *Spontaneity and non-complex thinking* (General Description 3). Component with General Description 3 encompassed pupils’ spontaneous contributions to the interactions, which revealed non-complex thinking. Non-complex utterances are reactions to closed questions (“Yes” or “No”), observations of objects they can find in their
everyday lives, or observations of actions, e.g., “I see the stars!” (if the stars look similar to the stars pupils observe every evening), “You are shining the lamp on the ceiling”. Components with General Description 3 also revealed a low level of EPCK. Applying the clustering technique to individual cases, we found that components self-organize into states of temporary stability. Lastly, in eight of the nine cases at least one particular type of state developed into an attractor state of substantial duration, with recurrent patterns and low variability of dominating components. Based on the dominating components, these attractor states revealed either Non-EPCK, Low EPCK or High EPCK. This means that EPCK (also high-level EPCK) only occurs in episodes, rather than being present all the time. Only in three cases did we find attractor states with a high level of EPCK, and these were cases where the visit was prepared for and the instructor was trained. In conclusion, EPCK indeed shows a variable pattern over the micro-level timescale, resulting in alternating states of different levels of EPCK over time. In most cases at least one type of state of a particular level developed into attractor states. It was only in cases in which pupils were prepared and instructors were trained that states with a high level of EPCK developed into High-EPCK attractor states.
6.3 CONCLUSION

Considering the results of all studies, the first condition for successful implementation of out-of-school programs is communication about goals and the alignment of the school’s goals with the aims of the network (or out-of-school program) as this might help to facilitate a good starting position for out-of-school science activities. The second condition for successful implementation is *preparation* (in the classroom) and *training* for teachers and instructors to apply an open teaching style that is focused on conceptual understanding. This style comprises the asking of thought-provoking questions, encouraging pupils to speak, and providing think-time, rather than using a closed style focused on giving instructions and providing information. In the current research, we found that conceptual understanding is co-constructed by an intertwined process of pupils’ actions and instructors’ actions, which cannot be explained by a simple cause-and-effect relation. Saliently, whenever the second condition for successful implementation was met, a high level of conceptual understanding developed into attractor states of High EPCK.
6.4 THEORETICAL DISCUSSION POINTS

In this section, four issues will be discussed. The first issue concerns implementation conditions for successful out-of-school education. Secondly, we will discuss how science talent is elicited during situated teaching and learning processes within the context of out-of-school learning. The third point concerns how science talent emerges in micro-interaction. Finally, the fourth point of discussion is how science talent develops in situated teaching and learning processes that take place during one lesson or over the course of several weeks.

6.4.1 Conditions for successful implementation of out-of-school programs

A necessary condition for successful collaboration in out-of-school programs is that participating partners communicate about and share goals (Kisiel, 2010, 2014; Tal & Steiner, 2006). In this thesis, we found that schools’ goals differed from the aims of the network in all cases except for their goals concerning pupils. Another salient result was that school characteristics (special versus regular, reform versus non-reform, large versus small) are connected to what schools find important, and that therefore schools’ optimal starting positions differ on the basis of these characteristics. Schools and out-of-school facilities should be aware of the differences when it comes to goals and find ways to adapt to one another in order to build bridges between learning in different contexts (Kumpulainen & Lipponen, 2011). Furthermore, we found that for successful out-of-school education in which conceptual understanding emerges, it is necessary that instructors and teachers are trained in eliciting conceptual understanding and that pupils are prepared for the visit. Other studies have also found that preparation is important (e.g., Behrendt & Franklin, 2014; Bitgood, 1989; DeWitt & Osborne, 2007; Griffin, 1998; Rennie & McClafferty, 1995). In accordance with Durlak & DuPre (2008), training those who carry out interventions is one of the success factors for implementation. Scholars in the field of out-of-school education also stress the importance of training both teachers (e.g., Behrendt & Franklin, 2014; Griffin, 2012) and instructors (e.g., Ash, Lombana, & Alcala, 2012).

In conclusion, schools differ – based on their characteristics – in the extent to which optimal fit exists between their goals and the goals of the network (or out-of-school programs), and this might determine the potential success of the out-of-school programs. The optimal conditions for the emergence of conceptual understanding are the presence of instructors or teachers who are trained in eliciting conceptual understanding, and the preparation of pupils before the visit.
6.4.2 How is talent elicited in situated teaching and learning processes?

We found that, in the context of out-of-school practice, conceptual understanding is elicited in real-time interaction by an instructor or teacher who uses an open teaching style, in which he or she asks questions that evoke conceptual understanding, encourages pupils to deepen their thoughts, and provides think-time. This finding indicates that the instructor or teacher has an important role in supporting or scaffolding pupils’ thinking (Hmelo-Silver et al., 2007; Van de Pol et al., 2010; Van Geert & Steenbeek, 2005). The importance of instructors’ scaffolding has also been acknowledged and investigated by Ash et al. (2012). The instructor’s elicitation of conceptual understanding in pupils during episodes of high-level EPCK sometimes amounts to the elicitation of misconceptions, or it implies a reaction to pupils’ misconceptions. This is in accordance with the finding in studies about PCK that misconceptions of pupils shape teachers’ PCK (Park & Oliver, 2007; Shulman, 1987; Van Driel et al., 1998), as at that moment the teacher has to use strategies to change conceptions for the better. Consider the following example described in Chapter 4. The instructor: “...and if we wait a little bit, the Sun will go down even further – until it sets. Do you know what that means?” The pupil answers: “Then the Moon comes.” This example shows that the pupil made a connection between the setting of the Sun and the rising of the Moon. The fact that the pupil thought that the Moon would come up when the Sun sets, could possibly indicate that the pupil did not understand that the appearance of the Moon is related to the spinning of the Earth and to the Moon’s orbit around the Earth. A way to find out exactly what the pupil was thinking is to ask follow-up questions, e.g., “How do you think it happens exactly, that the Moon rises when the Sun sets?” Asking (follow-up) questions is a form of scaffolding (see also e.g., Engel, 2011; Van Schijndel, Franse, & Rajmakers, 2010; Van de Pol et al., 2010), which supports pupils in thinking toward their “zone of proximal development” (Chin & Chia, 2004; Hmelo-Silver et al., 2007; Vygotsky, 1978).

In conclusion, the instructor has an important role in scaffolding pupils’ conceptual understanding by using an open teaching style that is focused on conceptual understanding, and this is likely to evoke misunderstanding in real-time interaction, which in turn shapes the instructor’s (expressed) PCK again. This is an example of an iterative process – the kind of process that is typically described in the context of theory of CDS.

6.4.3 How does science talent emerge in micro-interaction during situated teaching and learning processes?

Studying the micro-interactions of a broad network of interconnecting variables
revealed that the number of variables could be reduced to a maximum of four underlying components (components of intertwined teaching and learning processes). Factor analysis showed that pupils’ conceptual understanding is the result of a concerted effort of both pupils and teacher during processes of interaction that we can qualify as high-level EPCK, whereas spontaneous contributions of pupils typically occur in components of low-level EPCK. The components of intertwined teaching and learning processes in which the level of EPCK is expressed show a variable pattern with alternating peaks of different levels over time. This means that usually conceptual understanding (as a way of expressing science talent) and pupils’ spontaneous contributions to the interaction do not usually co-occur during lessons or, in this particular case, out-of-school activities. Although, pupils’ spontaneous contributions might occur in the form of expressions of curiosity caused by an intrinsic desire for knowledge (Berlyne, 1960; Engel, 2011), i.e., pupils’ spontaneous questions, we found that pupils’ spontaneous utterances often take the form of non-complex utterances. These spontaneous utterances were not always acknowledged by the instructor, which means that the instructor did not scaffold the spontaneous interaction to a higher level. Complex thinking (e.g., conceptual understanding) requires structure and guidance from an adult (teacher or instructor) who is able to scaffold the performance of pupils to a higher level. This finding is in accordance with other scholars who found that pupils perform better in structured, guided conditions (e.g., Alfieri et al., 2011; Meindertsma, 2014).

In conclusion, the broad network of interacting variables on the micro-level indicates that the emergence of science talent can be reduced to four or less components. Descriptions of the components revealed that spontaneity and eliciting conceptual understanding do not co-occur in the same component, indicating the need for more scaffolding of pupil’s spontaneous, non-complex utterances to a higher level of understanding.

6.4.4 How does science talent develop in situated teaching and learning processes?

The fourth theoretical issue reveals the knowledge we gained about the development of science talent in situated, intertwined teaching and learning processes during a lesson and over the course of several weeks. We found that science talent emerges on the micro level because of the variable patterns of the teaching and learning processes, and develops over a longer-term timescale of five weeks. Moreover, over the course of one out-of-school activity, the intertwined teaching and learning process develops towards attractor states of which one could be a High-EPCK attractor state. High-EPCK attractor
states are comparable with learnable and teachable moments (DeWitt, 2012; Haug, 2014) and talent moments (Steenbeek et al., 2011), in which pupils are helped towards conceptual understanding by the instructor or teacher and are motivated to learn about particular science concepts. Pupils and instructor optimally co-construct understanding in these High-EPCK attractor states, and this phenomenon is comparable with what Seymour & Lehrer (2006) defined in a study about Pedagogical Content Knowledge as “orchestrated classroom conversation”. In these moments teachers’ or instructor’s practices are attuned to pupils’ needs.

High-EPCK attractor states always alternate with other states with a lower level of EPCK, indicating that (elicited) conceptual understanding is not constantly present. The teaching and learning process shows a pattern of peaks in emergent science talent, rather than showing a constant level of expressed science talent. Over all cases, a relatively low frequency of High-EPCK states was found, namely in three cases. Their scarcity might be a fundamental feature of such states. Given all the constraints on situated, real-time teaching and learning, the best that can be expected is a certain frequency of such high-level EPCK states. It is likely that other types of states (especially low-level EPCK or non-EPCK) are needed to prepare for the occurrence of high-level EPCK and afterwards to process such states. This alternating pattern of high-level performances is consistent with what is known in CDS studies as “scalloping” (Fischer & Bidell, 2006; Fischer, Yan, & Stewart, 2003; Schwartz, 2009). The process can be likened to the shape of scallop shells, building up gradually and then dropping again. It is no big surprise, as such processes often take place when new skills are being learned that are difficult to apply (Fischer & Immordino-yang, 2002). Conceptual understanding is a complex skill as it encompasses the formulation of representations and abstractions of concepts. The scaffolding task of the adult is important for creating the peaks in the pattern of scalloping (Fischer et al., 2003). It is known that scaffolding in the form of asking thought-provoking questions, which is to elicit conceptual understanding, is a difficult skill for teachers (Chin & Chia, 2004; Roth, 1996). Chances are that this is also the case for instructors. It might explain why the scalloping pattern is present in all cases and the number of high-level EPCK episodes, comprising high-level conceptual understanding, is rather low.

In conclusion, teaching and learning processes on the micro-level timescale self-organize into attractor states. In this thesis, we showed that attractor states reveal different levels of EPCK. Attractor states with a high level of EPCK indicate the existence of science talent moments, which were only found in a few cases, and these attractors show an alternating pattern over time.
6.5 METHODOLOGICAL ISSUES

In this section, we discuss the merits and the limitations of the used methodology. Firstly, we discuss the importance of studying situated processes in case study designs. Secondly, we discuss the value of studying development by means of both short-term and relatively long-term studies.

6.5.1 Multiple case study design and the measurement of talent

In this thesis, we used situated teaching and learning processes to gain insight into how out-of-school programs contribute to the elicitation, emergence and development of science talent. In order to do so, we needed to observe the ongoing processes as they occurred in real, naturalistic out-of-school activities. Due to the labor-intensive nature of analyzing the dense measurements the data provided us, this method of observation is practically confined to the use of small sample sizes (cases). This approach contrasts with typical educational research, which uses large sample sizes for reasons of statistical power (Stamovlasis, 2016). Designs with a large sample size (e.g., designs that compare a group of pupils who followed an out-of-school program with a group of pupils who did not, as to their increase in conceptual understanding) typically make the assumptions that random variation is distributed over pupil properties and other contextual variables in the sample, and that random variations are independent from one another. The question, however, is whether variance found in the sample accounts for intra-individual variation. It is unlikely that the same type of results will be obtained in individual case designs as in typical group designs (Koopmans & Stamovlasis, 2016a; Molenaar & Campbell, 2009). It is most likely that teaching and learning processes are non-ergodic and that detailed analysis of individual cases is required if our aim is to understand the structure and properties of real-time processes of teaching and learning (Koopmans & Stamovlasis, 2016a). It can also be expected that cases are idiosyncratic, as is found in our EPCK study (different cases showed variations in the content of the EPCK components) and in other studies about PCK (e.g., teachers develop their PCK in different ways, see, e.g., Coenders, 2010; Van Driel et al., 1998). Idiosyncrasy implies that individual cases may not fit the group description at all (Gu, Preacher, & Ferrer, 2014).

Studying situated, intertwined teaching and learning processes in case study designs provided us with information about the relationship between pupils, instructors, teachers and other contextual variables that cause the elicitation, emergence and development of science talent (cf. Koopmans, 2016). By using carefully chosen cases (Flyvbjerg, 2006; Yin, 2009) that are relevant
and sufficiently different due to their properties, the current research made a valuable contribution to the existing knowledge about science talent and out-of-school learning. Furthermore, by studying situated, intertwined teaching and learning processes in these case studies, we have added to the existing research of PCK, as it provided a theoretical, methodological and empirical focus on the way in which PCK emerges in real time. This resulted in an instrument (EPCK-CS) that can be used to measure the new phenomenon EPCK across the different domains of science education (e.g., astronomy, physics), without losing the data of the context (and domain) in which the teaching and learning processes took place.

In conclusion, we are not merely concerned with aggregated information about differences between groups when it comes to conceptual understanding. Instead, given our CDS point of view, we are interested in how conceptual understanding occurs and self-organizes, and how this process is affected by events that are external to it (e.g., type of out-of-school activity, school characteristics, preparation in the classroom, training). By using small sample sizes, we were able to gain more insight into the actual process of elicitation, emergence and development of science talent, which might also be representative of cases with similar properties. By studying situated, intertwined teaching and learning processes in cases, we were able to develop an instrument that is applicable to a wide range of domains within out-of-school education, and probably also within in-school education.

6.5.2 Can we indicate the long-term effects of out-of-school programs?

In order to find out if and how out-of-school programs contribute to science talent, the aspect of time needs to be taken into account. However, it is important to notice that time is not a uniform dimension, i.e., time occurs on a variety of timescales. In this thesis, we have focused mainly on the short-term scale. However, if we want to understand changes in the long run in terms of long-term transformation or of remaining in the same position (Koopmans, 2016), e.g., a more or less constant, significantly larger level of conceptual understanding, or significantly longer EPCK attractor states, we need to observe the interaction over a larger time span. This larger time span was only taken into account in the study described in Chapter 3. The results suggest that the micro timescales are nested inside the longer-term scale. The open teaching style used in the out-of-school activity in the semi-optimal Case 3, for instance, resulted in pupils’ increased conceptual understanding during the activity itself, and this might also have had an effect on the observed increase in pupils’ conceptual understanding without the support of the teachers during the follow-up lesson five weeks later. Signs of emergent science talent, i.e., conceptual understanding, can therefore be found in short-term observations and these processes may develop into more complex or more prevalent understanding.
With regard to development of high-level EPCK as an intertwined concept of science talent, the current research can only provide an indication of the long-term effect based on the short-term dynamics. For instance, it is likely that attractor states of high-level EPCK might recur in long-term development. Additionally, conceptual understanding elicited and developed in visits with High-EPCK attractor states might become more robust in the future. For instance, it will become easier to soft-assemble high-level EPCK attractor states during the teaching and learning process, and high-level EPCK attractor states will become more frequent. However, we have not investigated this long-term relation, as we had no long-term out-of-school programs at our disposal in which the same pupils-instructor combination was repeated over several lessons. As we perceived EPCK as an intertwined instructor-pupil property, the same setting would be required for a study into long-term effects. Additionally, we were not able to investigate the relation between goals of schools with different characterizations and the teaching and learning processes that took place during their out-of-school visits. This would have been necessary in order to determine whether schools with optimal starting positions indeed show more effective teaching and learning patterns. In conclusion, to measure the development of science talent it is important to take into account time – in the form of a variety of timescales. Even measurements of (elicited) conceptual understanding in the short term are important, since these processes are nested inside long-term timescales. Conceptual understanding, which can emerge in the micro-interaction, is a sign of the long-term development of science talent. In order to investigate long-term development of attractor states, the same pupil-instructor coupling is required.
6.6 FUTURE RESEARCH

6.6.1 Future research on emergent and elicited science talent in out-of-school science programs

As a means to contribute to the external validity, it would be interesting to observe emergent science talent in cases that potentially have the same properties. In the current research, we found these properties by observing natural processes. Additionally, in the first study (described in Chapter 2), we found that school characteristics play an important role. In future research, it would be interesting to observe the intertwined teaching and learning processes in out-of-school activities of special schools across other science networks using the EPCK-CS, and to compare the analysis with regular schools. This will prove whether school characteristics are indeed related to the emergence of science talent. Representative cases which show significant patterns can be chosen to explain differences within the group and between the groups (Van Vondel et al., 2016a).

6.6.2 Future research on eliciting science talent

In this dissertation, the construction of the feedback loop between teacher/instructor and pupils is still underexplored. One way to find out exactly what and who is causing the feedback loop, is by investigating successions of utterances in the dyads and analyzing these dyads by means of a transition diagram (Guevara Guerrero, 2015; Steenbeek et al., 2012; Van Vondel et al., 2016a). A transition diagram visualizes the successions of variables, using transition matrix technique. A transition matrix consists of a cross table in which all the possible combinations of utterances and their relative proportion of occurrences are listed. To illustrate the benefits of studying the feedback loops between pupils and instructor, we applied this technique as an example to the follow-up lesson of the optimal case (Case 1) in study 2 (described in Chapter 3). By doing so, significant successive relations between utterances can be found (see Figure 1).

In this example, it turned out for instance that when the instructor evoked conceptual understanding, the utterance was followed by pupils’ conceptual understanding in 40% of the cases. This is an indication that conceptual understanding is indeed co-constructed by teacher and pupils, and that this co-construction starts with evoking. Another way of gaining more information about how instructors and pupils mutually influence each other as coupled systems, is by using the cross recurrence quantification analysis (De Jonge-Hoekstra, Van der Steen, Van Geert, & Cox, 2016; Shockley, Butwill, Zbilut, &
Webber, 2002). This analysis might provide information about the temporal relation between pupils’ conceptual understanding and instructors’ elicitation, and the relative strength and direction of this relation. However, if techniques such as transition diagrams or cross recurrence quantification analysis are used, we suggest to accompany significant patterns with transcriptions of utterances by pupils and instructors in which these relations are indeed identified – comparable with what was illustrated in Chapter 4. By doing so, it is possible to check whether the quantitative relationship also entails a relationship on the level of content. For instance, the instructor’s support in elicitation of conceptual understanding might be caused by the previous pupil’s conceptual understanding, or this support might actually be an initiation to which the pupil responds by showing conceptual understanding, or the support in elicitation of understanding might not be based on the same topic (e.g., question and answer do not have any relation). By using transcriptions, a qualitative interpretation of the relation can be provided.

6.6.3 Future research on science talent development

To further investigate how emergent talent on the micro-level develops over the long-term timescale, it would be interesting to find out whether schools that fit all the conditions for successful out-of-school education indeed show more effective teaching and learning patterns, in terms of developing High-
EPCK attractor states. In the current thesis, the special schools typically showed the most optimal fit (see Chapter 2), and two of the three cases with High-EPCK attractor states were special schools that were indeed involved in the baseline picture analysis. It would be interesting to find out whether similar optimal teaching and learning patterns can be found in other schools with similar conditions for successful implementation, and to find out how special schools differ from regular schools in their teaching and learning processes.

Secondly, it would be interesting to investigate long-term effects of out-of-school programs with the same instructor-pupil settings. In that way attractor states on the long-term timescale could be detected, using the coding scheme provided in the studies described in Chapter 4 and 5, and the analyses used in the study of Chapter 5 (principal component analysis and cluster analysis). Conditional for such research is the existence of long-term out-of-school programs that are accessible to the researcher, which was not the case during the current research. For out-of-school science learning, such research would contribute to the limited existing studies on the long-term effect of out-of-school education (Bamberger & Tal, 2008a; Popovich & Zint, 2012; Rennie, Feher, Dierking, & Falk, 2003).
6.7 IMPLICATIONS FOR PRACTICE

In this section, the practical implications of effective out-of-school education are described. The first implication concerns the conditions for successful implementation of out-of-school programs. The second implication concerns the development of sustainable attractor states of high-level EPCK.

6.7.1 Creating conditions for successful implementation

There are three success factors for out-of-school learning. The first is creating an optimal fit between schools’ goals and goals of the out-of-school program (or science network), the second is preparation for the visit, and the third is training for the instructors and teachers in applying an open teaching style that is focused on conceptual understanding. With regard to the optimal fit, this might be reached through communication between the schools and the science network/out-of-school facility about shared goals. This might have a positive spin-off in multiple ways. Firstly, when schools become aware of the aims of out-of-school programs, they can adapt their curriculum to the content of the visit in order to create a successful connection. Secondly, the articulation of goals concerning science education establishes awareness of a school’s practices and its current approach to talent, which might also result in adaptation of in-school education. Thirdly, when the goals of schools are communicated, out-of-school programs can be adapted according to the needs of schools. With regard to the latter, out-of-school instructors should be aware of the fact that for schools with different characteristics (e.g., special versus regular), the visit has different purposes. Using the baseline picture protocol, the goals can be identified that are related to certain school characteristics.

A second success factor is preparation for the visit, through embedding the visit into the school curriculum. This implies an important role for the teacher. A teacher’s insufficient background knowledge, inadequate skills at applying this knowledge in effective teaching (i.e., pedagogical content knowledge), and lack of time to prepare will greatly reduce the effect of out-of-school programs (see also e.g., Tal et al., 2005). Out-of-school organizations can overcome these constraints in two ways. Firstly, they can provide material with background information and practical recommendations for using the content (e.g., type of questions), such that teachers will feel more competent in preparing for the visit. Secondly, teachers’ development of PCK can be facilitated by inviting them for a pre-activity visit to the site. Inviting teachers to the site has been proven to be effective (Davidsson & Jakobsson, 2012). It enables teachers to identify problems that particular pupils might have with particular subjects, for
instance, which is knowledge that the instructor does not have. On the other hand, the instructor has a lot of content knowledge, e.g., the background of specific exhibits (Griffin, 1998). Communication about these issues (Kisiel, 2014) would put the teacher in a more empowered (cf. ownership in Durlak & DuPre, 2008) and, in our view, potentially more engaged position with regard to the actual out-of-school activity. If we want to improve the connected in-school and out-of-school programs, to guarantee that the out-of-school programs will have a sustainable impact, the instructors must also address the active role of the teachers (Tal et al., 2005). It is clear that following these first two suggestions will be time-consuming. However, this investment of time is certainly worthwhile, given the positive results found in this research. Moreover, if a better connection is made between in-school and out-of-school learning, out-of-school programs can serve as a means to achieving higher academic standards. In that way, instead of being something that simply adds to mandatory work in school, the visit is a way to achieve goals. Indeed, pupils show more conceptual understanding in programs in which they are prepared for the visit and in which the instructor or teacher knows how to elicit this understanding.

The third success factor is training. Instructors can only provide the suggested support if they themselves know how to increase the level of EPCK in out-of-school activities. The principles for applying a high level of EPCK—by means of an open teaching style that is focused on the support of conceptual understanding—can be learned in a short training, which in the current research has proven to be a successful ingredient for out-of-school learning. Similar short trainings can be provided for teachers.

In conclusion, in order for out-of-school science programs to be as successful as possible, coordinators of the science networks should communicate with schools about the goals of out-of-school learning, and instructors should stimulate teachers’ ownership and address their active role. Additionally, for learning to apply EPCK, a short training in open teaching skills that are focused on conceptual understanding is suggested.

6.7.2 Developing sustainable attractor states of High EPCK

For eliciting science talent and developing them during out-of-school activities, teachers and instructors need to create attractor states of high-level EPCK. Development of attractor states starts with the micro-interaction between the instructor or teacher and the pupils. For adults, this means that they need to ask questions that elicit conceptual understanding, encourage pupils to deepen their thoughts, provide them with think-time after questions, and ask
follow-up questions after a pupil has given an answer. Additionally, adults need to be aware of the first sign of science talent, which is a pupil’s expressed conceptual understanding, even if this entails a misunderstanding. Although we found that spontaneous utterances by pupils did not tend to occur in the same time sequence as conceptual understanding, they are still a sign of emergent talent. Moreover, whenever observing this sign, it is a challenge for teachers and instructors not to fall back into Non-EPCK attractor states unnecessarily.

For instance, instead of giving an explanation themselves, instructors can ask follow-up questions. However, support from an instructor or teacher of pupils’ conceptual understanding is not just limited to an open teaching style that is focused on conceptual understanding. Sometimes it is too difficult for a pupil to respond to an open teaching style (e.g., an open question). The instructor or teacher might then want to switch to a closed style, in which the information or instruction is provided. Also, these styles can influence the effect on pupils’ conceptual understanding, shown for example by their use of analogies (Dunbar & Fugelsang, 2005; Dunbar, 2000; Lehrer & Schauble, 2006) and (causal) explanations (e.g., Fender & Crowley, 2007; Tenenbaum et al., 2004; Van Schijndel et al., 2015). As a means of scaffolding pupil understanding, the teacher/instructor should adapt the style (closed or open) to the needs of the pupil at that particular moment in time.

In order to create sustainable attractor states of high-level EPCK in out-of-school education in the long run, a single training might not be enough. Video-recorded moments in which attractor states of high-level EPCK are expressed can be used in coaching sessions, in order for these attractor states to become more common. Additionally, these recordings can be used as exemplary cases for other (new) instructors in training sessions. Long-term training that uses videos to reflect on practices has proven to be successful for (museum) instructors (Ash et al., 2012). For teachers, similar coaching programs are suggested. For effective out-of-school programs, coaching should take place during each step of the program: a preparation lesson in the classroom, the visit itself, and a one or more follow-up lessons in the classroom. Additionally, these skills in applying an open teaching style and scaffolding pupils’ understanding can already be learned during teacher education, in order for teachers to develop their high-level EPCK into sustainable attractor states, which will most likely influence the effectiveness of out-of-school programs. Only little attention is paid to out-of-school learning during teacher education, though out-of-school visits during their education are helpful for prospective teachers to become familiar with science concepts and teaching skills (Tal et al., 2005; Tal, 2004), and thus to develop PCK.

In conclusion, for pupils’ science talent to emerge and to develop, instructors/
teachers should be aware of the first signs of science talent in their pupils (i.e., conceptual understanding and spontaneity) and take up their role in further eliciting this talent. They can do so by using an open teaching style that is focused on conceptual understanding, or by using effective closed strategies whenever open ones are still too difficult and do not help pupils understand the science content. Skills for applying an open teaching style can be learned in a short training or in teacher education itself, and can be further developed by means of video-feedback coaching. It's not rocket science if teachers and instructors become aware of their own talent in evoking pupils’ science talents!