The dynamics of children's science and technology talents: A conceptual framework for early science education

This article aims at discussing a theoretical framework for improving and evaluating science education for young children. This theoretical framework is intended to serve as a piece of usable knowledge for projects aiming to improve science education in primary schools. Major concepts such as science and technology talents of young children, the ability of adults to 'see' these talents, and the talent map (its dimensions and relation with brain development) are discussed. In our view, scientific talent is an emergent property. That is, talent for science and technology can emerge in every child if an upward dynamics can be established in the dynamical interaction between the child, the teacher and the material. In conclusion, general implications for schools with regard to science and technology talents in young children and how to promote these talents are discussed.
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In 2005, three Dutch scientists, among whom the president of the Dutch Academy of Sciences, started a research initiative to promote science and technology skills and interest in young children. The initiative was christened 'Talent Power' (Talententenkracht in Dutch). Although the official English translation of the program is 'Curious Minds', the literal translation of the Dutch *Talentenkracht*, Talent Power, better conveys the meaning and connotation that this word has for Dutch speakers. The word 'power' in the title is reminiscent of expressions such as 'girl power', which combine the concept of power with concepts that are not usually associated with it. The initiative emphasised that young children have a wealth of unexplored potentialities for scientific reasoning and exploring, and that adults, parents and teachers must learn to see these talents rather than ignoring them (Van Benthem, Dijkgraaf, & De Lange, 2005). Research groups were invited to participate in the initiative, which was hosted by a governmentally financed Institute for Educational Policy in Science and Technology (PBT, Platform Beta Techniek).

In 2009, the Ministry of Education launched a so-called Master Plan 'Opportunities for talent in science and technology', which explicitly endorses the principles of the 'talent power' initiative but also emphasises the importance of knowledge about brain development and neurocognitive processes for stimulating the science and technology talents of young children.

The aim of this article is to discuss a theoretical framework for improving and evaluating science education for young children, which is one of the results of a year of intensive cooperation between two academic research groups, two colleges for teacher education and five primary schools in the Netherlands (for a discussion of the other results we refer to Steenbeek, Van Geert, & Fraiquin, 2010). This theoretical framework, which resulted from work in the research schools spirit (Fischer, Goswami & Geake, 2010; Fischer, 2009), is intended to serve as a piece of usable knowledge for projects aiming to improve science education in primary schools.

Major concepts

The policy papers accompanying the Talent Power program refer to a number of crucial but not very well-defined concepts and terms associated with a particular (but again not very well defined) educational approach. This lack of clarity is probably not uncommon in policy documents, which challenges educators and scientists to come to clear but also usable specifications of the important terms.

The first major concept is that of (science and technology) talent. The advantage of using this concept is that it takes a positive stance and focuses on the existing talents of young children, instead of associating the aim of improving science education to a deficit approach ('we're lagging behind other countries!'). It uses a 'democratic' view on talent, in the sense that it assumes that every child is talented. In our observation, the disadvantage of the term talent is that most teachers, parents and school boards see it as a rare gift to the happy few. Even the scientific literature often puts it on a par with the concept of giftedness. For instance, the Oxford Dictionary of Education treats giftedness and talent basically as synonyms, and defines talent or giftedness as 'A term applied to pupils who have abilities which are developed to a level significantly above that of their year group, or who are judged to have the potential to develop such abilities' (Wallace, 2009). The literature seldom uses a fundamentally developmental notion of talent, as something that can emerge if the conditions are right. If teachers and policymakers tend to follow the dominant idea that talent is a gift, given to some but not all, they are likely to hold a so-called entity or dispositional view on talent. There is a wealth of research now that shows that such a dispositional view, in the learner and the teacher, is likely to hamper development and to reduce effort in learning and teaching. An incremental view on the other hand, defining an ability as something that can grow and develop as a consequence of educational effort, is likely to increase the teacher's and student's learning oriented activity, leading to higher development in comparison with disposition-oriented forms of teaching (see for instance Dweck, 2007; Dweck, Chiu, & Hong, 1995; Blackwell, Trzesniewski, & Dweck, 2007; Leroy, Bressoux, Sarrazin, & Trouilloud, 2007; Pajares, 1992; Calderhead, 1996; Runco & Johnson, 2002); people tend to adopt the dispositional versus incremental view of psychological abilities held by the organisation they work for (see Murphy & Dweck, 2010).

That is, the (implicit) theory of the teacher and the learner about a particular ability — in this case the ability to think scientifically in young children — is of great practical importance. Consequently, if there is any scientific evidence for the fact that particular abilities should in fact be seen as incremental instead of dispositional, and emergent instead of predisposed, this evidence should be made part of the (implicit) theories of science reasoning talent in teachers, also because the implicit theories of teachers have a major effect on the implicit theories of their students. Hence, there is a need for a usable, developmentally oriented notion of talent, if such a notion can be backed up by scientific evidence.

The second major concept in the programs is that of the adult's ability to 'see' the talented reasoning, acting and exploring of young children in the context of science and technology problems. This emphasis on the adult's ability to perceive is in line with the literature on expertise, which is that a crucial property of an expert is the ability to perceive, structure and evaluate information relevant to the field of expertise. In this case, it means that the expert has the ability to intuitively pick up the educationally relevant information in the child's behaviour (Hogan & Rabinowitz, 2009). It goes against the misunderstanding that experts are primarily characterised by explicit knowledge or by the ability to carry out highly protocolled chains of action. An advantage of this notion of expertise is that it forms an excellent starting point for an empowerment-oriented way of professionalising teachers, which must lead to better informed intuition and immediate and adaptive action. A disadvantage of this emphasis on the perceptual aspects of the expertise is that it may lead to the belief that seeing alone is enough and that the learning and development will take care of themselves. However, a developmentally oriented approach to science education requires that educational action and perception are coupled in a continuous dynamic loop. The question is of course to find out, together with the teachers, how such a loop can be established. In short, there is a need for a developmentally oriented notion of teachers' (and other adults') 'seeing' talented science reasoning, action and exploration.

The third major concept introduced in the programs is that of the *science talent map*. The Master Plan policy document defines the talent map as an evidence-based instrument that provides insight into the question which science talents children have (Master Plan, page 19). From this document, it is not particularly clear whether the talent map explores the child's science learning potential, or whether it is intended to describe a status quo, based on standard testing results, e.g. cognitive tests of what children can accomplish in the context of science and technology problems. What is needed, however, is a map of potentials of children as well as educators, which helps practitioners to stimulate development and explore new ways instead of unnecessarily confining their actions to wrongly interpreted normative data.

In this article, we shall provide usable specifications of these major concepts that resulted from the close collaboration with educational practitioners. We shall defend the following position with regard to the children's talent for science and technology reasoning: talent is an *emergent*, *distributed* and *dynamic* property. Furthermore, we shall contrast this view with what we see as more or less the standard view on talent, which is that talent is something that is either present or not in the person (i.e. not emergent), that it is a property within the person (i.e. that it is not distributed across the person and beneficial contexts such as good teachers and rich learning environments), and finally that it is some sort of fixed property in the form of a gift (instead of being something dynamic and changing).

The scientific context

As early as kindergarten, science programs can lead to an understanding of scientific (including mathematical and technological) concepts, principles and practices that far exceed the level of understanding children would develop under more traditional forms of teaching (Mantzicopoulos Patrick, & Samarapungavan, 2008; Mantzicopoulos, Samarapungavan, & Patrick, 2009; Gelman & Brenneman, 2004; Scientific American, 2010; Tytler, Waldrip, & Griffiths, 2004; Sarama & Clements, 2009; Hapgood, Magnusson, & Palincsar, 2004; Lehrer & Schauble, 2005; Lehrer, Schauble, & Lucas, 2008; Metz, 2004, 2011). All successful programs are based on a smart mix of active and inquiry learning, the child's self-regulated exploration and questioning and educational guidance and teaching by teachers with high-level educational skills (Alfieri, Brooks, Aldrich, & Tenenbaum, 2010; Kirschner, Sweller, & Clark, 2006; Mayer, 2004). However, in the context of discovery learning, adequate support is not a trivial issue. On the one hand, it requires highly developed questioning skills that not all teachers possess and need to be thoroughly trained (Roth, 1996; Barber, & Mourshed, 2007). In successful science learning and education, the professional quality of the teacher is a key factor (Barber, & Mourshed, 2007; Van Aalderen-Smeets, Walma van der Molen, & Asma, in press). In order to obtain a better understanding of these processes of active inquiry learning and self-regulated exploration and questioning in the context of expert educational guidance, we apply the framework of complex dynamic systems theory to education and development (for general introductions see Van Geert, 1991, 1994; Van Geert & Steenbeek, 2005a).

The theory aims to explain how processes self-organise in the interaction between the short-term dynamics of action and the long-term dynamics of development. As regards the educational context, we rely on the following conceptual models. The first is a *dynamic model of (short-term) joint action* (Steenbeek & Van Geert, 2007, 2008, Van Geert & Steenbeek, 2005b; Steenbeek & Van Geert, submitted). According to this model, activities emerge through the intertwining of the actions of agents that participate in this event with particular interests or concerns, evaluations, communications and tools to realise their interests. In an educational context, the major interests or concerns are those of competence, autonomy and relatedness (e.g. Deci & Ryan, 2009). These major concerns apply to the children as well as to the adults, for instance the teacher. Concerns are not fixed, but self-organise in the interaction (for instance in the form of the science activity in the classroom actively involving both teacher and children; see Steenbeek & Van Geert, submitted).

A second source of background inspiration is *the dynamic model of (long-term) scaffolding and of co-adaptation* (Van Geert & Steenbeek, 2005b; Steenbeek, Jansen, & Van Geert, submitted; Van Dijk, Van Geert, & Steenbeek, 2010). According to this model, growth, learning and development are deeply transactional processes. They can be seen as 'push-me pull-you' kinds of processes, where the child's progress triggers the adult's adaptive action to the child, which forms a primary condition for the child's development. Transactional processes and co-adaptation can explain successful and even unexpected growth, as well as stagnation and eventually decline of development. The transactional nature of development and education makes those processes utterly complex and basically self-organising. An understanding of this self-organising complexity of the developmental and educational process is an antidote against simplistic views on how development can be enhanced by 'introducing better educational programs or curricula'. In line with the research schools concept (Fischer, 2009; Fischer, Goswami, & Geake, 2010; Doucerain & Schwartz, 2010), teachers can inform researchers about the concrete, here-and-now complexity of teaching, whereas researchers can inform teachers about dynamic systems and complexity thinking as a framework for understanding the activity of teaching and educational reform.

Explaining the development of science talent in young children

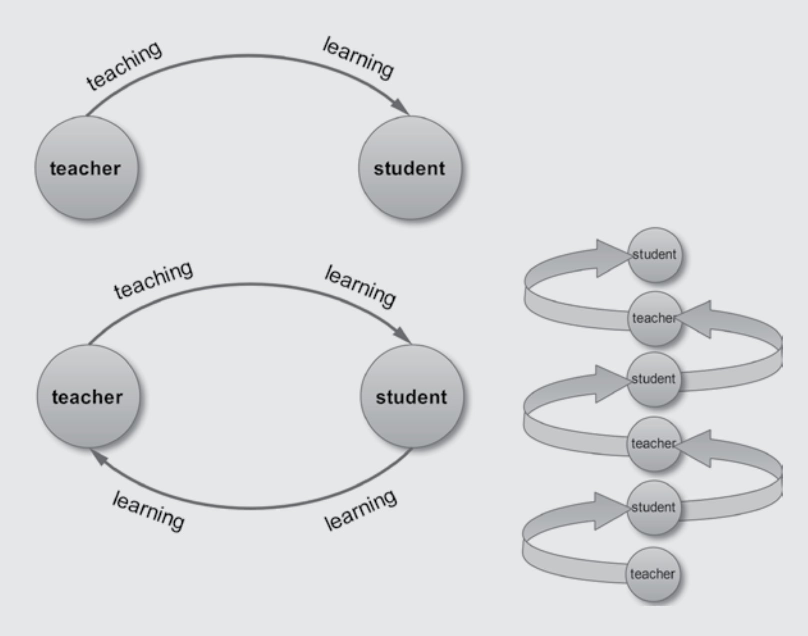
It is now widely accepted that science education is aimed at promoting conceptual and representational change in children (Carey, 2000; Mazens & Lautrey, 2003; Vosniadou, 1994; 2007, 2009; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001; Singer, 2007). We see this conceptual and representational change as the long-term process of change in the child's ability to construct explanations, make predictions, solve concrete problems, select and manipulate contexts and to negotiate help and assistance in getting the job done in the context of situation-specific, real-time and embedded action (Van Geert, 2008; Van Geert & Steenbeek, 2005a), Van Geert & Fischer, 2009). That is, the child's science and technology talent takes the form of what Fischer has called a *dynamic skill* (Fischer & Bidell, 2006; Schwartz, 2009; Doucerain & Schwartz, 2010). However, research shows that children's ideas of physical and technological phenomena are often highly fragmented, consisting of more or less isolated bits and pieces (see for instance Hannust & Kikas, 2007, 2010; Straatemeijer, Van der Maas, & Janssen, 2008). Studies of teachers' mental models of various physical and technological phenomena have shown that teachers hold mental models with a variety of misconceptions, and are thus likely to transfer these misconceptions to their students. The process of conceptual change in teachers can be conceptualised by means of the same process notions as those applicable to children and thus in principle requires a comparable process of active reconstruction from the part of teachers (Trundle, Atwood, & Christopher, 2007; McDevitt & Ormrod, 2008; Abd-El-Khalick, & Akerson, 2004; Bulunuz & Jarrett, 2010; James & Scharmann, 2007; Kang, 2007; Kikas, 2004; Trumper, 2006).

The developmental question boils down to how the child's *dynamic skills in science and technology* become more *complex* – according to some specific *scale* or standard of competence – and more *autonomous and competent* in the performance of this skill. A dynamic skill always takes the form of a 'soft-assembled' (Thelen & Smith, 1994) or self-organised activity in real-time, on-the-spot and in the form of real physical action (Van Geert & Fischer, 2009; Schwartz, 2009). That is, a skill is not some sort of fixed procedure, stored somewhere on the shelf of the mental bookcase, ready to be retrieved if needed. The actual skill employed in a concrete here-and-now situation is, each time a new, assembled out of elements retrievable from the person's memory and elements emerging in the actual context of concrete actions (Thelen & Smith, 1994). If applied to science talent, scientific reasoning skills always take the form of a science and technology activity that emerges in the dynamics between child, adult and materials that unfolds in real-time (Steenbeek, Jansen, & Van Geert,, submitted, or; Steenbeek & Uittenbogaard, 2009; Meindertsma, Van Dijk, & Van Geert, 2010; Van der Steen, Steenbeek, & Van Geert, 2010). Thus, instead of focusing science talent assessment on the individual child, one should first of all focus on educational contexts such as classrooms. The question is: are they capable of producing emergent activities that are characterised by promoting high levels of insight, creativity and emotional commitment of all the participants involved? In order to be able to educate teachers and parents, and ourselves, about what is currently known about talent, we first carried out an extensive literature survey, from which we distilled the following elements. It should be noted that the picture that emerges from the literature contains certain tensions, for instance between giftedness and hard work, which must be solved in order to obtain a usable conceptual framework. We shall specify our own view later in this section.

A dispositional definition would describe talent as *a person's ability or collection of abilities that will enable a person to reach excellence in a particular domain if this ability or abilities are put to proper use* (Van Geert & Steenbeek, 2007; Simonton, 1999, 2001). Thus, talent is a property or, more likely, a collection of properties of a particular person that determines the effectiveness of learning events or experiences, such as practice, teaching, and exploring. For instance, some children profit more from a particular instructional demonstration than others, simply because of the trivial fact that they are more interested in the demonstrated phenomena than other children (Schiefele, Krapp, & Winteler, 1992; Renninger & Hidi, 2002; Neitzel, Alexander, & Johnson, 2008). A crucial factor lies in the notion of *excellence*, which refers to a relational property: one excels relative to some standard (the issue of which standards to use will be discussed later; e.g. Ericsson, 1996).

The literature often associates talent with a high level of performance (excellence) in a particular content domain. It says that talent differs from excellence per se in that talent implies a high potential for further development, and is seen as based on a genetic endowment or gift. Giftedness is talent that is not yet observable (Gagné, 2004). According to Simonton (2003), the distribution of talent across the population – which applies to the underlying genetic traits as well as the results of talented performance after many years – is strongly skewed, and talent is thus seen as a rare commodity. The excellence that comes along with that talent or the gift does not emerge spontaneously, but usually comes as a result of great an extended *effort (*Ericsson, Roring & Nandagopal, 2007; Colvin, 2008; Coyle, 2008: Howe, 1999). Talented people are willing to invest this effort because they are highly intrinsically motivated (Winner, 2000).
Current models of talent see it as a *multidimensional*

Figure 1 The upward teacher-student spiral



phenomenon consisting of a variety of components, which, within the same talent domain, can also differ among individuals (Simonton, 2001). Talent is *a developmental and dynamic* property. The same talent may emerge at different points in development for different persons, and maybe eventually disappear (Simonton, 2001; Horowitz, Subotnik, & Matthews, 2009). The emergence or development of talent cannot be explained by a simple linear accumulation of talent-promoting aspects or properties, but is based on non-additive interactions between those aspects or properties. Various authors have called this the *multiplicative model*, or the *multiplier effect* (Ceci, Barnett, & Kanaya, 2003; Simonton (1999, 2001; Lykken, McGue, Tellegen, & Bouchard, 1992; Walberg & Tsai, 1983). The multiplier effect is often applied in the form of the classical *Matthew effect model* or the *cumulative advantage model* (see for instance Scarborough & Parker, 2003; Walberg & Tsai, 1983; Bast & Reitsma, 1997; Stanovich, 1986; Burstall, 1978; Bakermans-Kranenburg, van IJzendoorn, & Bradley, 2005). For instance, a child with an observable talent for science reasoning is likely to attract the interest of parents or teachers who tend to invest special effort helping the child develop this talent, which cumulatively strengthens the talent and creates a positive talent spiral. The assumption is of course that these parents or teachers are capable of recognising this talent and providing the right kind of support, an observation which already introduces the chance element that is a crucial aspect of any developing talent; e.g. Barron, 2006.

The notion of talent development that results from the literature contrasts with the idea from Curious Minds that basically every child has a certain talent for science reasoning. The difference lies in the perspective one takes on the meaning of talent and its cousin excellence. If talent is defined as excellence in comparison with other persons, it follows by statistical definition that talent is exceptional and for the happy few. However, if talent is associated with the fact that every developmental trajectory implies a multiplicity of possible futures, the talent trajectory is the one that maximises the potential of the individual. According to our dynamic systems view, none of these possible trajectories is inherently given. Whatever comes out of development is a dynamic process, resulting in emergence and self-organisation. Such dynamics can emerge more or less automatically, but they can also be caused by a deliberate effort. The simplistic view on teaching is that it is a more or less unidirectional process, a process of transmission in which the teacher is teaching the child who learns as a consequence of the teaching (Fischer, Goswami, & Geake, 2010; see Figure 1, top left).

Instead of this unidirectional process, we propose a bidirectional process in which the learning of the child can help the teacher learn how to improve his or her own teaching. If this coupling can be made, a positive upward spiral will emerge, comparable with the Matthew effect, but without the requirement that it needs a very specific and dispositional talent in the child, which acts as an almost magical and unexplainable condition bestowed on a minority of children. For instance, the child's enthusiasm for science can stimulate the teacher to train him or herself in how science enthusiasm and reasoning in the child can be further stimulated, and this in turn will stimulate the teacher to go on with his or her attempts towards improving the teaching, until a more or less stable self-sustaining level is achieved, which is considerably higher than the level at which the educational interaction would have stabilised without the reciprocal stimulation. The emergence of such an upward spiral depends, in this particular case, on the continuous and balanced interplay between the teacher and the student(s) (Azevedo, 2006; Barron, 2006; Barron, Walter, Martin, & Schatz, 2010; Krapp, 2007; Hidi & Renninger, 2006). Such a spiral emerges only if certain conditions are fulfilled. It is easy to think of conditions in which such a process will not get off the ground, but the important point is that the conditions are not extremely specific. In fact, any *emergent* sign of talent or excellence may grow into real talent and excellence if it becomes immersed in a positive feedback loop, which will lead to a spiral of change in which not only that talent grows but also the conditions for its growth are improving. Such a small seed may take a variety of forms ranging from an existing particular interest in science-related subjects to enthusiasm at the first confrontation with a real science subject in the classroom. In fact, we hypothesise that there is a considerable variability in conditions that facilitate the emergence of talent spiral. However, we also expect that successful conditions will have a distributed nature, i.e. that they reside in the dynamic interplay between the children, the adults and the culturally interpreted objects and material context (Barab & Plucker, 2002; Dai, 2005).

In the Curious Minds project we are trying to unravel the conditions that might lead to the emergence of such upward positive spirals, and we have found encouraging evidence that the emergence of such positive spirals is indeed possible (see Steenbeek, et al., 2010). One school, for instance, went through a process of change regarding more effective science and knowledge of teaching that was primarily fuelled by the social dynamics in the school's teaching team, in which creative application of science-related talent moments (an important concept which we will explain in the next section) became an issue among the teachers. In other schools, the spirals often start with the observation of teachers that the children are more enthusiastic and learn more if they, the teachers, know more about making science accessible to and interesting for their students. This observation often leads teachers to ask for personal coaching, to allow them to increase their teaching skills. Pedagogical efforts should primarily be invested in trying to create conditions for the emergence of talent moments leading to the creation of upward spirals, and less so in diagnosing 'real and rare talents' by means of standardised tests, with the aim of giving these children a pedagogical treatment that the non-talented children would probably not profit from.

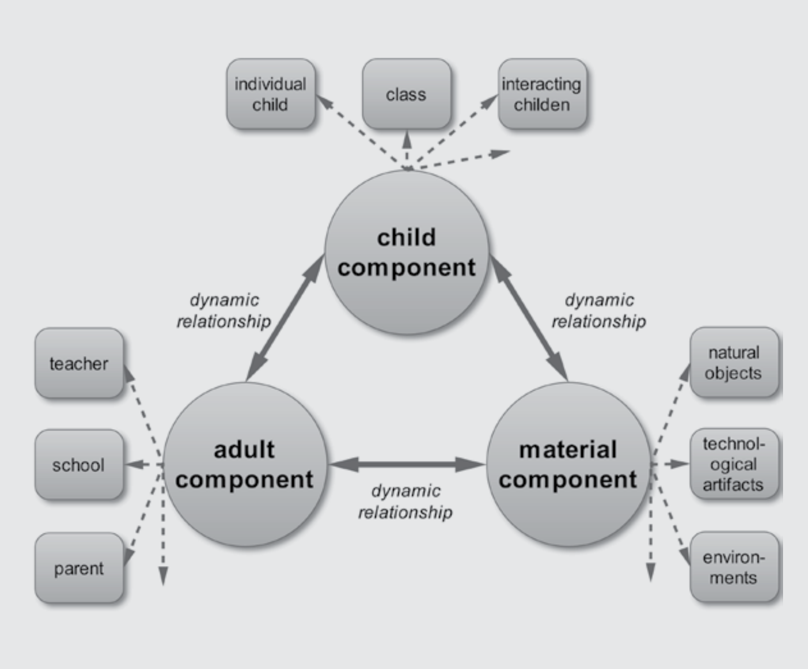
We shall now conclude this section with an attempt to describe talent for science and technology in young children as an emergent, distributed and dynamic property. We shall no longer define a talent as a disposition in the person, but rather as an ongoing process of transactions between (1) the children's abilities that enable them to reach excellence in the science and technology domain, to learn from rich educational contexts and to elicit rich educational interactions from their educators and teachers in particular, (2) their parents' or teachers' abilities to recognise the curiosity and interest of their children in the science and technology domain and to co-construct rich forms of science and technology thinking with them and (3) by creating and making use of material objects or contexts that are capable of eliciting rich and complex forms of science and technology thinking in both the children and their educators. When we speak about 'rich' and 'excellent' forms of science and technology thinking, we refer to a level of excellence relative to what we can expect from the children and educators under 'conditions-as-usual'.

Being a process, a particular talent for science and technology (in a particular child or children in their particular educational contexts) will emerge somewhere and some time, maybe because of a lucky circumstance that triggers the process of interest and activity in the child and its educators and that leads to the upward spiral described in this section.

Seeing science talent and creating the conditions for its emergence

The distributed and dynamic character of talent is represented in the form of the talent triangle (see Figure 2). The triangle represents a process of dynamic, reciprocal interactions between a child component, an adult component and a material component (educational models involving the combination of student, teacher and material objects involved in the teaching are far from new; however, what distinguishes the talent triangle from at least some of these models is that the talent triangle is a model of a dynamics, that is of actual real-time processes, and not a model of the statistical influences on one variable to another). Each component can be further specified (e.g., the child component can refer to a single child or a class). Two corners of the triangle, the child and the adult, refer to agents, and are described by means of building blocks adopted from our dynamic action model (Steenbeek & Van Geert, 2007; 2008), consisting of concerns, knowledge and insights, skills, motivation and drives, and emotions and appraisals. The corner representing the material objects or material context is specified in the form of affordances, i.e., properties that are perceived by the agents as 'invitations' for doing something (Foo & Hedberg, 2005; Bower, 2008). Although the educational concept of this child-adult-material triangle is not new, we give it new meaning by seeing it as a model of a distributed dynamics, namely as a process of short-term interactions between the components of the triangle, taking the form of real-time, talented science reasoning supported by an inspired teacher using talent-eliciting materials (Van Geert & Steenbeek, 2007; Steenbeek & Uittenbogaard, 2009). These components are mutually dependent, they are not to be treated as 'independent variables'. Talent development is the long-term dynamical process of changes in the properties of the talent triangle, e.g. in the level of abstraction of the interaction between the participants and the nature of the problems and contexts that support the talent.

Figure 2 The science talent triangle



Science talent of all participants involved manifests itself in the form of what we call *talent moments*. A talent moment is any classroom event ranging from a short spontaneous or elicited interaction to an entire lesson, in which a science or technology content forms the focus of attention. During such an event there is intensive communication between children and teacher. Such communication involves a to-and-fro process between child, adult and material contexts or objects, taking place on verbal and nonverbal activity levels, involving the dynamic construction of high-level cognitive representations (relative to the children's age and knowledge, and resulting from the interplay between the components of the triangle). Talent moments typically involve emotional absorption, enthusiasm, excitement and commitment to exploring what is as yet unknown or unexpected. The notion of talent moment is related to the well-known concept of the *teachable moment* (Bentley, 1995; Hyun & Marshall, 2003), but in comparison with the latter it emphasises the fact that the learning and enthusiasm is not only in the student, but also in the teacher and the teaching context. It is not only the student who learns from the teacher, but also the teacher and the school that learn from working with the students. During the course of the research collaboration with the schools, the teachers asked the researchers to help them find ways for introducing this concept in their classrooms. For this reason, we are currently developing a coaching module for teachers to help them create high-quality talent moments as a regular component of their teaching practice (Wetzels, Steenbeek, & Van Geert, 2011; Steenbeek, Van Geert, & Fraiquin, 2010).

The science talent map

The properties of the talent moments can be described in terms of the dimensions of the talent map, which we defined as 'a map of potentials of children as well as educators that helps practitioners to stimulate development' and, we might add, helps researchers to investigate and measure talent development. The talent map thus serves an applied goal, helping teachers to create optimal conditions for eliciting and improving the talent moments, and a scientific goal, helping researchers to define research questions and design instruments for assessing the properties of the talent moments, i.e. the expression of science talent in real-time, here-and-now interactions in the concrete context of the class. The talent map must describe the children's and teacher's functioning under optimal circumstances, and must thus help decide what these optimal circumstances should be and how non-optimal circumstances can be improved. Note that this idea is reminiscent of Fischer's distinction between optimal and functional levels of development (Fischer & Rose, 1994). The notion of the talent map can also be used in the broader context of the co-construction of science talent by the child and the adult, for instance in the family context (e.g., children visiting science museums with their parents).

Dimensions of the science talent map

In order to describe a map, one needs to specify its dimensions (e.g. latitude and longitude and a geographical map). Since the science talent map is an instrument for policy, including the planning of scientific research, its dimensions have been chosen on pragmatic grounds, in that we have been trying to find the smallest possible number of concretely specifiable dimensions covering the greatest number of aspects and properties that are relevant for educational practice as well as for scientific research. This pragmatic stance has resulted in the following five dimensions (see Figure 3).

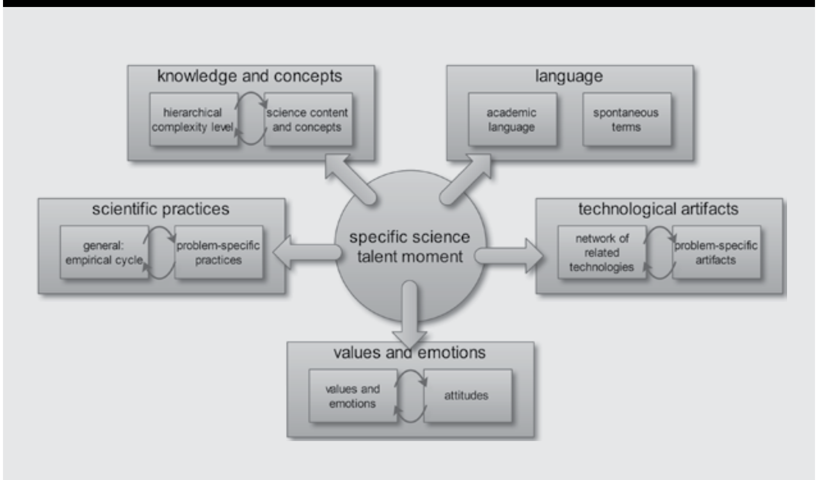
The first is that of **knowledge or cognition**. This dimension has two aspects. The first aspect is the *general cognitive level or complexity of the scientific reasoning* that the child and/or the teacher show during a particular process of thinking or exploration, i.e. the level on a developmental hierarchical scale as described by Dynamic Skill Theory (Fischer & Bidell, 2006; Dawson-Tunik, Commons, Wilson, & Fischer, 2005). This cognitive scale is content-neutral and applicable to thinking in naturalistic situations. The second aspect is the particular *science content* specific to the problem at issue, for instance contents referring to pressure and force, or contents referring to biological systems (Van Keulen, 2011).

The second dimension is that of science-related **language**, which Vygotsky already stressed as important for the emergence of higher order thinking and which is now often referred to by the term 'academic language' (Schleppegrell, 2004; Chamot & O'Malley, 1996; Henrichs, 2010). Language consists of the words and terms that scientific communities use to refer to particular concepts or knowledge, and which, by their specificity, help the cognitive processes of reasoning and understanding proceed in an adequate way.

The third dimension is that of **general and specific scientific practices or activity systems**, for instance the general practices of exploring a problem context to find an explanation for an unexpected observation, the practice of formulating hypotheses or expectations on the basis of existing knowledge, the empirical testing of such hypotheses in a way that allows for verification as well as falsification, and so on. It also concerns specific scientific practices related to experimenting with specific tools or objects. A simple and highly general model of scientific practice is that of the empirical cycle (De Groot, 1969), which can be introduced as a framework guiding the children's actions. The model of the empirical cycle can be extended with the model of the argumentation cycle (Toulmin, 1958/2003). Both models can be used as a general standard against which the science-related actions and argumentation of children can be specified.

The fourth dimension is that of **the technological artifacts or objects,** which constitute the range of material forms that scientific and technological concepts can take. For instance, the core concepts of pressure, volume and force are related to a host of technological tools ranging from balloons to bicycle pumps to combustion engines. These objects represent not only conceptual insights and knowledge, e.g. mental models of pressure and force, but also particular and culture-specific activity systems and affordances for action that children will gradually master. For the teacher it is important to understand which objects or material contexts generate affordances for action and understanding that are developmentally appropriate. Teachers can select and introduce such objects (and learn how to do so) and can learn to see such opportunities and affordances in the objects that are part of the natural school environment.

Figure 3 The dimensions of the science talent map



The fifth dimension is that of **attitudes, motivations values or emotions**, i.e., the 'movers' of one's action. Examples of attitudes and values are a positive evaluation of science and science-related practices, the absence of prejudice in judging scientific or observational data, the trust in the evidence provided by others, a critical attitude towards oneself and others and so on. As regards to science, a major 'mover' is the person's curiosity, the wish to find and understand new things, an emotion which should not only move the child but also the teacher (Deci & Ryan, 2009). Teachers can use the dimensions of the talent map in the form of a simple checklist of opportunities when they prepare or evaluate a science activity with their students. For instance, they can ask what the cognitive science concepts are that they wish to address or which language and science terms they can use or introduce. They can ask themselves in which practices or activity patterns they wish to introduce their exercise and which natural objects or technological artifacts they can use. Finally, they can ask which attitudes, evaluations and emotions the activity will elicit. At the individual child level, it can be assessed what the level of this child is with regard to the dimensions of the talent map, and the child's level can be compared with those of his peers. It can be used to bring weak students up to standard levels and to determine which aspects need additional educational attention. Researchers can measure the children's and teachers' science talent by observing real-time properties of learning and teaching interaction defined by the five dimensions. In order to be useful for that purpose, each dimension must be transformed into a 'developmental ruler', i.e., into a hierarchy of levels of cognitive, linguistic, pragmatic and evaluative complexity.

The science talent map and the brain

The dimensions of the science talent map can be described in the form of functional and constant properties, for instance specific cognitive contents, skills and activity patterns. However, such functional properties can only exist and develop by virtue of an underlying biological substrate, more precisely the human body. For instance, for children with physical, sensory or motor handicaps, the trajectory through the talent map will be different to that for physically normally developing children. Of particular importance in this regard is the development of the brain. Questions that immediately come to mind are, for instance, whether a young child's brain is sufficiently developed to be able to understand the often abstract notions that science reasoning appears to require, or whether children with high talents for science have different brains than typically developing children. However, the talent triangle model suggests that questions regarding the brain should not be limited to the children, but should also extend to the adults, the teachers for instance, who participate in the educational science activities. Take for instance the issue of brain development, executive functions, planning and inhibition. At first sight, scientific reasoning requires well-developed executive and planning functions, which depends on the development of the prefrontal cortex, a process that begins in early childhood and extends far into adolescence (Christoff, Keramatian, Gordon, Smith, & Mädler, 2009; Fischer & Bidell, 2006; Hansen & Monk, 2002). However, Thompson-Schill, Ramscar, and Chrysikou (2009) claim that the 'underdeveloped' prefrontal cortex of the child is better suited for exploratory and curiosity-driven activity than the fully developed prefrontal cortex of the adult, which is better equipped for goal-directed action and impulse inhibition. Thus, what superficially seems to function as a disadvantage can also be an advantage if put to proper use. Instead of seeing the young child's prefrontal cortex as a limiting factor for science-related activities, it can also be seen as an important opportunity. On the other hand, the adults' highly developed inhibitory and goal-oriented skills are not necessarily facilitating science reasoning, but can also hamper it if they stand in the way of unbiased exploration, imagination and free flow of thoughts. In fact, the talent moments that teachers seek to enhance not only stimulate brain development in children, in that they provide the children with opportunities to explore in a controlled and reflective context, but also brain development in the adult teachers themselves, to the extent that the talent moments help the teachers to rediscover intellectual flexibility and free exploration.

A similar reasoning applies to the relationship between the development of the prefrontal cortex and the ability for abstract thinking. Since scientific and technological reasoning requires abstract thought, it is thus easy — but probably also wrong — to conclude that the brains of the 4 to 5 year olds who participate in the Curious Minds program are not yet suited for the abstract concepts that this kind of reasoning requires and that teachers should wait until at least the age of eight years before confronting their students with causal reasoning and explanation. However, research has shown that the brain is far from an 'independent variable'. In reality the brain is a complex self-organising tool that shapes its own structure as it is used and that is characterised by a high amount of experience-related plasticity (Dehaene, 2007; Stiles, 2000). Moreover, abstract thought is not an all-or-none phenomenon, and neither is it limited to what happens inside an individual person's brain. Abstraction is a distributed and context-supported activity that follows a continuous developmental process starting long before and continuing long after the age at which abstract thought is considered to be fully 'developed' (Schwartz, 2009). In order for this developmental process in the brain to occur, it must be educationally supported from its very beginnings onwards, and the concept of talent moment sketches the contours of a context in which this support might be realised.

One dimension of the talent map refers to the evaluative and emotional components of science activities in young children and their teachers. The addition of this dimension is explicitly supported by recent contributions of brain development studies to education, which have provided neurocognitive evidence for the integrated nature of rational thought and emotion (Immordino-Yang & Damasio, 2007) and the importance of emotionally valued concerns and interests for cognitive development (Immordino-Yang & Damasio, 2007; Van Geert & Steenbeek, 2007; Woltering & Lewis, 2009). Although the intimate relationship between emotion, thought and cognitive learning and development has always been one of the basic beliefs of good educators, emotion and its kin motivation have too often been treated as 'additional factors' of the learning and teaching process and not as inseparable parts of teaching-learning dynamics that apply to the student as well as the teacher.

The educational concepts of talent moment and the upward teacher-student spiral (see Figure 1) have been developed with 'the brain in mind'. The talent moment combines strong positive emotional involvement with a high level of cognitive processing, in a context supported by a competent adult and talent eliciting objects and materials. The talent moment provides an ideal context for regulating cognitive inhibition in the children. In young children it will structure and regulate the 'overdose of suggestions and actions that the children generate, and in older children and adults (teachers) it will stimulate the participants inhibitions and anxiety to express what comes to their minds (Thompson-Schill et al., 2009). Talent moments capitalise on learning in the context of strong positive emotions, which strongly contributes to learning and interactive specialisation in the brain

(Immordino-Yang & Damasio, 2007; and Lewis, 2005). It is a form of socially embedded learning that appeals to the neurocognitive triggers of the 'social brain' (Frith & Frith, 2010). The talent moment is an explicitly supportive environment, distributing the cognitive load of the task across the participants and objects, thus allowing for shared and distributed abstract thought. Talent moments are intended to occur often and repetitively, thus allowing the participants to invest in an extended, 'deep' and frequent practice. These are (according to Fields, 2006) likely to contribute to myelinisation and consolidation of networks in the brain). If the teacher and the children get into a durable, self-sustaining pattern of mutual stimulation, they have created a context for long-term development, including brain specialisation, which is characteristic of trajectories leading to excellence.
Finally, we admit that the discussion on the relationship between talents for science and technology in the brain is highly speculative and no more than a starting point for further discussion.

Conclusion: What schools, teachers and researchers should know about scientific talents in young children and what they can do with this knowledge

First, against the often heard claim that (scientific) talent is a property that some children have and others do not, we put the claim that scientific talent is an emergent property, if the right dynamic conditions can be created. That is, talent for science and technology can emerge in every child if an upward dynamics can be established. This upward dynamics takes place in the dynamic interaction between the child, the teacher and the material/context. For some interactions, the upward spiral will rise to greater heights than for others, and this difference will no doubt be due to complicated combinations of genetic endowment and good luck as to support and timing. For the teacher, the parent and the researcher, it is important to realise that the dynamics of the talent triangle imply that emergent talent not only applies to the child but also to the adult who is part of the dynamics. One cannot stimulate another person's curious mind without stimulating one's own.

Second, scientific talent, and scientific reasoning, are distributed processes taking place with and between persons and material contexts, and which take the form of a dynamic skill. The notion of dynamic skill also implies that the ability to reason scientifically and abstractly is not an all-or-none phenomenon which 'is there' or 'isn't there'.
The ability will come and go and wax and wane dependent on the context and the opportunity, and in the process of development it will become a more or less consolidated property of the individual person, without ever losing its connection with other people and the material world.

Third, the science curriculum is a means for creating, increasing and maintaining the occurrence of 'talent moments' in which all the elements beneficial for constructive and well-guided learning come together, including the focus and absorption in the content, the enthusiasm and emotions, and the learning of both the student and the teacher.

Fourth, instead of confining the results of science education to changes in concepts in the representations, we introduce the picture of a 'science talent map' that is defined by a much richer structure of dimensions. General as well as content specific *knowledge* are closely related with *language* and specific words, with scientific and technological *practices* and action patterns, with natural, cultural and technological *artifacts*, and finally with a rich pattern of values and *emotions*.

In short, the framework presented in this article has scientific as well as applied consequences. As a theoretical framework, it is intended to guide research in learning and teaching processes based on a concept of 'talent' as a dynamic and distributed learning potential. It is a framework that can help the researcher to design tools for assessment that apply to concrete, real-time and here-and-now contexts of scientific reasoning in children and the supporting educators. As an applied framework, it gives teachers a theory of science and technology talent that goes beyond the dispositional and more or less static implicit theories about talent that they are most likely used to. This new theory, which emphasises the developmental, emergent and 'collective' (i.e. distributed) properties of talent, might help teachers to take a different educational stand towards the issue of talent, in particular in science and technology in young children. Maybe teachers will act differently if they no longer follow the metaphor that talent is a rare and hidden nugget of gold that they are likely to find only in very few children, and adopt the metaphor that talent is something that grows in a garden on rich and fertile soil and should be sown, nurtured and harvested.

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