

A dynamic systems model of dyadic interaction during play of two children

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This article describes the construction and validation of a dynamic systems model of dyadic interaction, applied to a dyadic play situation between children of different sociometric statuses. The introduction addresses research on social interaction, principles of dynamic systems and of simulation. We proceed with a discussion of our interaction model, which is inspired by the theory of Frijda (1986). The model describes the continuous interaction between concerns, drives, emotional appraisals, emotional expressions and behaviour of children during each moment of the children's play session. The empirical validation of the model focuses on group differences (averages and distributions of three types of dyads), which are based on a time-sampling of videotaped play interactions. The predictions of the model, which differ from those made on the basis of the current literature, are corroborated by our empirical data. The conclusion discusses the use of models in the explanation of social behaviour and development.

Social interaction is a central feature of human behaviour, in children as well as in adults. At least since Kurt Lewin, it has been known that, irrespective of a person's age, social interaction is a dynamic, transactional process (see for instance Herbst, 1957, for a remarkably modern account of behavioural dynamics). In order to have satisfactory social interactions with others, for instance during play, it is crucial for children to have a sufficient level of social competence or skill. Social competence is "the ability to achieve personal goals in social interaction while simultaneously maintaining

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positive relationships with others over time and across situations” (Rubin, Bukowski, & Parker, 1998, p. 645). Social competence is often indirectly specified by the child’s sociometric status. The sociometric status of a child is derived on the basis of social judgements of children in the child’s group or class and expresses the level of popularity of this child in this particular group. The status of a child is an indicator of the general evaluation of that child by others, coupled to certain expectations about the behaviour of the child at issue. Mostly, five sociometric statuses are distinguished (Coie, Dodge, & Coppotelli, 1982), namely popular, controversial, neglected, rejected and average statuses. In particular, children with popular and rejected statuses differ in their behavioural abilities during interactions with both peers and parents (Black & Logan, 1995; Goudena & Gerrits, 2003; Rubin et al., 1998). The literature reports two consistent patterns: one is the pattern of high social competence, high coherence of interaction and expression of positive emotions that is characteristic of children with a high social status, i.e., popular children. The second pattern refers to the association between low social competence, low coherence of social interaction and expression of negative emotions. This pattern is characteristic of children with low social status, i.e., rejected children. The literature corroborating these patterns is extensive and diverse (Asher, 1983; Asher & Parker, 1989; Black & Logan, 1995; Cirino & Beck, 1991; Denham, McKinley, & Couchoud, 1990; Edwards, Manstead, & MacDonald, 1984; Eisenberg & Fabes, 1995; Eisenberg, Fabes, & Bernzweig, 1993; Gnepp, 1989; Gottman, Gonso, & Rasmussen, 1975; Hubbard, 2001; Krantz, 1982; Miller & Olson, 2000; Rose-Krasnor, 1997; Vosk, Forehand, & Figueroa, 1983).

Relationships between emotional and interaction patterns and social status are almost exclusively reported in the form of statistical associations between variables (e.g., emotions and status). In reality, such observed associations are the result of processes of social interaction between children, in specific contexts and for a specific duration. In the literature, the actual processes or mechanisms that govern these concrete interactions remain underexposed. In this study, we attempt to address the issue of social status and dyadic interaction by means of a model that puts these underexposed aspects in a more central position.

Goal of this study and goal of this article

The central aim of the study reported in this article is to construct a model that generates patterns of interaction that correspond with observed interaction patterns in children of different sociometric statuses. The goal of this article is to provide a bird’s-eye view of the many aspects—theory construction, model building, and empirical testing—that are involved in the

construction of such a model. Building such a model is an example of a process approach, in which the emphasis lies on obtaining insight in the course of the process during a particular interaction in real time (e.g., a play situation lasting ten minutes, involving two children). Principles of dynamic systems theory have been used in an attempt to construct a simulation model of interaction during dyadic play, which is based on a broader theory of human action strongly inspired by Frijda's theory of emotions (Frijda, 1986). The dynamic systems view has been applied in various areas of social development, such as emotional development, parent-child interactions, self and identity, and attachment (Bosma & Kunnen, 2001; De Weerth, 1998; Fogel, 1993, 2001; Granic, 2000; Kunnen, 2000; Laible & Thompson, 2000; Lewis, 2000; Lewis & Granic, 2001; Olthof, Kunnen, & Boom, 2000; Van Geert, 1996). The present article aims at contributing to this literature by providing a dynamic model of social interaction during play among children. ①

THE DYNAMIC SYSTEMS APPROACH

What is a dynamic system?

The mathematical definition of “dynamic(al) system” is: “a means of describing how one state develops into another state over the course of time” (Weisstein, 1999, p. 501).

Thus, if x_t is a specification of a “state” at time t , a dynamic model takes the form:

$$x_{t+1} = f(x_t) \quad (1)$$

Which should be read as “the value of x at time $t + 1$ is a function “ f ” of the value of x at time t ”. A state is described by the value of a variable (or several variables, for that matter). The change in the value is a function of the variable's current value. Thus, a dynamic systems model of play in two children is an explicit model (the f in the equation) that describes how a current state of the play situation evolves into another state, at some later moment. That is, the next state is a transformation of the current state, according to some explicit model or set of rules. The states are specified in terms of the variables that are used to describe the play situation. There can be many variables, or only a small number. In line with the mathematical approach, the “means of describing” must be formal. That is, a dynamic system implies a fixed procedure that for any state, for instance that of a dyadic play situation, determines a successive state. This fixed procedure can be as simple as a verbally stated rule, for instance, but it can also be a mathematical equation or a computer program. Note that a dynamic model is “recursive”, or “iterative”. That is, it describes a procedure or function

(the f in the equation) that transforms x_t into x_{t+1} , x_{t+1} into x_{t+2} , x_{t+2} into x_{t+3} and so on. The series of successive x s forms the description of a process.

Any model that complies with this basic definition is a dynamic systems model. Thus, in our view, the term “dynamic systems” is not confined to a particular theory (such as Thelen and Smith’s, 1994, specific theory). Given this general definition, it is clear that the variety of dynamic systems models is great and that dynamic systems models cover a wide range, including Markov chain models, simulation models, differential equations (over time), and so forth.

One might even ask if, given such general definition, there exist models, in (developmental) psychology, that are *not* dynamic systems models. Such models exist, and they are common. For instance, a regression model that specifies the amount of positive emotion produced during a play session as a function of the child’s sociometric status, the play partner’s status and the quality of the toys, to name just an imaginary example, is not a dynamic systems model. It does not describe how a child’s current level of positive emotional expression is a function of the preceding level at some earlier time.

Is a model making a prediction about the future state of a variable a dynamic systems model? Take the following example. Several authors found, for instance, that if children have rejected status for an extended period the consequences are felt until far into adulthood (DeRosier, Kupersmidt, & Patterson, 1994; Haselager, Van Lieshout, Riksen-Walraven, Cillessen, & Hartup, 2002; Kupersmidt & Coie, 1990). Thus, the model specifies how rejection at time t (childhood) leads to rejection at time $t+1$ (adulthood):

$$\text{Rejection}_{\text{adulthood}} = f(\text{Rejection}_{\text{youth}}) \quad (2)$$

The model is a dynamic model if the relationship that it specifies between time t and $t+1$ also holds for time $t+1$ and $t+2$ (e.g., old age; unfortunately, given the big time leaps that the model entails, there will probably be no $t+3$, but that does not affect the principle of recursiveness). If it does not specify such a relationship, for instance if the relationship only holds for youth to adulthood, it is not a dynamic model (since it is not recursive or iterative).

It is likely that a model like this one specifies that the next state of rejection is proportional to the current state, for instance:

$$\text{Rejection}_{\text{adulthood}} = a * \text{Rejection}_{\text{youth}} + e \quad (3)$$

Which should be read as “rejection in adulthood is a proportion a of rejection in youth plus some random or error term e ”. If a model has this

particular format, it is called a linear (dynamic) model. It is a “linear” model if the sum (addition) of two solutions of the model (plug in two specific values for rejection and calculate the results) is also a solution of the model (a model is non-linear if the addition property does not hold). Linear does not necessarily mean “simple”: linear dynamic models can achieve any level of complexity. However, it is unlikely that it will be possible to specify developmental mechanisms (i.e., descriptions of actual developmental processes) without specifying non-linear terms in the models at issue (for a discussion see Thelen & Smith, 1994; Van Geert, 1994, 2003).

Finally, dynamic systems try to capture the most fundamental, qualitative aspects of a process by means of models that specify only the most essential mechanisms or relationships (Jackson, 1991).

Properties of dynamic models in the context of behaviour and development

The preceding section introduced two basic properties of dynamic systems: iterativity (also called recursiveness) of a function over time and the distinction between linear and non-linear models. The following properties are of particular interest in the context of behavioural and developmental dynamic models. The first of these properties is that the process described by the system has a characteristic “step size” or time scale (the interval between t and $t + 1$), which relates to the temporal resolution of the model. It is important that the model’s temporal resolution allows the researcher to specify the underlying process adequately. The question of which resolution to choose can be answered by asking oneself how often one would wish to sample the real process in order to obtain an adequate image of that process. It is clear that, to cover development, a process must be sampled at least twice, at the beginning and at the end. However, a researcher interested in the properties of a process—not just its initial and final states—wishes to capture the trajectory of the process, and thus must sample more frequently. For instance, capturing the process of rejection, or a comparable social property for that matter, would require its sampling on a time scale of months (or eventually weeks, in times of rapid change). Capturing the process of social interaction in a play situation requires a much finer time scale, for instance the scale of minutes or seconds. Note that this frequency defines an observational time scale or range of time steps, not just a single possible frequency. This time scale (co-) determines the step size of the dynamic model that intends to describe that process (see further the description of the dynamic model of social interaction).

The second property in this series is that the function (or mechanism) describing how one state of a variable is transformed into another state (the “f” in the above equations) must refer to the nature of the underlying

developmental process. More precisely, it must entail a meaningful theory or hypothesis about the nature of that process. If the variable at issue refers to an individual—which will mostly be so in developmental psychology—the theory or hypothesis must refer to a process that occurs in an individual. The problem with much developmental research is that it relates to relationships over groups and easily leads to confounding intra-individual variation (which applies to the mechanisms that apply to an individual) with inter-individual variation (differences in distributions over groups; Borsboom, Mellenbergh, & Van Heerden, 2003). For instance, several authors found a predictive relationship between children’s perceived security of the relationship with their parents and aspects of self-representation and social interaction two years later (Gerrits, 2004; Verschueren & Marcoen, 1999). What does this relationship mean in terms of developmental mechanisms that operate in individuals? It might mean that security of the relationship causally contributes to the growth of certain aspects of self-representation, such as openness (Gerrits, 2004). However, since the relationship is found across a group, it is likely that it does not apply to at least a considerable number of children in the group, or that for some children the relation is inverse. A developmental process model specifying the development of self-representation or social interaction must be able to account for the fact that the relationship can run both ways or is inexistent, irrespective of the fact that the majority of individuals might follow a path that corresponds to the finding that has been reported over the group. Thus, in order to understand why a predictive group relationship holds between, for instance, seven and nine years of age, and why it has its particular distribution, one needs to specify a model of individual processes. In principle, this model must be able to explain the predictive relationship, but also the distribution over the group (the structure of inter-individual variation) and properties of the individual trajectories (the structure of intra-individual variation).

The third property of dynamic models describing developmental or behavioural processes is that they can rarely be confined to specifying a single variable, such as the time-series of x_t in the equations above (an exception is the growth of early lexicon; Van Geert, 1991). That is, a ^② dynamic system describing development or processes, such as social interaction, most likely consists of a number of *coupled variables*. For instance, if in a dyadic interaction the child’s current emotional state (x) co-determines the child’s next emotional state but also the next emotional state of the child’s peer (y), and vice versa, the flow of the emotions is a coupled system:

$$\begin{aligned}x_t + 1 &= f(x_t, y_t) \\y_t + 1 &= g(y_t, x_t)\end{aligned}\tag{4}$$

Which can be read as “the value of x at the next moment in time is a function of the value of x at the preceding moment and of the value of y at the preceding moment” (with a comparable reading for y). These coupled systems show how variables mutually influence one another.

The fourth property is that these coupled, iterative, non-linear systems are characterized by self-organization. A characteristic feature of behaviour is the emergence and maintenance of structures over time, e.g., a pattern of interaction between two children, with turn-taking, maintaining and changing topics, and so forth. These patterns are in general not predetermined. They emerge spontaneously when two, socially skilled persons, interact. This spontaneous emergence of patterns, order or structure, which is not based on some external instruction or blueprint, is known under the encompassing term of self-organization. The emergent patterns must be both stable and flexible, i.e., maintain themselves for a certain amount of time, in different circumstances and under external pressure or perturbation (e.g., external distractors). The flexible yet stable patterns that spontaneously emerge are known as “attractors”, i.e., states (or cycles or patterns) towards which the system is automatically drawn, given a broad range of starting points and conditions.

In principle, dynamic systems of the kind described in the above equations are deterministic. However, in human behaviour, accidental events play an important role. A final property of dynamic systems that model behaviour, for instance social interaction, is that they must incorporate chance. In such a system, chance usually does not average itself out, but can be strengthened or weakened dependent on circumstances, and has an important function in the creation and maintenance of behavioural patterns. These properties will now be illustrated by means of an example.

Muriel and Rosa: an example of dynamic systems principles in a play session

Muriel and Rosa are playing together with plastic monkeys and a play tree. At time t , Rosa reaches for a monkey. As a reaction, at time $t + 1$, Muriel reaches for various parts of the tree and assembles it. With the tree assembled, Rosa puts the monkey in the tree and reaches for a second monkey. This interaction clearly demonstrates the principle of coupled systems, i.e., of mutual influence. A little later, Rosa accidentally glances at the Playmobil-motorbike, after which she immediately turns her attention away from playing with the monkeys, and starts to play with the motorbike. Seeing the motorbike is the cause, and the consequence is that the attention suddenly switches from the monkeys and the tree towards the new toy. This event is an example of non-linearity: before this moment, Rosa had already

looked at the motorbike, but with no direct consequence on her behaviour. This situation also illustrates the role of chance (Rosa's accidentally spotting the motorbike). Several seconds later the tree suddenly tips over, with the result that the monkeys are scattered across the table. Muriel begins to laugh. Rosa reacts by also laughing, resulting in continued giggling. The giggling is a nice illustration of the principle of iteration and the maintenance of an attractor: the fact that both Muriel and Rosa are giggling keeps them giggling.

The play session shows a succession of three relatively coherent episodes (monkeys, motorbike, giggling). The children did not plan this pattern in advance. The pattern is an illustration of a self-organizing process.

Summary and preview

We have now given an overview of some important properties of the dynamic systems approach. Given the recursive or iterative nature of the processes described by this approach it is difficult, if not impossible, to understand how these processes shape the form of the phenomenon of interest—the course of social interaction, long-term development, etc.—without implementing them in the form of a simulation model. In the next section we will present a global discussion of this method.

USING SIMULATION AS A TOOL IN SOCIAL SCIENCES

What is simulation?

A simulation model of a process is a reduced, shortened, and idealized imitation of the time course of the real process (Gilbert & Troitzsch, 1999; Schmidt, 2000). An important first step is to identify the basic characteristics of the process that we want to imitate. These characteristics will be translated into the variables of the simulation model. A second step is to identify the basic relations between the variables. To be able to represent these relations in the form of a simulation model, the variables must be mathematically formulated, i.e., turned into the format of the equations specified in the section on dynamic systems theory. This model is then translated into a computer program that generates changes in the variables over a number of steps, imitating the steps in the real process. The expectation is that this computer program covers the characteristic main features of the real process.

Within the field of social and developmental research, simulation is a relatively new method. Examples are models of consumer behaviour, play interaction, mother–child interaction, robots that can express emotions in

communication with people, and the role of emotions in the study of social norms (Breazeal & Scassellati, 2000; Casti, 1997; Jager, 2000; Olthof et al., 2000; Schmidt, 2000; Staller & Petta, 2001).

Finally, it should be noted that the authors of the present article focus on simulation of dynamic models. Thus, contrary to trying to model as many aspects of a system as possible in order to approach the system's complexity as closely as possible, dynamic system simulations try to capture the essential features of the system's behaviour (and must therefore justify what the authors see as "essential" in the behaviour at issue).

What are the advantages and disadvantages of simulation in comparison with other methods?

An important advantage is that simulation forces the researcher to formulate his theory in a precise and detailed manner. This is necessary in order to translate the theory into a simulation model (Axelrod, 1997). A second advantage is the fact that the model generates detailed predictions on different levels—the course of trajectories as well as distributions of outcomes over groups—that can be tested with empirical data. A third advantage is that processes can be simulated that, for several reasons, such as ethical reasons or the mere availability of time, cannot be studied in real life. Fourth, insight in the course of a process can be obtained in a manner that is otherwise nearly impossible, namely by simply manipulating values of parameters. In this respect, modelling is related to experimental methodology, because a model can be simulated under different conditions (Gilbert & Troitzsch, 1999). A fifth advantage is the fact that computer simulations are able to provide convenient representations of dynamic aspects of processes, which are often highly complicated (Gilbert & Troitzsch, 1999). For instance, they can be used to represent relations between levels of development, for instance between the individual level (processes within a person) and the group level (relations within a group).

A comparison between different types of models

In the social sciences, roughly three types of simulation model can be distinguished: system models, connectionist models, and agent models. System models describe a process in the form of a set of coupled equations, similar to the format described in equation 4. Connectionist models specify relations between an input, for instance a sensory input of a face showing a particular emotion, and an output, for instance an emotional response. The input–output relation is modelled by means of layers of nodes. Agent or multi-agent models consist of components or models that model real agents, i.e., persons that act on other persons and on their environment. Each agent

contains a model description that can either be a system or a connectionist model. These types of models have in common that they deal with dynamic systems, in which variables mutually interact, influence each other, and change over time. Thus, basically all the models can be described as dynamic system models, only differing in the way that they realise this dynamic system character (see for instance Thelen & Bates, 2003).

An example of a comparison between different types of models is the simulation research of mother–child interaction by Olthof et al. (2000). They compared a connectionist and a system model. In the system model, three variables were distinguished that acted as determinants of the interaction process, namely the irritability of the child, the sensitivity of the mother, and the intensity of an external stressor. Results of both types of simulation showed considerable differences. However, in both types of simulation, small changes in the intensity of the stressor caused abrupt changes in the type of interaction, for example changing an effective interaction into an ineffective one.

The model of interaction that we describe in this study is a combination of a dynamic system model with a multi-agent model, in which the variables are organized in the form of two agents reacting to one another. In the next section we will first describe the theoretical foundations of this model and then specify how it has been implemented in the form of a simulation model.

THE MODEL

Theoretical foundations of the model variables and parameters

Frijda's emotion theory: the connection between concerns, emotions, and behaviour

In line with the requirement that a dynamic model should capture only the most essential aspects of the phenomenon that it models, we asked ourselves if there was any existing theory that provided a comprehensive description of the essential aspects of human (inter-) action. We found such a theory in Frijda's emotion theory (1986). Although Frijda's theory focuses on emotions, it encompasses a general theory of action. It says that emotions are changes in action readiness, emerging as reactions to events that are crucial to the concerns of the individual. An emotion is a tool for realizing concerns, finding its expression in the behaviour of the individual. A concern is "the concept used for an individual's motives, major goals, interests, attachments, values, ideals, sensitivities, and aversions and likings" (Frijda, 2001, p. 54; see also Hermans & Hermans-Jansen, 2001). In other words, a concern is a disposition for wishing that a certain situation will occur or not

(Frijda, 1986; Sloman, 1987). Aiming for concerns is a form of intentional behaviour. Intentionality does not imply that the corresponding behaviour must be consciously and deliberately planned. Intentions, i.e., the realization of specific concerns, can occur largely unconsciously (Bargh & Chartrand, 1999; Bargh & Ferguson, 2000; Bargh, Gollwitzer, & Lee-Chai, 2001; Ferguson & Bargh, 2004). Various authors have also argued that such intentions self-organize in a context-and-person-specific way (Gibbs & Van Orden, 2003; Kappas, 2002; Shaw, 2001). Although many, if not most, concerns are largely “automatic”, some concerns are of course conscious and deliberate, such as a person’s wish to buy a particular book or CD.

Concerns can be defined at various time scales and levels of generality. For instance, the concern “love for a person” is reflected both in the concern to strive for nearness and in the concern to maintain the relationship. An example of a short-term concern is a child’s current, context-dependent preference for a certain balance between playing together with another child and playing alone. Depending on what level of generality a concern is describing, concerns can refer to something that is largely person-dependent, context-dependent, or something that emerges in the interplay of a specific context and a specific person. Thus, the notion of “concern” has a broad range of meanings, which all refer to an essential feature of intentional—as opposed to purely reactive—systems, namely the system’s or organism’s current intention that it tries to achieve through its actions. In our dynamic model, we define “concern” in a way consistent with Thelen and Smith’s (1994) notion of “soft-assembled” properties, namely as the temporal and local set of factors that cause a person to strive for a certain balance of actions with which that person is optimally satisfied.

The level to which concerns are realized or satisfied in the present situation is constantly evaluated and this evaluation is expressed in the form of a direct emotional appraisal (Frijda, 1993). Emotional appraisals are linked to drives (see also Damasio, 2003). The notion of “drive” is of comparable generality to the notion of “concern” and refers to the intensity of the action by means of which the organism tries to achieve its concerns. Realization of a concern (or bringing it closer to realization) has a positive influence on the emotional appraisal of this moment. If the concern is not (sufficiently) realized, the emotional appraisal of this moment is negatively influenced. With a negative emotion, a drive will emerge that leads to behaviour aimed at undoing this negative emotion. Emotions can be distinguished both on qualitative (different emotions) and quantitative (intensity) grounds (Oatley & Johnson-Laird, 1996; Sonnemans & Frijda, 1994). In our model, we simplify emotions by reducing them to a single quantitative dimension that specifies the intensity of the emotional expression regardless of the accompanying emotional quality (see Cacioppo & Gardner, 1999; Russell, 1980; Watson & Tellegen, 1985, for similar

approaches). On the other hand, our model represents the qualitative distinction between emotions in the form of different effects that positive, neutral, or negative emotions have on the preference for concerns (see Cabanac, 2002; Panksepp, 2000, for a general, biological underpinning of the effect-related aspects of emotions). A comparable approach, including emotions as a drive for behaviour, was used in a computer model made by Frijda and Swagerman (1987; see also Moffat, Frijda, & Phaf, 1993).

Involvement and autonomy—the first input parameter group

Our dynamic model specifies the realization of one important concern dimension that refers to the realization of a specific balance between the concern “autonomy” and the concern “involvement”. Autonomy is the tendency to be or to act on one’s own while involvement is the tendency to direct one’s behaviour towards an other person (note that “autonomy” refers to a simple behavioural tendency to focus on one’s own person and is not used in any morally or ethically inspired sense of “personal autonomy”, related to self-efficacy and independence). Consistent with our earlier claim that a concern can be defined on different time scales and levels of generality, we justify the choice of these two concerns (or the underlying concern dimension) in the following way.

First, the concern for autonomy versus involvement can be conceived of as referring to a general, long-term aspect of a person’s identity or personality. Recent literature emphasizes the fact that in forming self and identity, a good relation with oneself and with others go hand in hand (Bosma & Gerlisma, 2003). Finding a good balance between autonomy and involvement can be seen as one of the greatest challenges of development over the course of a lifetime (Grotevant & Cooper, 1998; Guisinger & Blatt, 1993, 1991; note that authors such as Grotevant use different terms, namely individuality versus connectedness). Also Frijda distinguishes an important group of concerns that can be summarized under the denominator of “identity striving”. These concerns deal with self-esteem and appreciation of others, and personal warmth and attention (Frijda, 1986), and are related to nearness, togetherness and connectedness. This nearness concern remains important during the whole lifetime. Frijda mentions Bowlby as an important source (Bowlby, 1980).

At a similar level of generality, autonomy and involvement can be conceived of as important factors in social competence, in which the essential duality between self and others is expressed (De Koeijer, 2001; see also the literature mentioned in the introductory section). Popular children have obtained a good balance between their concerns for autonomy and involvement (De Koeijer, 2001). In addition, they are able to weigh and

strive for these concerns in a manner that adequately reckons with the current situation or context (Cappella, 1996; Warner, 1996). At the other end of the spectrum, we find children with a completely different balance between autonomy and involvement, namely autistic children and children with related problems. Their concern with involvement is considerably less or sometimes very low, partly because they lack the abilities to effectively interact with others and partly because they derive only a little joy from interacting with others (see Bauminger, Shulman, & Agam, 2003; Jordan, 2003, concerning social play in autistic children).

On the time scale of real action that our model intends to describe, the concerns involvement and autonomy are specified as strictly context dependent, temporal properties, derived from the general properties described above and from the context in which they occur. They refer to the child's and peer's temporal, context-specific value of self-directed, and the value of other-directed, play behaviours. In the dyadic play situation that forms the topic of our study, the play behaviour of the children can vary from strictly solitary play with toys to highly interactive constructive play. At any moment in the play situation, they can choose (dependent on the play context, and in either a conscious or non-conscious manner, as we shall see) a form of play behaviour that is either autonomy-oriented or involvement-oriented, depending on what is the most obvious or pleasurable choice at that particular moment. This temporal preference is determined by child-specific aspects referring to a child's general tendencies towards autonomy versus involvement and by context-specific aspects, for instance by the simple fact that the researcher has asked the children to play together, or by a host of properties relating to the attractiveness of the play partner, for instance the play partner's social status or popularity (see Steenbeek & Van Geert, 2005a, for a more complete overview of the factors that determine the attractiveness of the play partner).

In the model, the values of the involvement (play actions directed towards or together with the other child) and autonomy concerns (play actions directed towards the child itself) are represented by two parameters, which together form the first group of parameters.

The influence of behaviour on the realization of concerns—the second input parameter group

As described above, at each point in time, evaluation of the concerns in the form of an emotional appraisal leads to a drive, which leads to specific behaviour. The group of behaviours referred to by the collective term “playing together” is connected with the current, context-dependent concern involvement. The group of behaviours “playing alone” is coupled to the current, context-dependent concern autonomy.

The basic idea is that by expressing a certain behaviour (e.g., responding to the play partner in co-operative playing action), the child aims at increasing his or her appraisal (e.g., increase pleasure), which, in model terms, is formally equivalent to bringing the corresponding concern (involvement in this example) closer to its realization. As appraisal increases, the effect of a particular action (e.g., playing together) on the further increase of appraisal diminishes. This means that, at some time in the process, the effect of a more preferred action (e.g., playing together) on the increase in appraisal will be smaller than that of a less preferred action (e.g., playing alone). At that time, the child will switch to that other type of action (the switch being co-dependent on a host of additional, contextual factors). For sufficiently variable and free behaviours, such as those occurring in play, the above-mentioned principles will lead to a succession of solitary and joint actions, the frequencies of which will reflect the differential values of autonomy- versus involvement-related behaviours and which will correspond with the preferred balance between autonomy and involvement mentioned in the section on the first parameter group. The relation between evaluations (e.g., the amount of “reward” expected from an activity), preferences and proportions of activities over time is a well-documented principle from learning theory, known as the Matching Law (Heth, 1992).

An obvious property of the concern involvement is that it can only be well satisfied if there is real joint action or communication, i.e., if the play partner responds coherently. If the response of the play partner is enjoyable and fun, it will contribute more to increasing appraisal than if it is unpleasant or annoying. Put differently, the appraisal effect of an action diminishes less rapidly if the action has more pleasurable consequences. This principle is expressed in our model by means of a second group of input parameters, namely the magnitude of the effect of the behaviour on the realization of concerns. We assume that socially competent, i.e., socially effective children can realize their concerns more easily by displaying adequate behaviours than socially less effective children. On the other hand, if playing together is unpleasant for a child (for instance because the play partner shows annoying or boring behaviour), the child’s concern for involvement will also be satisfied more rapidly than if the child were playing with a pleasant companion (because this is not the kind of involvement that the child is aiming at).

The strength of the relation between emotional appraisal and emotional expression—the third parameter group

The model makes the simplifying assumption that a drive is linearly dependent on the level of emotional appraisal of this situation. This

appraisal can be translated into a positive, neutral, or negative emotional expression of the child. The limits of the appraisal, i.e., the level at which a neutral expression is likely to turn into a positive or a negative expression, can vary per child, and eventually also per situation (Oatley & Jenkins, 1996). The ease with which a child translates an emotional appraisal into a specific expression can be tuned by means of a third input parameter group.

The influence of emotional expression on the preference of concerns—the fourth input parameter group

A central feature of a functionalist theory of behaviour, or of emotions for that matter, is that the effects of behaviours regulate the way that the behaviour will be displayed in the future. In our model we assume that an emotional expression is such an effect. For instance, a positive emotional expression following on or accompanying a particular behaviour will tend to increase the future frequency of that behaviour, which, in our model, is similar to saying that it will increase the strength of the concern that corresponds with this behaviour. More precisely, a behaviour accompanied by a *positive* expression increases the preference value of the corresponding concern; behaviour accompanied by a *negative* expression decreases the preference value of the concern. A neutral expression has no influence on the preference value of concerns. In social organisms, such as human beings, emotional expressions regulate not only one's own behaviour but also the behaviour of conspecifics, assuming of course that the latter perceive this emotional expression. According to Preston and de Waal's perception–action model of empathy (Preston & de Waal, 2002), perception of emotional expressions in another subject automatically invokes the associated behavioural responses. Moreover, positive emotional expressions in particular, such as laughs or smiles, have a strongly communicative function (Russell, Bachorowski, & Fernández-Dols, 2003). In line with these findings, we assume that emotional expressions have an effect on the preference of a child's concern, irrespective of whether they are the child's own or those observed in the play partner. For instance, imagine that both children are playing together at time t , and that this playing together is currently accompanied by positive expressions by one of the children. The result is a higher value for the preference of involvement on time $t + 1$ for both children.

Non-intentional principles of behaviour—the fifth input parameter group

The preceding groups of parameters govern the intentional aspect of action, linking concerns to appraisals, appraisals to drives, actions and

emotions and emotions back to concerns. In addition to these intentional aspects, we believe that actions are also driven by automatic, non-intentional processes. In a social organism, humans in particular, the perceived behaviour of conspecifics has a direct influence on the organism's own behaviour, which is most directly seen in the act of imitation. Imitation is a primary, very elementary form of reflexive behaviour already present in newborn children (Meltzoff & Moore, 2000). In Preston and de Waal's (2002) model the behavioural effect of emotions perceived in others is immediate, unless inhibited. They refer to the notion of "emotion contagion" (see also Doherty, 1998; Hatfield, Cacioppo, & Rapson, 2002). Comparable forms of direct effects on other persons' behaviour are behaviour contagion (Grosser, Polansky, & Lippitt, 1951; Wheeler, 1966; Wheeler, Smith, & Murphy, 1964), social contagion (Levy & Nail, 1993) and mood contagion (Neumann & Strack, 2000). Research on what social psychologists have coined the "chameleon effect" shows that people tend to show an automatic mimicry of other persons in a group, relating to facial expressions and behaviours (Chartrand & Bargh, 1999). This mimicry is related to cohesion between group members and it is suspected that it contributes to effective behaviour co-ordination among members of a group (Chartrand & Bargh, 1999). The immediacy or non-intentionality of the mirroring of other persons' behaviour has recently found a neurophysiological underpinning in the discovery of so-called mirror neurons, which, among other functions, prime a person to repeat an action perceived in another person (Rizzolatti & Craighero, 2004). Thus, there exists a certain non-intentional tendency to mirror what another person is doing, and this tendency may not always be consistent with the action related to the person's immediate concern. In the model we introduce this tendency in the form of a symmetry parameter, which is a non-intentional action parameter (i.e., it is not related to the immediate concern, e.g., playing together).

A second non-intentional action parameter refers to the fact that in a dynamic systems model the next step in an action sequence is a function of the preceding step (see equation 1). The recursive nature of action thus corresponds with a certain automatic tendency to remain in one's action mode until this tendency is overruled by an intentional drive towards a different action (that is, actions tend to behave like autoregressive functions). The action mode is an attractor. Attractors differ in terms of stability, i.e., in the strength of the influence needed to move the system towards another attractor state. In our model, this non-intentional tendency to remain in one's action mode is specified by a continuity parameter (a comparable concept is that of behavioural momentum, which is defined over a longer time scale than our notion of continuity; see Nevin, 1988).

Dependent on person and context characteristics, a child shows more or less continuity and symmetry. The level of symmetry depends largely on contextual influence, i.e., the “contagiousness” of the play partner (Levy & Nail, 1993), which is likely to be bigger in popular children than in rejected ones. In the example of the play session of Muriel and Rosa, the giggling is a good illustration of both symmetry and continuity. Muriel giggles because Rosa giggles, and vice versa. In addition, their own giggling makes them go on giggling.

The output variables social behaviour and expression

The model distinguishes two kinds of observable (i.e., overt output) variables, which have already been introduced in the preceding sections, namely the output-variable behaviour and the output-variable emotional expressions (these are just terms to distinguish two different kinds of behaviour, namely the play behaviour and the emotional expressions). The behaviour output variable consists of either behaviour directed towards the other person (all behaviours falling under the denominator “playing together”) or behaviour aimed at oneself (behaviours falling under “playing alone”). All actions that are aimed at interaction—ranging from actual playing together to attempts to engage the other child in doing things together—fall under the denominator “playing together”. Emotional expression is “every form of utterance that accompanies and expresses an experienced emotion” (Oatley & Jenkins, 1996; Russell, Bachorowski, & Fernández-Dols, 2003) and is related to a specific context (Camras, 1992). As stated earlier, our model specifies only the intensity of the emotional expression, varying from negative to positive, on a nine-point scale.

Additional model parameters

The dynamics in the interaction process are not only determined by the model’s input parameters. An additional influence is derived from a range of variables that are not specified in the model. For instance, the attractiveness of the toys, the “script” of the play session and the mood of the two children when they enter the play session may all affect the actual course of the playing. These additional influences are implemented in the form of an adjustable random factor that is added during each step in the model. The random factor takes the form of an autoregressive function, namely a random walk with an adjustable, limited bandwidth.

Since the level of realization of a concern is dependent on the ratio between the total performance time of the concern-related behaviour and the total elapsed time, the modelled agents (i.e., the children) must be issued

with a memory that retains some sort of information about the course of the play session so far, in particular the cumulative appraisal function. In principle, the memory covers the whole play session. By means of an additional input parameter, it is possible to set a limit to the episode covered by the child's memory. The chosen limit is set to half the length of the play session at most.

Finally, the model covers a short time scale, namely the duration of a single play session. However, each play interaction is likely to have a learning or adaptive effect on a child. For instance, repeated negative experiences with a particular peer will reduce the initial involvement concern of the next play session. It is possible to run an arbitrary number of play sessions, and in this way simulate long-term effects. This possibility will be extended in future versions of the model.

Summary of input and output parameters

Based on properties of the dynamic systems theory, and the emotion theory of Frijda the following assumptions can be distinguished in our model. First, child-specific factors and context-specific factors dynamically intertwine in the values of the parameters and the course of the interaction process. Child-specific factors refer to ranges within which a child's parameter values may vary. The context-specific factors consist, first, of properties of the play partner as perceived by the child (e.g., a popular status) and, second, of the preceding actions of the child and the play partner.

Second, the model runs on the basis of six input-parameter groups (including the additional parameters) and produces a succession of play behaviours (aimed at playing together or aimed at playing alone) and emotional expressions.

Table 1 shows all the input-parameter groups, the accompanying input parameters, and what precisely can be adjusted.

Time course of the model

Temporal resolution

As explained earlier, dynamic models have a characteristic temporal resolution, i.e., a characteristic number of steps, ranging from continuous time to steps covering successive generations (e.g., in biological population models). Since the scoring of behaviours and emotional expressions of the observed play sessions (see later) occurred with a one-second resolution, the dynamic model consists of discrete steps corresponding with one second. Thus, a seven-minute observation is modelled by 420 steps.

TABLE 1
 An overview of the groups of input parameters, the specific parameters that are distinguished, and what can be adjusted

<i>Input-parameter groups</i>	<i>Which parameters are distinguished?</i>	<i>What can be adjusted?</i>
1. Concerns	Involvement	Strength of the concerns in relation to each other
	Autonomy	
2. Influence of behaviour on the realization of concerns	Influence of playing together	Strength of the influence of behaviour on the realization of a concern
	Influence of playing alone	
3. Relation between emotional appraisal and emotional expression	Positive expression	Ease with which emotional appraisal is translated into an emotional expression
	Neutral expression	
	Negative expression	
4. Influence of emotional expression on preference of concerns	Influence of positive expression	Strength of the influence of emotional expression on the preference of a concern
	Influence of negative expression	
5. Non-intentional principles of behaviour	Continuity	Strength of the non-intentional principles in relation to each other
	Symmetry	
6. Additional model parameters	Memory	Duration of the memory span
	Randomization	Magnitude of the randomization

The process at one moment (one step in the model, for instance a second)

The upper part of Figure 1 shows that at time t the child has a particular value for the preferred level of a concern and a particular value for the realized level of a concern (what is shown for one child applies also to the other). Recall that the *realized* level is a function of the ratio between the total performance time of the concern-related behaviour and the total elapsed time on the one hand, and the magnitude of the contribution of actions to the realization of the corresponding concerns on the other hand. The concern is the *preferred* ratio (between “playing together” and “playing alone” behaviours). At time t (and every point in time), the difference between the preferred and realized value of a concern results in a specific drive, which, in the model, is nothing but the absolute numerical difference

between the two proportions. Since there are two concerns (autonomy and involvement), the total drive is the sum of the two differences. An ideal situation has a drive with value of zero, which means that the preferred and realized levels of both concerns are the same. It is a situation in which the concerns are optimally satisfied.

First, the total drive is linearly transformed into a particular emotional appraisal. This emotional appraisal is transformed into a positive, a neutral, or a negative expression, by means of an S-shaped (sigmoid) function that determines the probability of a particular expression, e.g., a mild positive expression, such as a smile. For instance, a strong drive means that the concern is not yet sufficiently realized, leading to a low (i.e., an inverse) emotional appraisal value, with a bigger chance for a negative expression. Second, the drive generates a specific behaviour, which in the model is limited to either “playing together” or “playing alone”. Since there are two drives, one drive for each of the two behavioural categories (playing together or playing alone), the drive with the highest current value determines which of the two behaviours will actually be displayed. The levels of drives, concern realization, play behaviour and emotional expression of child 1 and child 2 that result from the model calculation at time t will now form the input of the calculation at time $t + 1$.

The process at two consecutive moments in both children

The lower part of Figure 1 shows the processes occurring between two children over two consecutive time steps. For simplicity, the figure shows only one concern (but remember there are two). An example might simplify the explanation. Suppose that at time t , Muriel and Rosa are playing together, i.e., both display the behavioural category “playing together”. Also at time t Muriel begins to laugh, thus, at time t a positive expression accompanies the behaviour playing together. First, the occurrence of playing together in both children at time t , will result in an increased level for the *realized* value of the concern involvement for both children at time $t + 1$ (see the section on the second input parameter group). If only Rosa had displayed behaviour from the playing-together category, for instance by trying to capture Muriel’s attention for what she is doing, the realization of the concern involvement would not have changed, since realization of that concern requires that both children show a playing-together behaviour. For playing alone, concern satisfaction is updated if only the child herself displays playing-alone (we have made the simplifying assumption that in this case the behaviour of the other child does not matter). Second, the co-occurrence of the positive expression of Muriel with both children displaying playing-together at time t , will result in an increased level for

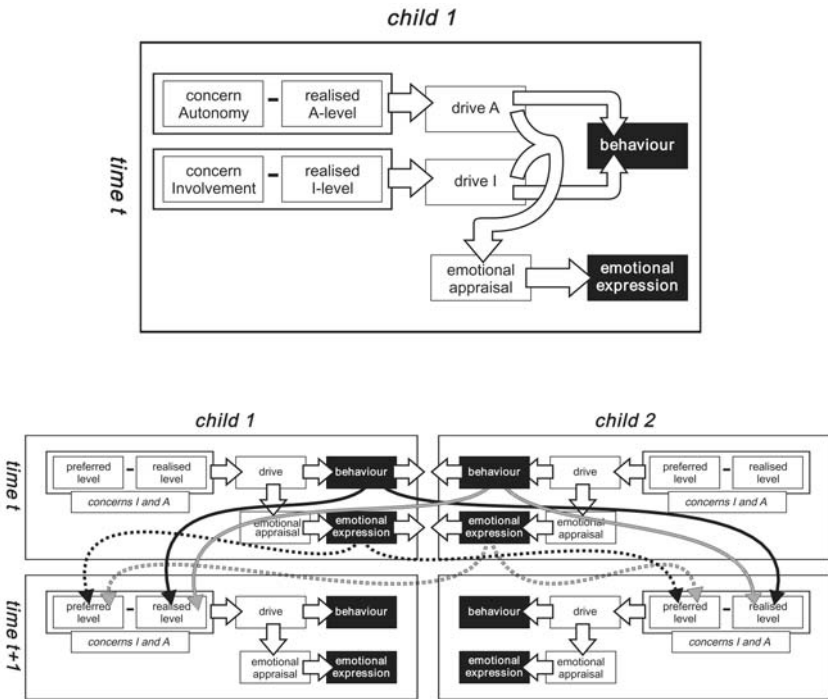


Figure 1. The process at one moment (one step in the model, for instance a second), and the process at two consecutive moments in both children (see text for explanation).

the *preferred* value of the concern involvement for both children at time $t + 1$ (see the section on the fourth input parameter group). This means that at time $t + 1$ the values of the concern involvement are increased, while the values for the concern autonomy are the same as at time t . On the basis of these new concern and realized level values, it is now possible to calculate which behaviour and emotional expressions both children will show at time $t + 1$, in accordance with the rules specified in the preceding section.

Because all influences appear not only within each child, but also occur between the two children, eight influences per concern are active between two consecutive points in time (these influences are represented at the bottom of Figure 1 by black and grey arrows and black and grey dotted arrows; the arrows are limited to one concern only). In a complete simulation run, the model goes through 420 such steps, corresponding with seven minutes' play time. For a more detailed technical description, see Appendix 1. (For a manual of the model, see Steenbeek & Van Geert, 2002, and for a copy of the model itself, running under Microsoft Excel and Visual Basic, we refer to the website www.inn.nl/~vangeert.)

Simulating children of different sociometric statuses

Our starting point is that all differences between children that are relevant to the kind of social interaction that we want to simulate must be caught in the form of differences in the values of the input parameters. Each type of child in this particular context is represented by a specific set of values of the input parameters.

Table 2 shows the settings of the groups of input parameters for children of different sociometric statuses, in the context of playing with a play partner of a particular status. For example, column 1 represents a specific set of parameters for a child with a rejected status in the context of playing with a play partner with an average status. Column 2 represents the settings of this play partner. Note that the context for this average play partner is formed by playing with a rejected child. Columns 3 and 4 represent the settings of an average-status child playing with another average-status child, and columns 5 and 6 refer to an average child playing with a popular child. In the Excel model, parameters can be set by means of verbal descriptors that correspond with preset parameter values (see Table 2 and Appendix 2). Note that verbal descriptors (used in the model's set-up work sheet) correspond with numerical values than can be fine-tuned in the numerical parameter worksheet.

Theoretical assumptions

The theoretical assumptions behind the setting of input parameters for different types of children are as follows: first, an average child with an average play partner is considered to have *standard* input parameter settings. These standard settings have been obtained by estimating the best possible set of model parameters, based on a qualitative comparison with the empirical data from "average dyads" (see later). Starting from this standard set, we assume that a child will have a higher concern for involvement to the extent that the child's play partner has a higher sociometric status. This assumption is based on the idea that the status difference between children implies an inequality in social power. The popular child has "referent power" (see French & Raven's power/interaction model, 1959; Raven, ⑤ 1992), because it is the popular child who is the "best-liked member of the group" (the dyad) (Forsyth, 1990, p. 217). This power difference will influence the interactions between individuals with different power levels (Snyder, 2001). For instance, the child with the lowest status in the dyad (the child with the lowest perceived power) will manifest more "defensive behaviour", which will show in the form of "appeasement smiles" (see ⑥ Bugental, 1996, about power in the context of care-giving relationships) and

TABLE 2
Settings of input parameters of children of different sociometric status in the context of playing with a play partner

Type of dyad	Rejected dyad		Average dyad		Popular dyad	
	Rejected	Average	Average	Average	Popular	Average
Status of child	Rejected	Average	Average	Average	Popular	Average
Status of play partner	Rejected	Average	Average	Average	Popular	Average
1 Concerns	I much stronger than A I = average A = high	I little bit stronger than A I = high A = average	I stronger than A I = average A = average	I stronger than A I = average A = average	I little bit stronger than A I = high A = average	I much stronger than A I = average A = high
2 Influence of behaviour on realization of concerns	Positive = moderate Negative = difficult	Positive = moderate Negative = moderate	Positive = moderate Negative = moderate	Positive = moderate Negative = moderate	Positive = moderate Negative = moderate	Positive = moderate Negative = difficult
3 Relation between emotional appraisal and emotional expression	Positive = big Negative = big	Positive = average Negative = average	Positive = average Negative = average	Positive = average Negative = average	Positive = average Negative = average	Positive = big Negative = big
4 Influence of emotional expression on preference of concerns	Continuity = average Symmetry = high	Continuity = average Symmetry = low	Continuity = average Symmetry = average	Continuity = average Symmetry = average	Continuity = average Symmetry = low	Continuity = average Symmetry = high
5 Non-intentional principles of behaviour	Continuity = average Symmetry = high	Continuity = average Symmetry = low	Continuity = average Symmetry = average	Continuity = average Symmetry = average	Continuity = average Symmetry = low	Continuity = average Symmetry = high

Notes: "The table can be read as follows: a child with a rejected status that plays with a play partner with an average status (rejected dyad; upper left of the table) has as setting for the first input parameter group concerns that his/her concern involvement is much stronger than his/her concern autonomy, which is expressed as "I much stronger than A".^a I = concern involvement, A = concern autonomy. The average dyad has standard settings (average, moderate). Everything that differs from these standard settings is printed in italics (*high, low, difficult, big*).^cInformation about the corresponding ranges of numerical values of these settings of input-parameter groups for children of different statuses in the context of playing with a play partner with a different status can be found in Appendix 2.

in the form of behaviour that responds to the initiatives of the other (Eisenberg, Cameron, Tryon, & Dodez, 1981).

The consequence of this power-difference approach is that a child with a rejected status playing with an average play partner has the same concern settings as an average child playing with a popular play partner, reflecting the fact that in both cases the children play with children of a higher sociometric status. A child who plays with a play partner with a lower status has settings that correspond with the downward difference in social status. Thus, an average child playing with a rejected child has the same parameter setting for his concerns as a popular child playing with an average play partner.

The cells that are *printed in italics* in Table 2 show for which child–context combination the settings for input parameters differ from the standard settings. For instance, the popular child that plays with a play partner with an average status, has a lower value for the concern involvement, and a higher value for the concern autonomy, verbally expressed as “*I little bit stronger than A*” (given his relatively “unattractive” play partner), whereas the standard setting is “*I stronger than A*” (remember that these verbal descriptions correspond with adjustable numerical parameter values).

Note that in our empirical arrangement, and therefore also in our simulated sessions, a child with an average status can play with a play partner that has a rejected status, an average status, or a popular status (columns 1, 3 and 5, respectively). For instance, if Rosa (average status) plays with Muriel, who has popular status, Rosa will have a *high* value for the concern involvement and a *low* value for the concern autonomy (first input parameter group). This is expressed in column 6 in the table as “*I much stronger than A*”. If, on the other hand, Rosa plays with April, who has a rejected status, Rosa’s settings for her concern involvement will be much *lower*, whereas her concern autonomy will be *higher*. Since the children have been asked to play together, we assume that the context-specific concern for involvement is higher than the autonomy concern. In this way, the expectations of the (modelled) children are varied as a function of their personal properties (preferences) and as a function of the context (the play partner’s attractiveness). Note again that these preliminary verbal descriptions refer to numerical values that can be further numerically adjusted.

VALIDATING THE MODEL

The empirical data

The empirical validation of the simulation is based on our empirical study, which is described in more detail in Steenbeek & Van Geert (2005a). Given

the scope of the present article, we shall confine ourselves to presenting a summary.

Participants

Grade 1 pupils with a mean age of 6.5 years, with an upper limit of 8.8 years and a lower limit of 5.8 years, participated in this study. From a group of 83 children (47 boys and 36 girls), 24 dyads were selected on the basis of their sociometric status (popular, average, rejected). Each dyad consisted of two same-sex children who were not close friends. Three types of dyads were formed. The first consisted of a child with a rejected status, coupled with a neutral play partner with an average status, which we will abbreviate as the “rejected dyad”. The second group contained dyads of a popular with an average child (the “popular dyad”). The third group of dyads contained an average with an average child (the “average dyad”).

Procedure

The empirical study was done in collaboration with the University of Utrecht, and the design is based on Goudena & Gerrits’ design (2003). *The main goal of this collaborative project was to study differences in interaction of popular and rejected children, in a standardized play context, with dyads composed as described above.* Although gender is likely to play a role in the nature of the interaction, it was not taken into account in the present study.

First, the sociometric status of the participants was determined on the basis of repeated measures of a rating test (Asher, Singleton, Tinsley, & Hymel, 1979), which was analysed with the computer program SS-rat (see Maassen, Akkermans, & Van der Linden, 1996, for a detailed description of SS-rat). Second, the dyads were videotaped during a ten-minute play session in a separate room in the school, while playing with four groups of toys (Tarzan figures, kitchen toys, Playmobil toys and Lego toys). The only instruction was to play together with the toys on the table. After giving the instruction the researcher left the room, leaving the children alone with the toys and the camera. After ten minutes, the researcher came back and the play session was ended.

This procedure (testing the status of the children and videotaping them) was repeated after one and a half and three months. In principle the second and third round were selected for coding. Due to practical limitations, only 17 dyads were coded twice and 7 dyads were coded once. This resulted in a total of 41 coded interactions (“rejected dyad”, $n = 13$; “popular dyad”, $n = 14$; “average dyad”, $n = 14$ ¹).

The recordings were coded with the computerized system Observer 4.0 pro (Noldus Information technology, 1999), based on a coding system

introduced by De Koeijer (2001). Changes in expressiveness and behaviour of each videotaped child were separately coded for every one-tenth of a second (event sampling). To determine the inter-observer reliability between the observers, we used a non-parametric permutation test (see Van Geert & Van Dijk, 2003). The reliability was determined before the coding started, and can be considered good, in terms of percentage agreement (.8 for behaviour, $p = .01$; .81 for expressions, $p = .01$).

Variables

Two variables were coded: *emotional expressions* and social behaviour, which amounts to the children's *contribution to coherence* of each child separately. Coherence refers to the children actually playing together; "contribution" meaning that one child attempts to involve the other child in some common action. (*Contribution to*) *coherence* was coded with the help of the partial variables *verbal turn*, *non-verbal turn* and *focus*. *Verbal turn* refers to verbal utterances; *non-verbal turn* refers to non-verbal communicative utterances; and *focus* involves the direction of gaze of the children towards the play partner, towards the toys, or towards something else. *Emotional expressions* were coded on an intensity scale ranging from (4 to 5. Categories (4 to (2 represented negative expressions, (1 to 1 neutral expressions, and 2 to 5 positive expressions. For more information about the coding of these empirical variables, we refer to Steenbeek & Van Geert (2005a).

These variables were translated into 20 operational variables, which each expressed an aspect of *emotional expression* or *coherence (actual playing together)*. A description of these operational variables can be found in Table 3.

Model fitting

Generation of model output

Remember that the model's output consists of each child's *emotional expression* and of social behaviour, more precisely each child's *contribution to coherence (actual playing together)*. Per model run, the output variables are transformed into twenty *operational variables* (the same as described in Table 3; empirical study).

By running the model 5000 times, for each set of parameters that represents a specific type of dyad, we obtained the model output that we used for the comparison with the empirical data. All averages and distributions resulting from the model runs of different types of dyads are significantly different.

TABLE 3
Operational variables, such as derived from the empirical data and from the model
output variables

<i>Variables</i>	<i>Description</i>
<i>Child or play partner</i>	
Directedness	Proportion of coherent behaviour (“playing together”) over the total of all behaviours (both “playing together” and “playing alone”) of the child
Positive expressions ^a	Proportion (percentage of time) of positive expression over the total number of expressions (neutral, negative or positive expressions)
Intensity positive time ^a	Proportion of total average intensity of positive expressions
Intensity positive number	Proportion of intensity of positive expressions divided by the amount of positive expressions
Proportion shared positive	Proportion of positive expressions of this child, accompanied by a positive expression of the play partner
Negative expressions	Proportion (percentage of time) of negative expression over the total number of expressions (neutral, negative or positive expressions)
Intensity negative time	Proportion of total average intensity of negative expressions
Intensity negative number	Proportion of intensity of negative expressions divided by the amount of negative expressions
<i>Dyad</i>	
Coherence dyad	Proportion of time that both children show coherent behaviour (“playing together”) of the total time of the play session
Shared positive dyad ^b	Proportion of shared positive expressions over the total number of expressions. This variable can be read as a measure for “coherence of positive expressions”
Shared negative dyad	Proportion of shared negative expressions over the total number of expressions. This variable can be read as a measure for “coherence of negative expressions”
Contrast dyad	Proportion of contrast in intensity of expression of both children over the total time. The time that both children express a neutral expression is not included (coded as zero)

Notes: ^aConcerning variable *positive expression* (1) and *intensity positive time* (2): in (1) the intensity of the expression is not calculated, in (2) the proportion in relation to the intensity is calculated. ^bConcerning variable *shared positive dyad*: 1. A high level of *shared positive expression dyad* does not necessarily imply a high level of positive expressions per se.

An overview of the fitting methods and the statistical method

The current validation method focuses on whether the model gives an adequate representation of the general characteristics of the sample. This group-wise validation is a first step towards a second validation that focuses on individual process characteristics, such as patterns of the operational

variables over the course of an interaction. In the current article, we will confine ourselves to validating with the first method.

The validation existed of three distinct fitting methods, namely fitting over averages, fitting over distributions, and a sensitivity analysis. The statistical problem is that a total of 5000 model runs of dyads with a specific status are compared with 13, 14 and 14 empirical dyads with that particular status, respectively. To solve the statistical problem of the major difference in size between empirical and model samples (13, 14 and 14 versus 5000 simulations each), we use random permutation analysis or Monte Carlo methods, which are particularly convenient for small or unbalanced datasets (Manly, 1997; Todman & Dugard, 2001). For a more thorough description of these fitting and statistical methods, see Steenbeek & Van Geert (2005b).

Fitting over averages

First, an analysis over the total *pattern* of empirical averages is performed. This pattern consists of a 20*3 matrix of averages (20 variables, three status groups). There are two such patterns: one based on the empirical data, the other based on the model output. In this analysis, we estimated the goodness-of-fit of our model by calculating the distance between the simulated and empirical values of each variable (the “chi”). The advantage of the chi is its intuitive simplicity: it is a direct measure of the distance between model and data matrix. The chi-distribution for the null-hypothesis is calculated by means of a repeated random-permutation procedure, which produces a parameter-free estimation of the *p*-value of the goodness-of-fit index. The chi, i.e., the summed distance (summed over all variables, over all status groups) was smaller than could be expected on the basis of chance (random assignment of simulated averages to variables; *p* = .02). That is, the probability that the match between the pattern based on the data and the pattern generated by the model is based on chance alone is very small.

Second, each variable is analysed separately. We shall confine ourselves to giving an overview of predictions for six theoretically important variables that differed between the status groups in a statistically significant way (see Steenbeek & Van Geert, 2005b, for further details).

This is the more interesting part of the analysis since it allows us explicitly to test predictions that our model makes with regard to specific variables. Recall that the existing literature describes two patterns, one based on a strong association between high social status (popularity), high social competence, high coherence of interaction and positive emotions; the other based on a strong association between low social status (rejection), low social competence, low coherence and negative emotions. Our model, on the other hand, describes the course of (coherence of) interaction and positive versus negative emotions during a play session, based on the dynamics of

concerns and emotional appraisals as described in earlier sections. For the present dyadic interaction situation, this model predicted outcomes for the interaction and emotion variables that were not consistent with the patterns described in the literature about general differences between popular and rejected children (see introductory section).

Figure 2 gives an overview of predictions for the six previously mentioned variables. Our model predicted more coherence, i.e., real interaction, in the “rejected dyads” than in the “popular dyads” (compare the observed averages—white symbols—with the averages based on the model—black symbols; the relevant variables are *coherence dyad* and *directedness child*). The predictions regarding these two variables are consistent with the data. The model also predicted more positive expressions and higher intensity of positive expressions in the rejected child (in the “rejected dyads”) than in the popular child (in the “popular dyad”). These predictions were also consistent with our data; the relevant variables are *positive expressions child* and *intensity positive time child*. The model predicted that the rejected child would share more positive emotions with his average play partner than the popular child would share with his average play partner. This prediction was not corroborated by the data (variable *proportion shared positive child*).

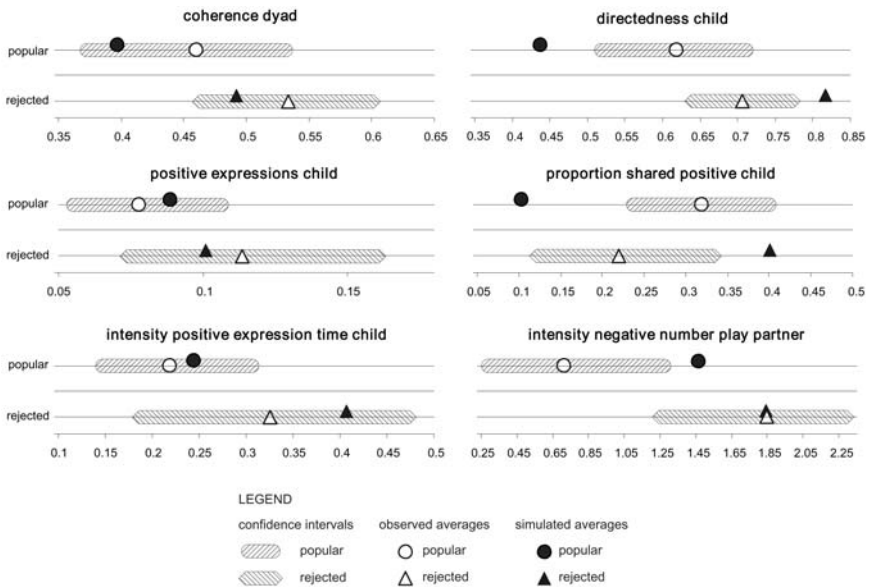


Figure 2. Results of fitting of averages of six empirically significant variables for the “popular dyads” and “rejected dyads”. Simulated averages (black symbols) are compared with observed averages (white symbols), and confidence intervals of observed averages.

Finally, the model predicted that the number of negative emotional expressions would be small for the three dyad groups, but that, if negative emotions occurred in the play partner, they would be more intense if they were addressed toward the rejected child than if they were addressed towards the popular child. This prediction was again supported by the data (variable *intensity negative number play partner*).

With these distinct variables, the fit between the averages based on the data and those based on the model was determined in the following way. To begin with, the 95% confidence interval of the empirical average of the variable at issue was calculated, by means of a bootstrap method (Manly, 1997). Subsequently it was, first, checked whether the simulated average falls within the range of the empirical confidence interval and, second, whether the rank order of the simulated averages of the three status groups is the same as the empirical one, with the rank order of the popular versus rejected dyads being the most theoretically relevant. Figure 2 shows the rank orders and confidence intervals for the six variables described above. If we confine ourselves to the comparison between popular and rejected dyads, both criteria (interval and rank order match) are satisfied for the variables *coherence dyad*, *positive expressions child* and *intensity positive expression child*. The rank order criterion is satisfied for the variables *directedness child* and *intensity negative emotion play partner*. There is no fit for the variable *proportion shared positive emotions in the child*.

Fitting over distributions

Do the simulated model distributions give a good representation of the observed, empirical distributions of all variables? This is a question that is seldom asked in empirical research, which most often confines itself to averages or other central values. However, a model that claims to describe a process—such as the present dynamic systems model—should also be able to predict the distribution of the values that will be found in particular groups or subjects. Our model generates predictions about distributions in a natural way, namely by simulating dyadic play sessions a great many times, each session based on a specific parameter set (i.e., one for the rejected, one for the average and one for the popular dyads; remember that the model incorporates stochastic variables, which account for the distribution). Comparable to the averages, the goodness-of-fit is determined over the entire pattern of distributions and over the distributions of variables separately.

The specification of a goodness-of-fit indication over the total *pattern* of empirical distributions was performed in the following way (remember that the pattern consists of twenty distributions for three status groups and that there is one pattern based on the data and another on the model). To

describe each distribution in the pattern of distributions, two criteria were used, namely the position of the peak of the distribution, and the histograms of the distributions. For both criteria, we found that the distance between simulated and empirical data was smaller than could be expected on the basis of chance ($p < .01$). The p -value was determined on the basis of a random permutation procedure, comparable to that used for the pattern of averages.

Second, a goodness of fit was determined for each distribution separately. The distribution of a variable based on the data and the distribution based on the model was described in the form of histograms with the same number of bins and the same range, such that the histograms could be easily compared. The fit between model and data histograms is expressed in the form of a chi-value, i.e., the sum of absolute differences between the histograms (a chi-measure). The testing procedure is somewhat comparable to a maximum likelihood procedure (with the likelihood measure replaced by the chi). That is, we try to show that the model (i.e., the model specified by the parameter sets that are assumed to describe the three types of dyads) provides a better fit of the distribution than alternative models. The alternative models are based on parameter values that differ from those of the original model. One type of alternative model is based on parameter values drawn from a range of values around the values of the original model. The original model fits significantly better than the alternative models in about two-thirds of the variables (20 variables and three status groups yield 60 comparisons, 43 of which were significantly better for the real model, $p < .01$). The superiority of the original over the alternative models is particularly clear for the rejected dyads and average dyads but less so for the popular dyads. Note that the parameter values of the original model and those of the alternative models overlap. If alternative models are based on parameter ranges that do not overlap with the parameter values chosen for the original model, all variables except one yield significant p values ($p < .001$), in favour of the real models. (7)

By way of example, we shall discuss the correspondence between the distributions of the empirical data, the original model and the two types of alternative models for the variable *coherence dyad* (the example comes from the average dyads; see Figure 3). There exists a considerable overlap between the distributions of the empirical data with the data simulated by the original model, although the model distribution is flatter than the data distribution. The distribution based on the first type of alternative model (overlapping model, upper part of the figure) produces more values in the lower range of the variable. The second type of alternative model, the parameters of which do not overlap with those of the original model (non-overlapping model, lower part of the figure), generates a distribution consisting almost exclusively of low values. Note that many of the empirical (7)

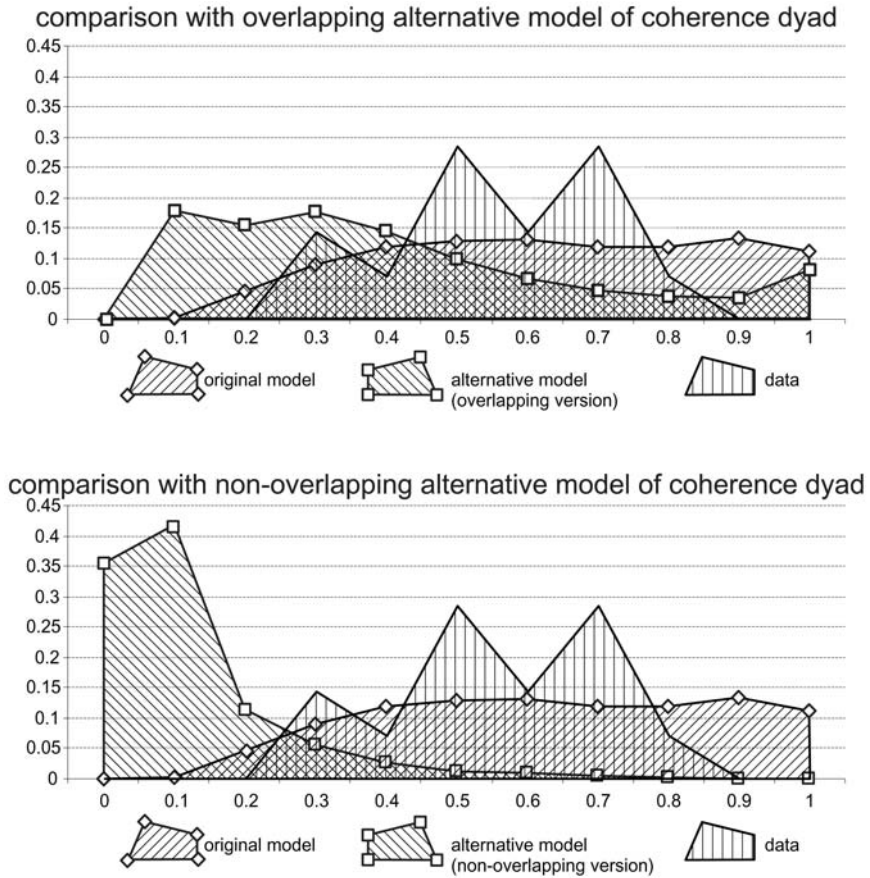


Figure 3. An example of the comparison of distributions of one variable in particular, namely coherence dyad. The distribution of the observed cases is compared with the distributions generated by the original model, and by two alternative models.

variables—and those simulated on the basis of the original model for that matter, are characterized by skewed distributions.

Exploratory qualitative analysis of sensitivity

Finally, a form of *sensitivity analysis* was applied in order to determine the robustness of the model. There occurred no discontinuities, instabilities, and fluctuations in the charts that could point to oversensitivity of the model (this oversensitivity would greatly hamper the possibility of fitting the model parameters to empirical data). In order to check for eventual insensitivity of

the model, we took the empirical confidence intervals as criterion. If the model is insensitive in a particular parameter, the model's output remains within the confidence interval for any possible value of that parameter ("any possible" within a preset range). None of the parameters turned out to be insensitive. Further details of the sensitivity analysis can be found in Steenbeek & Van Geert, 2005b.

CONCLUSION AND DISCUSSION

We have shown that it is possible to build a dynamic systems model of social interaction during play, based on an existing, general theory, Frijda's theory of emotions, concerns and behaviours. The benefit of building such a model is twofold. First, the attempt at building a simulation model obliged us to refine and extend existing theory in a new manner, for example by incorporating principles of iterativity, mutual relationships, context dependency, and processes in real time. Second, the dynamic model enabled us to generate highly specific predictions about group-wise properties, such as averages and distributions, relating to children of various sociometric statuses. It turned out that the majority of the model's predictions of the group-wise properties were corroborated by our empirical data.

Note that these predictions were not trivial and were in fact inconsistent with the existing literature on general differences between popular and rejected children (see introductory section). Among other things, our predictions, which were corroborated by our empirical findings, entailed that in this particular interaction situation, rejected children (in a "rejected dyad") show more of the involvement-category behaviours than popular children do in their dyads. The difference consists of more positive expressions and more contributions to coherent behaviour (actual interaction).

There are two possible explanations for this inconsistency. First, the behaviour of children in interaction processes is likely to be influenced by two aspects, namely the social-competence aspect and the social-power aspect. Possibly, the differential effect of these aspects depend on the situation in which the interaction takes place. Our research setting is a controlled play situation that the children can view as a kind of task or assignment. In this situation, the power aspect has probably more influence on the behaviour than the social-competence aspect. This is in contrast to free-play situations, in which the social-competence aspect is probably more important.

Second, our model does not specify the likelihood of occurrence of these different situations in the daily life of children. Our research setting—a play situation more or less imposed on them and monitored by adults, i.e., researchers—need not be the standard situation for these children.

Especially rejected children are likely to spontaneously experience this type of interaction—in which they express a lot of positive emotions and coherence—considerably less than their more popular peers. Hence, their overall experience might be one of negative emotions and little interaction, as described by the literature.

Our contribution, we believe, is that we see emotions and interactions no longer as a child-specific property, but as the product and expression of interaction processes, in which both child-specific factors and context-specific factors play a role. We have attempted to explain these processes by means of a dynamic model, involving concerns, appraisals, emotional expressions and behaviours. A major advantage of our model is that it can incorporate various types of situation, and by doing so can generate situation-specific predictions.

A future extension of the validation is to check whether the model also provides an adequate representation of the behavioural and emotional *trajectories* during individual play sessions. Visual inspection shows that the observed and simulated trajectories are qualitatively similar, but a thorough statistical check is work for the near future.

Another future extension concerns the design of a longitudinal model in which the development or change of interaction over the course of several months can be simulated. The idea is that children learn from previous interactions and transfer the learning effect to subsequent interactions. A model like this should enable us to show how interactions with specific types of children develop over the course of time. Another planned extension of the model consists of a simulation of parent–child interaction. The question concerns the nature of the difference between child–child and parent–child interaction as expressed in the values of the input parameters. Another possible refinement relates to interactions between other types of children, such as aggressive children, bullies or children with specific social roles.

Finally, research such as that presented in this article, which combines dynamic model building with empirical research, is not very common, at least not in developmental psychology. We see our research as an illustration of a process of investigation that is based on a constant and mutually supporting interaction between knowledge obtained from the dynamic model and knowledge obtained from empirical study.

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APPENDIX 1

Steps in the calculation of the model

1. Specify all parameter values
2. Initialize the variables for the calculation of the model
3. Run main routine (420 times):
 - a. *Step 1*: calculate the **preferred behavioural state** (preferred proportion of involvement over autonomy) on the basis of the current values of the concerns
 - b. *Step 2*: determine the value of the **behavioural weights**, i.e., the weights associated with the behaviours playing alone and playing together, respectively, on the basis of the current value of the corresponding drives
 - c. *Step 3*: add the influence of the **non-intentional principles of behaviour** (symmetry and continuity) to the behavioural weights
 - d. *Step 4*: calculate the value of the **random factor** for both types of behaviour, and add the random factor to the behavioural weights
 - e. *Step 5*: select the **behaviour** on the basis of the highest value of the behavioural weights
 - f. *Step 6*: determine the level of the **realized behavioural state** (i.e., concern realization) following the selected behaviour, by means of the following substeps:
 - i. update the memory to cover the new level of concern realization
 - ii. determine the influence of the selected behaviour on the realization of the concerns depending on the memory
 - iii. calculate the level of concern realization on the basis of the memory
 - g. *Step 7*: calculate the **drive** on the basis of the difference between the preferred behavioural state (see *Step 1*) and realized behavioural state
 - h. *Step 8*: calculate the **emotion level** on the basis of the drive
 - i. *Step 9*: calculate the **emotional expression** (positive, neutral, negative) on the basis of the emotion level
 - j. *Step 10*: calculate the influence of the emotional expression on the value of the **concerns** (i.e., preferred behavioural states)
 - k. *Step 11*: return to *Step 1*

APPENDIX B
 Numerical values corresponding to settings of input parameters of different sociometric status in the context of playing with a play partner

Type of dyad	Rejected dyad		Average dyad		Popular dyad	
	Rejected	Average	Average	Average	Popular	Average
Status of child partner						
1 Concerns	$I = .8; A = .2$	$I = .6; A = .4$	$I = .7; A = .3$	$I = .7; A = .3$	$I = .6; A = .4$	$I = .8; A = .2$
2 Influence of behaviour on realization of concerns	$I = .81$ $A = .66$	$I = .99$ $A = .54$	$I = .81$ $A = .54$	$I = .81$ $A = .54$	$I = .99$ $A = .54$	$I = .81$ $A = .66$
3 Relation between emotional appraisal and emotional expression	Positive = .05; Negative = 0; 0.4; 0.2	Positive = .05; 0.45; 0.7 Negative = .05; 0.45; 0.3	Positive = .05; 0.45; 0.7 Negative = .05; 0.45; 0.3	Positive = .05; 0.45; 0.7 Negative = .05; 0.45; 0.3	Positive = .05; 0.45; 0.7 Negative = .05; 0.45; 0.3	Positive = .05; 0.45; 0.7 Negative = 0; 0.4; 0.2
4 Influence of emotional expression on preference of concerns	Positive = .1 Negative = -0.1	Positive = .06 Negative = -0.06	Positive = .06 Negative = -0.06	Positive = .06 Negative = -0.06	Positive = .06 Negative = -0.06	Positive = .1 Negative = -0.1
5 Non-intentional principles of behaviour	Continuity = 0 Symmetry = .4	Continuity = 0 Symmetry = .05	Continuity = 0 Symmetry = .2	Continuity = 0 Symmetry = .2	Continuity = 0 Symmetry = .05	Continuity = 0 Symmetry = .4

Notes: ^aThe table is the numerical equivalent of Table 2 in the text. ^bThe third input parameter group specifies the values of a sigmoid function that determines the probability of positive, neutral and negative expressions. The parameters represent the function's intercept, maximum, and the position of the median value on the x-axis respectively.